D5.7 Regional feasibility studies of new DH in consolidated urban environments, technical financial and administrative roadmaps

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PROJECT SUMMARY

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Topic	EE-04-2016-2017 New heating and cooling solutions using low grade sources of thermal energy

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Acronyms

COP	Coefficient of Performance
DH	District Heating
DHN	District Heating Networks
EC	European Commission
GIS	Georeferenced Information System
H2020	Horizon 2020 EU Research and Innovation programme
HP	Heat Pump
PEF	Primary Energy Factors
RoI	Return of Investment
w/w HP	Water/water Heat Pump

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1. Executive summary

D5.7 summarises tasks T5.6 and T5.7 and the main output is the definition of a procedure for the identification of opportunities of waste heat reuse with a practical application based on real data in both Basque country region and Mazovia region.

The studies included in both tasks are:

- T5.6 – Phase 1 of the regional study, with an energy and administrative planning of DH in consolidated urban environments, which have been led by EVE with the collaboration of MAE, TECNALIA and IBS. The main output from this task is the methodology to define roadmaps for the planning of new DH networks in existing urban areas. This methodology has been developed through its practical applications, with identification of potential sources. Technical, administrative and financial constraints are considered in the identification of these potential sources. Considering that administrative & policymaking environments vary in Europe, administrative roadmaps are focused on the particular cases of the regions/countries directly represented in RELaTED: Basque Country (EVE) and Mazovia (MAE).

- T5.7 – Phase 2, where potential DH development have been identified at regional scale, led by EVE with contributions from TECNALIA, IBS and MAE. Based on phase 1 and regional workgroups, potential sites for DH development are identified based on predefined key factors such as economic factors, available residual industrial heat or vicinity of urban areas, among others. Based on these criteria, a set of 2-3 locations are defined and analysed on detail for each region. The final outcome of this task is the identification of at least one suitable location per region, for the deployment of a new DH network with the RELaTED configuration based on a feasibility study.

The work carried out in both phases allows the definition of an implementation roadmap based in the studied areas but with application to other regions. The

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roadmap considers every step which must be considered in order to identify potential areas where a low temperature DH based in industrial waste heat can be located. The roadmap should be carried out by a public entity in the region, in order to have a general vision of the possibilities of this technology, as well as promote every project that can be made.

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2. Introduction

This deliverable summarises the activity carried out within Task 5.6 & 5.7 and the main output is the definition of a procedure for the identification of opportunities of waste heat reuse with a practical application based on real data for both Basque country region and Mazovia region.

The deliverable reports on the two phases of the regional studies:

- **Phase 1 (T 5.6):** Based on predefined criteria that takes into account economic, geographical and energy aspects, a set of 4 locations are identified as suitable for the Basque (led by EVE) and Mazovian (led by MAE) regions, where more detailed studies on heat supply, distribution infrastructure, substations & backup heat production are performed at feasibility study level on phase 2. The summary of this phase is included in the main body of the present deliverable, while detailed information on the processes followed are included in annex A (for Basque Country) and annex B (for Mazovian region).

- **Phase 2 (T 5.7):** The final outcome of this task, included in this deliverable, is the identification of one suitable location per region for the deployment of a new DH network with the RELaTED configuration. Based on phase 1 and regional workgroups, potential sites for DH development are identified based on predefined key factors such as economic factors, available residual industrial heat or vicinity of urban areas, among others.

Furthermore, the definition of the implementation roadmap is included for the selected areas based on the work carried out in both phases.

The document first introduces in section 3 the methodology proposed. The work carried out is summarised in section 4, while a more detailed description is included in Annex A to D to explain the main outcomes from the practical application of this methodology to the Basque country and to Mazovia. Section 5 includes the definition of implementation roadmap. Finally, section 6 describes the main conclusions and lessons learnt from the study.

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3. Methodology

The methodology for locations' selection is based in four steps (see Figure 1):

1. **Information compilation and georeferencing:** The information for the analysis is gathered and integrated in a georeferenced information system project (GIS project, in advance). The main information is:
    a. **Identification of heating sources,** supported by questionnaires and inputs from the main stakeholders.
    b. **Identification of heating demand in public buildings** as a catalyst to foster replication of waste heat reuse. This analysis is supported by open sources such as cadastre
    c. **Estimation of heating demands of buildings from domestic sector,** supported by open sources such as cadastre.
2. **Algorithms definition:** Pre-established procedures are applied to transform or complete the georeferenced information.
3. **Geoprocessing:** Different geo-processes are applied to analyse heat locations spatially (in relation to its nearby municipalities) and identify a pre-selection of the most suitable locations for DH development.
4. **Prioritization and selection:** From the first pre-selection of locations identified, different criteria are employed to prioritize and select the 2 best locations for further feasibility studies, one for each region.

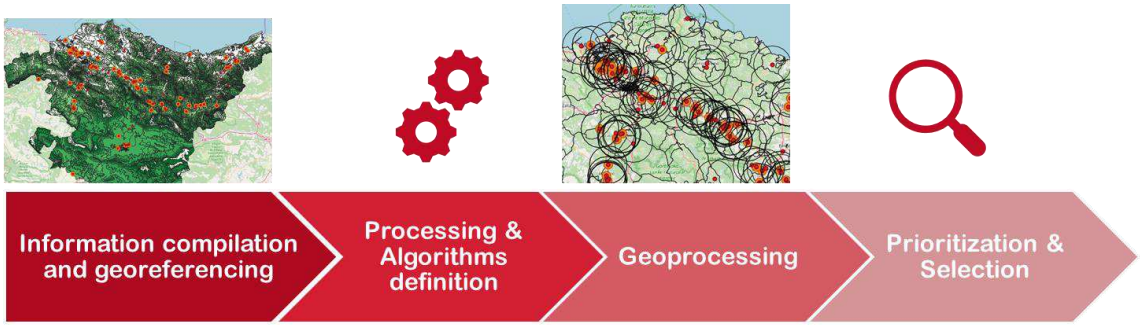

Figure 1. Methodology for the selection of potential locations.

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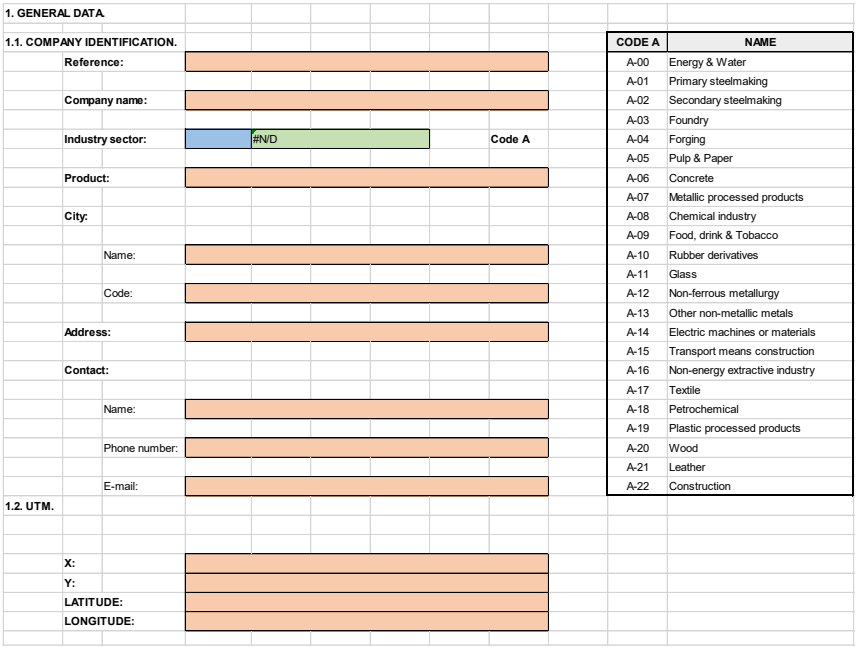
3.1. Information compilation and georeferencing

Firstly, all the information necessary for the analysis is gathered and processed to be integrated in a GIS project. For this purpose, the following actions are done:

- Download information from public sources (e.g. census tracks cartography, total population per census track, municipal cartography, etc.).
- Identification of industrial heat locations with good quality of residual heat.
    - Data is gathered by EVE and MAE with questionnaires distributed among regional companies.



1. GENERAL DATA

1.1. COMPANY IDENTIFICATION.

Reference:

Company name:

Industry sector: #N/D Code A

Product:

City:

Name:

Code:

Address:

Contact:

Name:

Phone number:

E-mail:

1.2. UTM.

X:

Y:

LATITUDE:

LONGITUDE:

CODE A	NAME
A-00	Energy & Water
A-01	Primary steelmaking
A-02	Secondary steelmaking
A-03	Foundry
A-04	Forging
A-05	Pulp & Paper
A-06	Concrete
A-07	Metallic processed products
A-08	Chemical industry
A-09	Food, drink & Tobacco
A-10	Rubber derivatives
A-11	Glass
A-12	Non-ferrous metallurgy
A-13	Other non-metallic metals
A-14	Electric machines or materials
A-15	Transport means construction
A-16	Non-energy extractive industry
A-17	Textile
A-18	Petrochemical
A-19	Plastic processed products
A-20	Wood
A-21	Leather
A-22	Construction

Figure 2. Questionnaire distributed from EVE, section “General data”.

- The following data are extracted for the municipalities within the residual industrial heat locations’ boundaries

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- Energy consumption (gas, coal, etc), which is assigned to its corresponding municipality in the municipal boundaries shape layer.
- Demand of surrounding public buildings demand which are georeferenced in a specific shape layer.

- Definition of the calculation criteria to determine the useful waste energy of the companies in the inventory.
- Process and georeference the data from the above information as well as other relevant information. This information is represented in specific shape layers within the GIS Project.
- The information gathered can be summarised following the table below:

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Table 1. Example of table used in annexes A&B to summarized the sources of information integrated in GIS project for each region.

TYPE	INFORMATION	YEAR	SOURCE	PROVIDER
Specific for the project	Residual industrial heat locations			
	Gas consumption at municipal level			
	Public buildings demand			
	Others			
Public sources	Population per census track			
	Elevation model			
	Territorial planning			
	Other			

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3.2. Processing and algorithms definition

Once information is collected and integrated in the GIS project, some algorithms need to be done in order to prepare the information for its analysis.

The **key indicators** for identification of the most suitable locations are those that show a match between the existence of a proper heat source and an important energy demand in the surroundings:

- Available residual industrial heat: boilers, furnaces, etc.
    - Power
    - Total Annual Energy availability (operating hours)
    - and temperature level [ºC] of the source).
- Energy demand for heating (gas, DH, …) per municipality.
- Other indicators:
    - Population density.
    - Terrain slope, etc.

Based on these key indicators, the following criteria is applied to identify consumption and production points:

- A circular buffer of a determined radius with centre on the production points is applied to define the area of influence, this is, to identify nearby locations that could use the recovered heat. The selection of the radius should take into account if highly dense municipalities are left out of the buffer, increasing or decreasing the radius to effectively match production and consumption points.

- In order to filter the interactions between producers and consumers, interactions are limited to those more interesting for the particular case, e.g. energy demand (gas, coal, electricity, etc.) is at least five times higher than the offer of the industrial residual heat location, or e.g. areas with high population density are in the area of influence of large heat producers. This is important to guarantee the proper exploitation of the residual heat location.

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- In case the number of preselected interactions between producers-consumers is high (or low, depending on the case), the buffer or the ratio energy consumption / energy availability would be changed to adjust the number of interactions to a desired number.
- Other criteria could be applied such as residential use percentage if the number is still high.

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3.3. Geoprocessing

The geoprocessing allows the spatial analysis of the heat locations, showing those municipalities with more potential to convert the waste heat from industrial processes in the surroundings into useful heat.

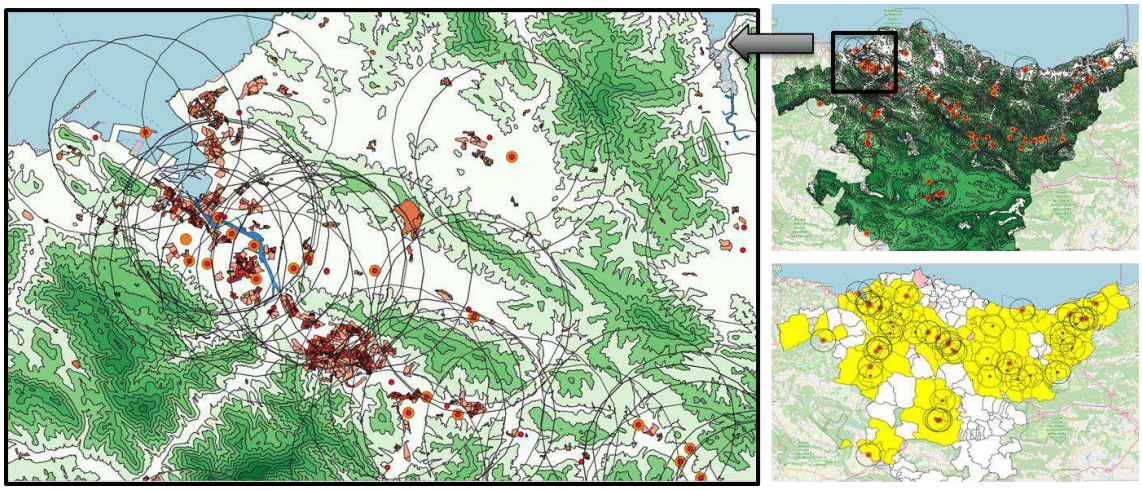

Figure 3. Geoprocessing of information on Basque country.

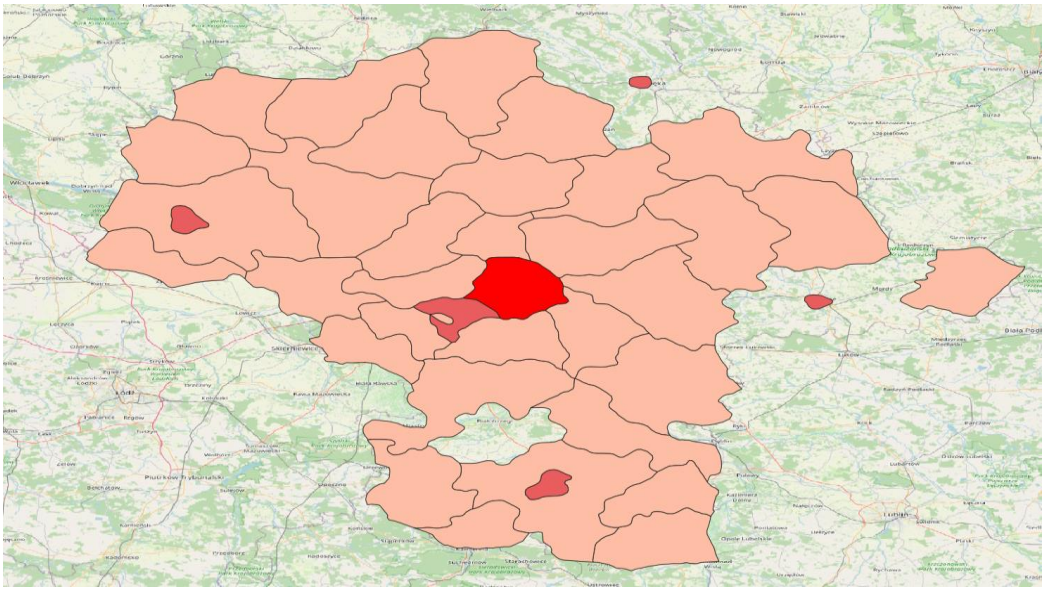

Figure 4. Geoprocessing of information on Mazovia.

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Once all the information is geoprocessed, based on the criteria explained in previous section, the number of potential heat sources and heat users is reduced to a reasonable number.

The pre-selected locations can be summarised in a similar table to the following:

Table 2. Example of table used in annexes A&B to summarized the pre-selected locations in each region.

Cluster	Number of buffers	Enterprises reference	Type of residual heat	Municipalities related
X	3		Direct use or via heat pump	
			Direct use or via heat pump	
			Direct use or via heat pump	

Please note that the column “Type of residual heat” refers to the thermal level of the waste-heat at the location:

- Direct use: >70-80 ºC.
- Heat pump: < 70 ºC (approximately 30 ºC).

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3.4. Prioritization and selection

Once the most interesting clusters are identified, the next step is to prioritize those municipalities with high potential of deploying waste heat DH networks based on their main features of the towns and their energy consumption. Interesting features, based on previously explained **key indicators,** include:

- Highest populated areas.
- High population densities.
- Short distance between densely populated areas.
- High energy demand per km^2.

The summary of the features can be shown in tables as follows:

Table 3. Example of table used in annexes A&B to summarized the main features of the municipalities with regards to population and residential sector in each region.

Population Size	Nº of towns	Average population	Avge. population density (citizens/km^2)	City	Avge. Energy consumption (GWh/y)	Avge. Energy consumption Density (GWh/km^2.y)
>100 kHab						
100-50 kHab						

Regarding the waste heat sources interesting features, the main are:

- Heat availability, measured by operation hours (or years) and magnitude of the heat.
- Heat quality, represented or quantified by the thermal level. Sources that produce heat with thermal levels in the range [30-70 ºC], need a boost in

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temperature to be used for DHW and space heating applications, especially if space heating is met by conventional radiators.

Water-to-water heat pumps (w/w HPs) are considered as temperature boosters located at the consumption point, i.e. in the buildings. RELaTED heat pump performance ratio is defined by the following equations:

$COP = (-0.0018 \cdot T_B - 0.0876) \cdot T_S + 0.1935 \cdot T_B + 7.4839$ (Equation 1)

Where:

- T_B: is the inlet temperature to the evaporator (e.g. waste stream).
- T_S: is outlet temperature of the condenser.

Taking this equation into account, the relationship between the heat at source location and at building can be summarised with a **4** average for seasonal COP that is applied for the w/w HP in the temperature ranges of T_S [60-70 ºC] and T_B around 30 ºC.

The intersection of these above features results on the potential areas for waste heat DH network deployment. In big and highly populated cities/municipalities, it could occur that the interesting areas don't cover the whole city; but can be concentrated in areas, and therefore the city can further be split in other areas, since there are several waste heat sources and highly populated neighbouring areas.

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3.5. In depth analysis of the pre-selected areas

The methodology applied in the second phase of the regional feasibility studies of new DH in consolidated urban environments, technical financial and administrative roadmaps starts with the identification of the following characteristics for the pre-selected areas:

1. Typologies of the buildings within the location, which, in the present case, is done by visual inspection from the Google Earth available information:
    a. Multifamily building.
    b. Semi-detached buildings.
    c. Single family buildings.
2. Building' characteristics:
    a. Surface being heated.
    b. Type of heating system:
        i. Individual.
        ii. Centralized.
    c. Power installed (kW).
    d. Energetic demand (kWh/year).
        i. Heating.
        ii. DHW.
3. Calculation of the pipe dimension from the source to the consumption point through the optimized path.
    a. Energy losses (kWh/year).
    b. Installation total costs (euros).
4. Calculation of the investment in heat pumps,
    a. Individual.
    b. Centralized.
5. Business model.
    a. Incomes.
    b. Outcomes.
    c. Payback.

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4. Main outcomes

The main outcomes of the study for both regions show:

- The methodology has been applied to identify the most interesting potential areas for waste heat recovery, with successful identification of several candidates.
- The main variables which must be taken into account are:
  - Available waste power (kW).
  - Total Annual Energy availability (operating hours).
  - Temperature level [ºC] of the source.
- It has been found that those industries with high quantities of waste heat dissipated by cooling towers are very interesting in order to achieve the objectives set in the project, due to the following reasons:
  - The interventions necessary to reuse the waste heat from cooling towers could be considered of low technical impact, without great modifications on the main industrial process as cooling towers represent an auxiliary process.
  - Thermal level of cooling towers (35-45 ºC) is optimal to be used coupled with LTDH thanks to the proximity on the thermal levels.
  - The benefits are double for the industrial company, due to the injection of waste heat into a potential business model and due to reduction of costs on the cooling towers (water treatment, hydraulic pumps consumption, etc.).
  - Furthermore, the reuse of waste heat that is already being cooled down in an auxiliary process ensures that no additional energy is used in the primary process.

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- Despite the above, the lack of interest from the industrial heat producers to reuse their waste heat conditions the study. The lack of data from the industrial source implies that any pre-analysis would be inconclusive. Therefore, different criteria is applied based on those sources that provided detailed data.

More specific outcomes per region are summarised below.

4.1. Basque country

The application of the developed methodology to the Basque country shows 27 areas of highly potential for heat recovery.

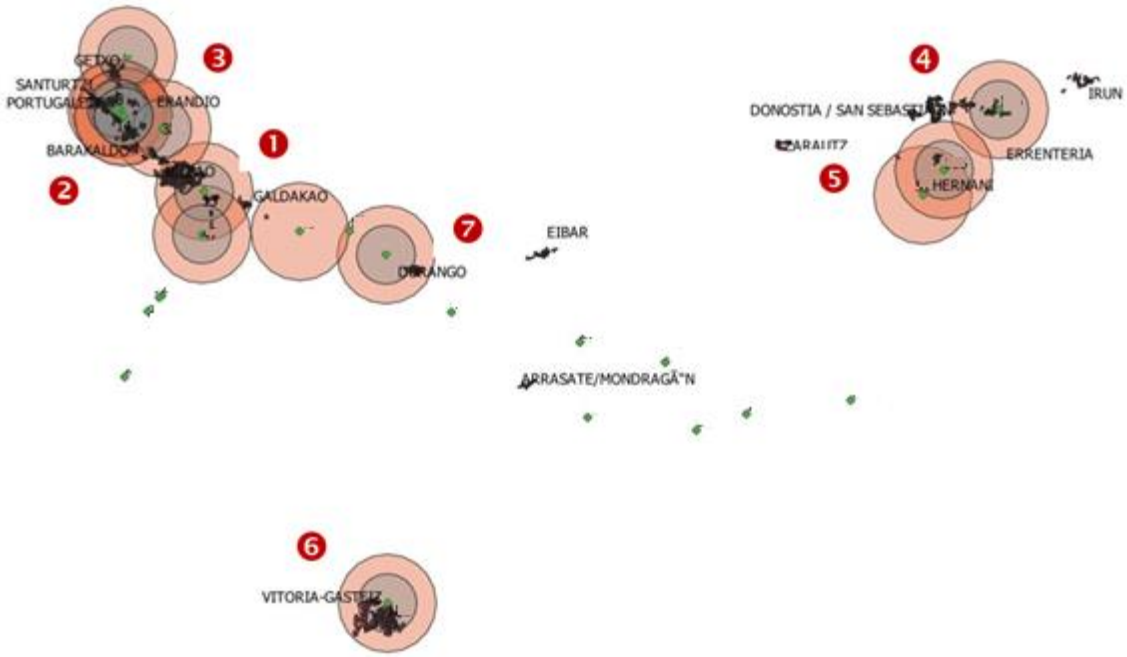

Figure 5. Selected interactions between waste heat sources with an annual heat production> 10 GWh/year (represented with a green diamonds and numbered), and high/medium dense areas in cities with higher population than 20,000 inhabitants (identified with the name).

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Based on the explained criteria, from all the pre-selected areas those industrial sources with large cooling towers were chosen and further analysed: Basauri and Abanto Zierbena.

4.1.1. Basauri

The study of the San Miguel quarter as area of interest for waste heat recovery from the industrial source shows the following:

- The total investment is close to 5M€, being the cost on the network piping (1.1M€) and the substations and connection (2.3M€) the items with the highest investment needs.
- The total savings are 535,124 € per year.
- This results on a payback period of 10 years.
- Regarding the GHG emissions avoided, the total number amounts to 1,645 tons of CO_2 per year.
- Regarding the primary energy, 7,264 MWh are avoided per year.

4.1.2. Abanto Zierbena

The study of the Las Carreras quarter as area of interest for waste heat recovery from the industrial source shows the following:

- The total investment is 5,3M€, being the cost on the network piping (0.9M€) and the substations and connection (2.7M€) the items with the highest investment needs.
- The total savings are 142,695 € per year.
- This results on a payback period of 14 years.
- Regarding the GHG emissions avoided, the total number amounts to 1,276 tons of CO_2 per year.
- Regarding the primary energy, 5,283 MWh are avoided per year.

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4.2. Mazovia

The application of the developed methodology has been simplified in the case of Mazovia region due to lack of available data. Furthermore, the configuration of DHNs studied for Mazovia for waste heat injection is based on conventional systems to complement the work done for Basque Country.

The application of the simplified process to the Mazovia region results on the identification of the relevant heat sources, their buffers, and those areas with higher consumption (see Figure 6).

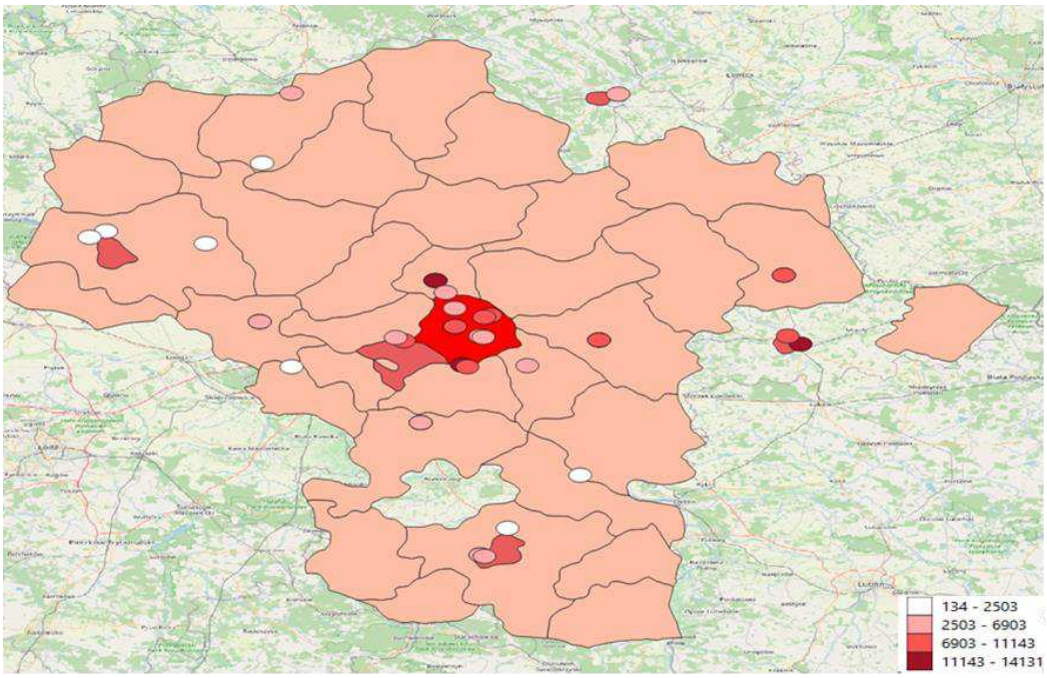

Figure 6. 3 kms buffers around the available waste heat sources. The legend shows the meaning of the buffer's colours.

From the analysis included in annex B, it can be concluded that Warsaw region is the county with higher potential since:

- It has the highest number of flats connected to the DH.

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- It is the highest consumption of DH, with over 6,600 GWh/year.
- It contains the highest number of identified waste heat sources for potential use in the DH.

Furthermore, from the visual inspection of Figure 6, three are the most interesting buffers (those with darkest tone of colour), this is, those containing a higher number of buildings. Visual evidence shows that none of them are fully located in the Warsaw county, and therefore no interaction is fully satisfactory.

Since the criteria applied don't fully comply with expectations, the prioritization and selection of municipalities with high potential of deploying waste heat DH networks is based on those industries which have shown an interest on the study, as reflected in **Table 4**.

Table 4. Pre-selected locations. The enterprise is represented with a number to anonymize the process.

Cluster	Enterprises reference	Type of residual heat	Counties related
1	4	Direct use	**Pruszków**
2	7	Direct use	**Radom**

In Annex D, these clusters are analysed in detail, being the main information summarised as follows:

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4.2.1. Pruszków

The Pruszków case is a waste heat injection to an existing DHN. Due to confidential issues, the data provided by the industrial source cannot be disclosed. Therefore, the viability analysis takes as assumption that the available heat is enough to double the energy demand already provided by the DH. The outcomes of the study show:

- The total investment is close to 25M€.
- The total savings are ≈15M€ per year.
- This results on a payback period of <2 years.
- Regarding the estimation of GHG emissions avoided, the total number amounts to 38Mtons of CO_2 per year.
- Regarding the estimation of primary energy, 204,019 MWh are avoided per year.

4.2.2. Radom

The Radom case is a waste heat injection to an existing DHN to substitute heating based on coal production.

- The total investment is close to 170k€.
- The total savings are 136,459 € per year.
- This results on a payback period of less than 2 years.
- Regarding the GHG emissions avoided, the total number amounts to 308.7 tons of CO_2 per year.
- Regarding the primary energy, 2,478 MWh are avoided per year.

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5. Roadmap

In the present section, the roadmap developed in T5.6 for the planning of waste heat injection into existing or new LTDH networks in urban areas is described. Considering that administrative & policymaking environments vary along Europe, the developed roadmap is focused on the particular work performed for Basque Country, with the focus on addressing non-technical stakeholders such as political and financing actors. Therefore, it focuses on political visions drawn from the conclusions and lessons learnt from the technical developments of tasks 5.6 and 5.7. The complete roadmap consists on the following points:

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Table 5. Roadmap for the planning of waste heat injection into existing or new LTDH networks in urban areas.

	BLOCK	ACTIONS
ACTION BLOCKS	1. Technical	1.1 Assessment and geolocalization of waste heat sources in industrial processes
		1.2 Assessment and geolocalization of consumption points
		1.3 Network design
	2. Financial	2.1 Assessment of investments
		2.2 Assessment of economic performance
		2.3 Key economic indicators
		2.4 Pricing schemes for new heat injections
	3. Environmental	3.1 Key environmental indicators
Tools		4.1 Source of finance
		4.2 Legislative plans
		4.3 Investments plans
Administrative constrains		

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Technical block

- Technical actions for the identification, estimation and geolocalization of residual heat sources. Available waste power (kW), Total Annual Energy availability (operating hours), and temperature level [ºC] of the source are the main variable which must be taken into account. In addition, those industries with high quantities of waste heat dissipated by cooling towers could be prioritised over others since:
    - The interventions necessary to reuse the waste heat from cooling towers could be considered of low technical impact, without great modifications on the main industrial process as cooling towers represent an auxiliary process.
    - Thermal level of cooling towers (35-45 ºC) is optimal to be used coupled with LTDH thanks to the proximity on the thermal levels.
    - The benefits are double for the industrial company, due to the injection of waste heat into a potential business model and due to reduction of costs on the cooling towers (water treatment, hydraulic pumps consumption, etc).
- Technical actions for the estimation and geolocalization of consumption points.
    - Big tertiary buildings (offices, sport centres).
    - Public buildings.
    - Residential buildings, despite their low heating demand density, could be considered if tertiary sector heating demand is not relevant in the vicinity of the waste heat sources.
- Network design for the design of the infrastructure for the heat injection.
    - Thermal level considerations if the waste heat reuse is part of a new LTDH development.

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Financial block

- Assessment of investments:
  - Equipment and civil works.
- Assessment of economic performance:
  - Cashflow.
  - Avoided costs.
  - Operation and maintenance costs.
- Estimation of economic indicators (payback, RoI).
  - As general reference, if payback is higher than 2-3 years, it is considered as high in terms of industrial typical expectations. In those cases, additional finance sources should be investigated.
- Pricing schemes for new heat injections.

Environmental block

- Assessment of environmental indicators.

Policy tools

- Finance sources:
  - Public subsidies.
  - Tax reductions.
- Legislative plans from public sources to ensure high ratios of low temperature DH deployment by 2030.
- Investment from public sources.

Administrative constraints

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5.1. Technical blocks

5.1.1. Technical actions for the estimation of waste heat sources in industrial processes

The potential sources of a region need to be identified and estimated by regional experts that understand the energetic characteristics and problems of the area.

In this sense, the first approach is to compile the data from questionnaires distributed to the main energy consumers among the biggest industries in the area. The results from the questionnaires must have the proper relevance, allowing the analysis of the energetic structure and the strategic factors as well as to establish the future trends. The main objective is to design and deployed an energetic roadmap focused on the improvement of the energy framework in terms of industrial competitiveness.

The questionnaires should include the following questions:

- Energy consumption of the company.
- Type of energy use:
    - What energy vector is used: gas for boilers, etc.
    - Direct or indirect use of the energy vector.
    - Use of electricity: thermal and non-thermal uses, etc.
- Description of the productive process.
- Technical characteristics of the equipment:
    - Furnaces: combustion, electrics.
    - Boilers.
    - Generators of electricity based on combustion engines.
    - Compressors.

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- Cooling towers.

For the industrial sector, the main outcomes should give answer to the following indicators:

- Energy consumption, total and by subsector.
- Energy intensity, total and by subsector.
- Type of energy use: boilers, direct use, electricity.
- Technical characteristics of the equipment: Furnaces, boilers, cogeneration, compressors, cooling towers.
- Structure of the energy consumption: performance, efficiency, etc.

Moreover, the collected information should indicate the available waste energy, thermal level and annual working hours of the equipment.

The work carried out in RELaTED shows that large cooling towers are one of the best choices to be used with LTDH networks since:

- Full or, at least, high availability. Therefore, no back-ups systems are mandatory.
- Thermal level of cooling towers (35-45 ºC) is optimal to be used coupled with LTDH thanks to the proximity on the thermal levels.
- There is no impact on the main productive processes of the industry as cooling towers are an auxiliary process.
- The benefits are double for the industrial company, due to the injection of waste heat into a potential business model and due to reduction of costs on the cooling towers (water consumption, electricity, water treatment, etc.).

Furthermore, it is common that industrial plants need to report potential health issues related to their cooling towers (legionella), as it is the case in regions such

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as Basque Country. This information is a perfect basis for the study here explained.

5.1.2. Technical actions for the geolocalization and estimation of consumption points

The potential of a waste heat source to be used in DH networks is highly dependent on the relevance of anchoring capacity of thermal loads nearby. Therefore, the collected information per industrial heat source must be geoprocessed to understand not only its quality and quantity but also its vicinity to high consumption points (high dense areas). In this way, geolocalization is a support tool to visually understand the potential for the waste heat reuse.

Once the industrial waste heat sources are properly represented in adequate GIS, the next step is to represent the potential consumption points. In this sense, big tertiary buildings (offices, sports centres, etc) and public buildings are of high interest, due to their large energy intensity.

On the other hand, if public buildings are not on the vicinity or the consumption is not relevant, residential sector could be of interest despite their relative low consumption density.

For building energy demand estimation, existing energy certificates or energy audits are of great help to quantify the demand. In case these are not available, a quantification process based on available data (cadastre, etc…) and energy analysis tools such as modelling, and simulation must be carried out to characterize the energy consumption on the vicinity of the heat source:

- Space heating demand.
- DHW demand.
- Dynamics of the demand or consumption patterns.
- Total power needs.

This process must end with the identification of suitable areas for waste heat injection into an either existing or new DH network, where the waste heat

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availability is capable of supplying all or a high amount of the energy needs of the analysed district.

5.1.3. Network design

The next steps focus on the design of the infrastructure for the heat injection. The infrastructure is based on a pipe buried network, though which the water at low temperature circulates from the industrial source to the final consumption points.

The design of the network follows the logic of similar networks. The design process should give the following outcomes:

- Pipe dimensions (length, diameter).
- Flow.
- Pressure losses.
- Energy losses.

If the heat injection connects to a previously existing network or to a central heating system, the distribution within the buildings would take advantage of the already installed network. Otherwise, the distribution within the buildings must be considered.

Thermal level

If the heat injection from the waste heat source is devoted to a previously existing LTDH, no further considerations must be considered.

However, if the waste heat reuse is part of a new LTDH development, the thermal level implications need to be considered. Three cases are mainly encountered:

- Space heating is provided to NZEB, with low temperature distribution systems.
- Space heating is provided to medium/high temperature distribution systems such as conventional radiators.

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- Domestic Hot Water.

In those cases where DHW and/or space heating is provided at temperatures higher than those of the distribution system, HPs must be distributed along the network, either at dwelling level or as at building level in a centralized form.

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5.2. Financial block

To assess the potential of the waste heat for DH heat production, the economic model already included in “D4.5 - Heat Producer Case” is proposed to simulate the potential cashflow of the heat producer to support the investment into new heating installations, from a general point of view. This model is a simplified version of the real economic incomes and outputs that a heat producer would incur. This helps identify how the inclusion of the waste energy into the DHN impacts economic behaviour.

The model focuses on the energetic and economic effects based on the heat injection (heat flow), as represented in next figure. The parameters for the economic model are shown in the schematic below. The figure is divided into the operator (left side) and the user (right side):

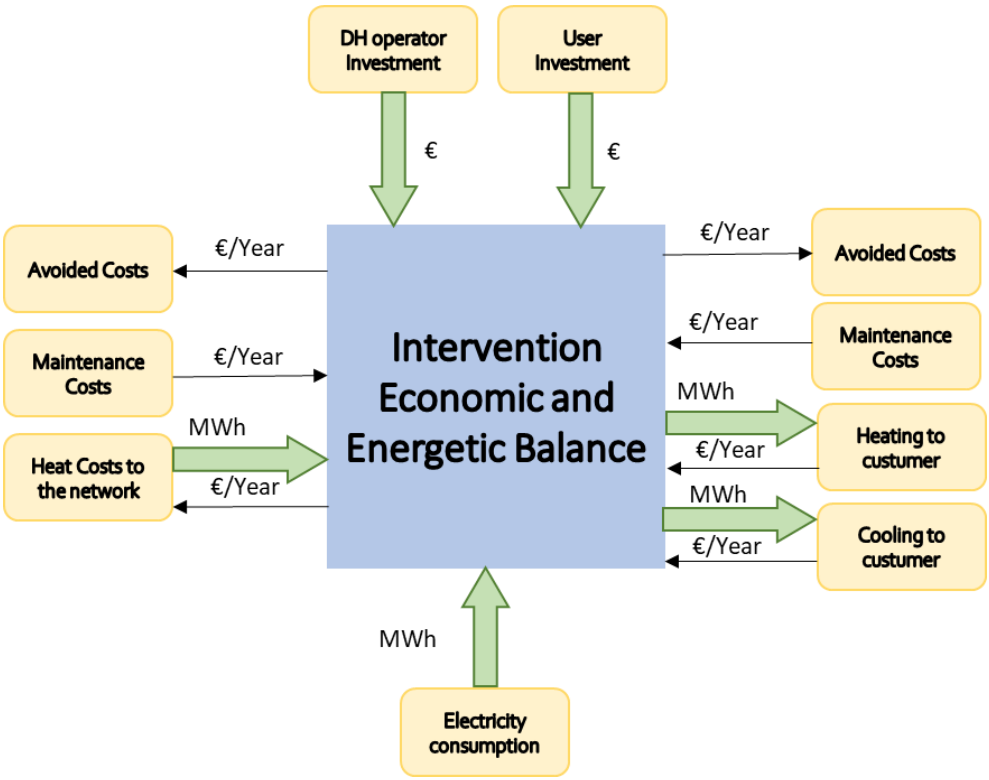

Figure 7. Economic model.

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5.2.1. Assessment of investments

This includes capital expenses and operational costs that are related to the new installations.

Main elements of investment are:

- Civil works to adapt the industrial processes for the use of waste heat.
- Heat exchangers.
- Hydraulic pumps & associated costs.
- Buried pipes & associated elements (filters, valves).
- Ditches.
- Substations.
- Heat pumps.

The investment could be either financed by:

- Potential operator,
- the industry, with its waste heat source, or
- the final user.

Generally, the final investment can be split among all the stakeholders in different shares.

Furthermore, the following costs exist:

- Maintenance costs: to the operator.
- Maintenance costs: to the user.

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5.2.2. Assessment of economic performance

Economic figures related with energy flows

This includes energy costs, such as service costs, paid by users in the new installations.

- Heat to the network: associated revenues from supplying waste heat to DHN (output).
- Heat to customer: the associated costs (input) for including the price of the heat delivered to the customer after the intervention.
- Cooling to customer: not relevant in this case.
- Electricity consumption (input): The electricity consumption (in MWh) that is used in the new installations.

The associated revenues from supplying waste heat to DHN must ensure a suitable Return of Investment (RoI) for the heat producer (industrial waste heat source) and an attractive price for the user as they need to switch off from the conventional heat of source (previous scenario) to heating based on waste heat.

The proposed methodology in the present study is the analysis of viability of this kind of projects, where both industrial waste source and final users obtain avoided costs, as a cashflow, due to the investment in the project. The avoided costs are not a real economic flux, but a simulated figure used to represent the improvement on operational costs due to the injection of waste heat.

The avoided cost included are:

- DH avoided costs: in cases of pre-existing DH networks where the heat is injected, the DH operator would avoid fuel cost thanks to the heat injection.
- User avoided costs: in cases of new LTDH developments, the waste heat injection would substitute conventional heating systems such as individual or centralized boilers. Therefore, the user would save on fuel.

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In the case of the user's investments, they are not paid off by the direct income from heat production, but by the reduction of the service costs (avoided costs). From the point of view of the industrial source, other avoided cost that is not a real economic flow or revenue, but must be taken into account, is the reduction on the use of auxiliary processes for waste heat treatment such as cooling towers (reduction of water treatment, electricity, etc.).

The assumptions taken for the viability analysis are unlike to happen in reality. More plausible scenarios are presented below, where either the figure of an operator or the industry user would support the investment, aggregate the demands and operate the waste heat injection into the DH as well as the supply to the costumers. Likewise, in case a DH operator could appear as an investor in the project, it should be taken into account that the investment is paid off by either an increase on the input flow of heating into the network (with the associated revenues) or the substitution of conventional heating plants by other sources with less costs (for example, including waste heat sources into the network).

5.2.3. Key economic indicators

Once the magnitude of the investment and the cashflow are estimated, the next step is to calculate the economic factors that indicate the suitability of the investment. Very simple recommended economic indicators are RoI and payback.

In the case of payback, this indicator must be examined in each case, but as a general rule, paybacks higher than 2-3 years are considered as high in terms of industrial investments. In those cases, additional finance sources should be investigated.

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5.2.4. Pricing Schemes

As said previously, in the scenario of waste heat reuse in new or existing networks, economic schemes must be elaborated for fair remuneration for heat injection at small scale, properly accounting for the cost and amount of heat sold to the network with adequate net metering based on smart meters that accounts the net heat injected to the grid.

Regarding the pricing mechanism for which the industrial heat sources would account cost and charge the customers for their service, it must be considered that, like any other business, the heat source must cover the cost for providing a service (heat) to their customers, be competitive over alternative heat sources and, ultimately, gain a profit from producing and distributing heat. In the case of the overall cost for the DH, it depends on three main factors:

(1) the connection costs for the customers,

(2) the costs of the distribution network, which depend on the size of the DHN and its thermal loads,

(3) the production costs of heat (Li et al., 2017).

The combination of these three factors will determine the price for the DH customer and, therefore, the renumeration, while in the case of the industrial heat source, only the production costs of heat should be covered as both the costs for connection and distribution are already covered by the network. The production costs would then include:

- the fixed component (due to smart metering, billing), which will represent a small fraction of the total.
- and, the energy demand component, which will mean the highest proportion.

However, no load or flow demand component should be considered for the small producers as these are covered by the DH operator.

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To account the costs of heat sold to the network, the following economic schemes are proposed for the waste heat recovery and injection into LTDH.

Scenario 0 – viability plan:

In the viability plan, it is assumed that the investment to include heat injection from industrial sources is carried out by the users, who support the investment on the demand side (pipes, heat pumps, substations), and the industry, who supports the investment on the supply side (hydraulic pumps, heat exchanger, piping).

This investment is paid by avoided costs. In the demand side, the user would stop paying for conventional heat sources such as individual gas boilers; in the supply side, from the point of view of the industrial source the avoided cost would be those resulting from the reduction on the use of auxiliary processes for waste heat treatment such as cooling towers (reduction of water treatment, electricity etc).

This scenario is used during the viability plan, being unlikely to happen in reality. This scenario is only used for the viability phase, as in real practice the wide number of buildings involved need the figure of a third party in the form of an aggregator or a DH operator to develop the project.

Scenario 1:

The investment to include heat injection from waste heat is supported by the industrial heat source, whereas the rest of the DH network is maintained by the DH operator. This investment should be paid by charging for the heat injected until a fair ROI is reached. The industrial heat source would charge the full price to the individual consumers and split this economic input between itself and the individual producers; a potential scheme could be:

- The DH operator keeps a fraction of the total price (~30%) to cover its O&M costs.

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- The rest (~70%) of the cost charged to the user is paid to the industrial source to pay for the heat injected until a fair remuneration is achieved, that needs to be evaluated for each case.

- Additional positive impacts to reduce the payback period of the investments include reduction of costs to treat the waste heat on the industrial source (water treatment, hydraulic pumps consumption, etc.).

Scenario 2:

- The investment to include heat injection from industrial sources is carried out by the operator. This investment should be paid by charging for the heat injected until a fair ROI is reached. This scenario simplifies the billing, as the DH operator would charge the full price to the individual consumers for the waste heat injected in order to cover its O&M costs and to pay off its investment without further share with third parties as in scenario 1.

Additional positive impacts to reduce the payback period of the investments include reduction of costs to treat the waste heat on the industrial source (water treatment, hydraulic pumps consumption, etc.).

Further plausible scenarios could be a combination of the ones described.

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5.3. Environmental block

The reuse of waste heat into LTDH networks brings not only economic but also environmental benefits that include:

- Strategic regional benefits in terms of energy independence, reducing imported goods (fuel) by locally available waste heat.
- Environmental benefits, with avoidance on GHG emissions and savings on primary energy consumption.

Regarding GHG savings, the estimation of the benefits could be calculated following the methodology included in the *Tool to support the calculation of GHG emission avoidance from renewable electricity, renewable cooling and renewable heating projects under the Innovation Fund (v2.0 - 24.03.2021).*

5.4. Tools

The present block presents the tools that the promotors have to foster this kind of interventions.

5.4.1. Sources of finance

In those cases where the potential for waste heat reuse is relevant but the investment is not attractive for the industrial actor, additional sources of finance are to be provided by the different governments at European, state, and regional level. These different public bodies have established objectives in terms of energy efficiency and renewable energies to fight climate change. To achieve these objectives, the mentioned public bodies develop policies based mainly on legislation (regulations) and financial incentives. Within the former, there are two fundamental tools that contribute in this matter: subsidies and tax deductions.

Subsidies

Direct financial support to improve energy efficiency or increase the use of renewable energies. In Basque Country, different aid programs based on these

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two aspects have been published for more than 30 years. In the case of financing programs for the promotion of energy efficiency, any technology that involves a reduction in energy consumption is subsidized. In general, the percentage of subsidies is around 20% of the eligible cost. In the case of subsidies programs for the promotion of renewable energies, any renewable energy generation technology is subsidized: biomass, geothermal energy, aerothermal energy and solar thermal energy. In this case, the percentage of aid is around 30% of the eligible cost. Likewise, the provincial governments have also established different aid programs to promote energy sustainability in their territories, both for the promotion of energy efficiency and for the installation of renewable energies, although their budgets are lower. Investments to reuse waste heat form industrial sectors into urban areas by means of LTDH, contribute to the objectives defined in the bases of these finance programs, and are therefore subject to a general subsidy.

Tax deductions

The second instrument that could be of use to reduce the payback on waste heat reuse is tax deductions. This tool aims to enhance companies to make investments in projects that seek sustainable development, conservation and improvement of the environment and the more efficient use of energy sources

In the Basque Country, taxpayers can deduct 30 % of the investment on this kind of projects

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5.4.2. Legislative plans from public sources to ensure high ratios of low temperature DH deployment by 2030

In parallel to the finance programs, the regulatory pillars of energy sustainability must facilitate the uptake of waste heat recovery, articulating the basic normative and regulations for the promotion of low carbon technologies. At European level, different Directives have been published such as Directive 2012/27 / EU on energy efficiency, Directive 2010/31 / EU on the energy efficiency of buildings, modified by Directive 2018/844, as well as Directive 2018/2001 on the promotion of the use of energy from renewable sources. In all of them, the promotion of sustainable technologies in efficient district heating systems is sought, especially renewable technologies. As a consequence, in the Basque Country, this philosophy was transposed at the legislative level, through Decree 254/2020, which establishes that local administrations must establish by regulation the obligation to provide centralized energy supply systems and use of renewable energies.

Other tools such as open data sources are of high interest to perform this kind of studies. The government of Basque Country has launched GeoEuskadi. Infraestuctura de datos espaciales - IDE Euskadi in this sense.

5.4.3. Investments from public sources

Finally, a possibility to carry out this type of projects, where its economic profitability is not attractive for private companies, is the creation of a public company that undertakes both the investment and the operation of the facilities.

At local level, in the Basque Country some experiences have recently been initiated by public companies that have undertaken DHN projects based mainly on biomass technology. They are currently in the monitoring and follow-up phase.

At the regional level, although there are experiences in the field of construction where the social function is predominant, there are no previous experiences exclusively in the field of thermal installations given the uncertainty generated by this type of projects.

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5.5. Administrative constraints

The main barrier that exists in the execution of the DHN is the use of public land for the implementation of the pipe network. The part associated with thermal generation, both in the part of the use of waste heat and in the part associated with heat pumps, does not pose any greater problem than that relating to a conventional thermal installation.

Conventional services, associated with pipes which must be provided to a building (electricity, water, gas and telecommunications) do not pose any problems, given that the legislation has been adapted to those supplies, generating a special regime for them in order to be able to use public land.

The thermal networks do not have this regime, so they are at the expense of what is indicated by the regulations of the City Councils, so it is necessary to request a permit for the use of public land: Municipal Concession. Thus, the response of each City Council can be different, positive or negative, depending on the situation.

A solution to this situation is the declaration of the DHN as of public interest. This regulatory figure is established at the national level, and thanks to it, the execution and development of projects is streamlined, since it reduces by half all the procedures related to the execution and development of projects in public administrations. In addition to this, obstacles to the implementation of this type of installations are avoided.

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6. Conclusions

The main lessons learnt and conclusions from the analysis are listed below:

- The methodology developed within RELaTED identifies interesting interactions between heat sources and high dense areas, but fails to encounter fully successful outcomes.
- The paybacks are lower for Mazovia than Basque Country mainly due to the existing DH infrastructure in Mazovia, what makes the investments needs lower for this region.
- Access to data is essential: Although a specific methodology is described to find the most interesting heating sources in the region taking into account heat quality, highest populated areas, etc, the interest from the industrial counterpart is crucial for a successful waste recovery. The lack of data from high potential sources with no interest makes the study (and the further construction works) difficult.
- It is crucial for public authorities to map correctly the available waste heat streams. With easy access to this information, assessing the financial benefit and developing adequate policies would be more feasible.

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8. Annex A. Regional feasibility studies of new DH in Basque Country

For Annex A: Regional feasibility studies of new DH in Basque Country, see separate document.

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9. Annex B. Regional feasibility studies of new DH in Mazovia

For Annex B: Regional feasibility studies of new DH in Mazovia, see separate document.

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10. Annex C: Technical, financial and administrative roadmaps of new DH in consolidated urban environments in Basque Country

For Annex C: Technical, financial and administrative roadmaps of new DH in consolidated urban environments in Basque Country, see separate document.

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11. Annex D: Technical, financial and administrative roadmaps of new DH in consolidated urban environments in Mazovia

For Annex D: Technical, financial and administrative roadmaps of new DH in consolidated urban environments in Mazovia, see separate document.

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Annex A: Regional feasibility studies of new DH in Basque Country

Date: 17/02/2022

Version: 1.0

Deliverable	Annex A
Name	Regional feasibility studies of new DH in Basque Country
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1. Introduction

This annex reports on the application for Basque Country of the methodology developed within Task 5.6. The application of this methodology has identified opportunities of waste heat reuse with the Basque country region on two phases:

- **Phase 1 (T 5.6):** a set of 2 locations are identified as suitable for the region, as summarised in the present annex A.
- **Phase 2 (T 5.7):** The identified locations are analysed in detail for the final selection of one suitable location for the deployment of a new DH network with the RELaTED configuration. Based on phase 1 and regional workgroups, potential sites for DH development are identified based on predefined key factors such as economic factors, available residual industrial heat or vicinity of urban areas, among others. Furthermore, the definition of implementation roadmaps is included for the selected areas.

The structure of the present annex meets the following:

- **Information compilation and georeferencing:** short explanation of the information collected and visual representation of it.
- **Geoprocessing:** analysis via GIS tools of the main waste heat sources' locations and nearby municipalities to identify the most interesting areas in terms of interactions between energy availability and highly populated areas.
- **Prioritization and selection of municipalities with high potential of deploying waste heat DH networks:** from the interactions identified, those areas with higher potential of waste heat DH deployments have been selected.

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2. Information compilation and georeferencing

Firstly, all the information necessary for the analysis is gathered and processed to be integrated in a GIS project. Detailed information regarding the approach followed for the compilation of the information is summarised in the next section.

2.1. Information compilation

Data is gathered by EVE with questionnaires distributed among regional companies (see Figure 1).

1. GENERAL DATA.

1.1. COMPANY IDENTIFICATION.

Reference:

Company name:

Industry sector: #N/D **Code A**

Product:

City:

Name:

Code:

Address:

Contact:

Name:

Phone number:

E-mail:

1.2. UTM.

X:

Y:

LATITUDE:

LONGITUDE:

CODE A	NAME
A-00	Energy & Water
A-01	Primary steelmaking
A-02	Secondary steelmaking
A-03	Foundry
A-04	Forging
A-05	Pulp & Paper
A-06	Concrete
A-07	Metallic processed products
A-08	Chemical industry
A-09	Food, drink & Tobacco
A-10	Rubber derivatives
A-11	Glass
A-12	Non-ferrous metallurgy
A-13	Other non-metallic metals
A-14	Electric machines or materials
A-15	Transport means construction
A-16	Non-energy extractive industry
A-17	Textile
A-18	Petrochemical
A-19	Plastic processed products
A-20	Wood
A-21	Leather
A-22	Construction

Figure 1. Questionnaire distributed from EVE, section “General data”.

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The data is then analysed, and the useful waste energy of those companies is calculated for those where data was available.

To do this, the following was performed:

1) Drew up tables for each equipment type to be analysed, with the necessary parameters for calculating the useful waste energy.
2) Defined the calculation criteria for each equipment type, as listed in the following section.
3) Made all necessary calculations to establish the useful waste energy and analysed the results.

2.1.1. Calculation criteria

To determine the useful waste energy of the companies in the inventory, it was necessary to establish certain criteria, which varied depending on the equipment to be analysed, as explained below. The equipment included boilers and furnaces, self-generation, compressors and cooling towers.

2.1.1.1. Boilers and furnaces

Where the consumption of the unit is unknown, but the number of operating hours per year is, we use the following assumption for both boilers and furnaces: total consumption is assumed to be 40% of the rated capacity of the equipment multiplied by the number of operating hours.

Where no figure is available for either consumption or total annual operating hours, we decide not to establish a total consumption figure, as we do not have sufficient relevant data for this purpose.

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Source quality

Finally, we analyse the quality of the sources, based on two criteria: annual operating hours and gas output temperature. The criteria for classifying the quality of these aspects are shown in the table below:

Table 1. Source quality classification criteria.

Source quality	Hours	T_{source}
A	≥ 6,000	T_{gases} ≥ 400 °C
B	3,000 ≤ Hours < 6,000	150°C ≤ T_{gases} < 400 °C
C	< 3,000 h	T_{gases} < 150 °C

Where A is the highest quality, B is average quality and C is low quality.

It should be noted that in some cases the figure for total operating hours is not available, and it is therefore not possible to establish the quality based on the number of hours. Similarly, in cases where no useful waste energy has been obtained, source quality is not assessed.

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BOILERS

The inventory of companies contains 183 boilers of different characteristics (one electric). However, no data was provided regarding the gas output temperature. Several aspects have been taken into account in determining this value from previous know-how, as shown in the following table:

Table 2. Assumptions to estimate the gas output temperature in boilers.

Economizer	Fluid	T_{gases}
Yes	All	125 °C
No	Steam	$T_{generation}$ + 15 °C
	Superheated water	$T_{generation}$ + 20 °C
	Hot Water or Thermal Fluid	$T_{generation}$ + 50 °C

In cases where there is no economizer, where the fluid is air or “Other”, and in cases for which we did not have sufficient information to establish the above criterion, each case was studied individually and establish the gas output temperature values manually to match the real situation at the plant.

It should also be noted that the gas output temperature factor obviously does not apply in the case of an electric boiler.

FURNACES

The inventory of companies contains 350 furnaces of different characteristics.

For the purposes of the study, we analysed two types of furnaces separately: fuel-burning furnaces and electric furnaces.

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THERMAL FURNACES

Of the 350 furnaces in the inventory, 200 (57% of the total) are fuel-fired.

However, no data was provided regarding the gas output temperature. Several aspects have been taken into account in determining this value from previous know-how, as shown in the following table:

Table 3. Gas output temperature in thermal furnaces.

Heat exchange unit	$T_{max\ required}$	T_{gases}
Yes	$T_{max} \geq 800$ °C	400 °C
	400 °C $\leq T_{max} < 800$ °C	300 °C
	$T_{max} < 400$ °C	120 °C
No	$T_{max} \geq 900$ °C	T_{max} - 200 °C
	600 °C $\leq T_{max} < 900$ °C	T_{max} - 100 °C

Where we did not have enough information to establish the above criterion, each case was studied individually and set the gas output temperature values manually to match the real situation at the company.

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INDUCTION FURNACES AND ELECTRIC ARC FURNACES

Of the 350 furnaces in the inventory, 150 are electric, of which 69 are induction furnaces, and 12 are electric arc furnace. This add to a total of 81, which means 54% of the electric furnaces and 23.1% of the total.

We included induction furnaces in our study of potential waste energy, on the grounds that, because they include a cooling system, there is a low temperature source (≈ 30 ºC) which could be recovered.

Specifically, it has been estimated that in order to cool the induction furnaces, the equivalent of 20% of the heat consumed is extracted, which could be used to heat water using a w/w HP. For electric arc furnaces, this number is reduced to 10%.

We also analysed the quality of the sources, using just one criterion: the number of operating hours per year. The criterion for classifying quality based on hours in operation is shown in the following table:

Table 4. Source quality classification criterion.

Source quality	Hours
A	Hours ≥ 6,000 h
B	3,000 h ≤ Hours < 6,000 h
C	Hours < 3,000 h

Where A is the highest quality, B is average quality and C is low quality.

It should be noted that in some cases the figure for total operating hours was not available, and it is therefore not possible to establish the quality based on the number of hours.

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2.1.1.2. Self-generation

The section on self-generation includes the following equipment:

1) Combustion engines.
2) Turbines.
3) Combined cycles (Gas turbine + Steam turbine).
4) Steam turbines.

Hydraulic turbines are not considered for obvious reasons.

To calculate the potential for recoverable energy, we considered the first three elements since steam turbines are associated with a steam boiler, which potential for energy recovery has been analysed in the section on boilers.

In the case of gas turbines, 100% of the recoverable heat energy is assumed to come from hot gases as no cooling circuit is associated. In the case of the engines, 50% of the recoverable heat energy is assumed to come from combustion gases and 50% from the engine's cooling circuit.

2.1.1.3. Compressors

The inventory lists 456 compressors in 90 companies, for which we have the following information: number of compressors, total power (kW) and average age.

In order to obtain the useful waste energy that might be obtained from these units, we need to determine their operating time. To do this, we took the maximum figure for working hours of boilers or furnaces in the company with the compressor(s). Having established this figure, we assumed that the compressors operate at 60% of rated capacity and that 60% of consumption could be recovered as useful waste energy in the form of hot water at 80–85 ºC.

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2.1.1.4. Cooling towers

The inventory lists 234 cooling towers in 59 companies, for which we have the following information: number of cooling towers, total power (kW) and average age.

For the purposes of the study, we do not include companies with induction furnaces and electric arc furnace, as this might have resulted in duplicated heat recovery figures, distorting the final results. We therefore analysed 167 cooling towers in 44 companies.

As with the compressors, in order to establish the useful waste energy that might be obtained from these units, we needed to know their operating time. To do this, we took the maximum figure for working hours of boilers or furnaces in the company with the cooling towers. Having established this figure, we assumed that 50% of the cooling capacity could be used, and thus obtained the value of useful waste energy.

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2.2. Information georeference

A selection of 73 sources with good quality of residual heat (A) are selected from the 613 identified in the questionnaire performed according to the temperature range and the operative hours of the source. These criteria have conditioned to select heat related to waste heat from boilers, and other industrial process fumes' temperature heat recovery (e.g. electric arc furnace-EAF, float glass furnaces and clinker kilns).

After the analysis was done, it was found that those industries with high quantities of waste heat dissipated by cooling towers are very interesting in order to achieve the objectives set in the project, due to the following reasons:

- The interventions necessary to reuse the waste heat from cooling towers could be considered of low technical impact, without great modifications on the main industrial process as cooling towers represent an auxiliary process.
- Thermal level of cooling towers (35-45 ºC) is optimal to be used coupled with LTDH thanks to the proximity on the thermal levels.
- The benefits are double for the industrial company, due to the injection of waste heat into a potential business model and due to reduction of costs on the cooling towers (water treatment, hydraulic pumps consumption, etc.).

Those sources are georeferenced and included as a shape layer inside GIS project. Once the potential heat sources have been georeferenced, the next step was to analysed the potential consumption points for the waste heat, this is, municipalities in the vicinity of the industrial points. Regarding the information collected on energy consumption, it is important to remark that Basque Country is a heating dominated climate, where space heating and DHW are the major consumption. Cooling is not representative for residential buildings. Space heating and DHW are generally satisfied by natural gas, with an extensive gas pipe network distributing to most of the towns with a population higher than 5,000

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people. Therefore, gas consumption is used as an indicator of the energy use at municipal level.

From the potential consumption points within the municipal boundaries of the residual industrial heat locations, the following data is compiled and analysed:

- Gas consumption, which is assigned to its correspondent municipality in municipal boundaries shape layer.
- Demand from public buildings (gathered from Basque Government), which are georeferenced in a specific shape layer. In this matter, information from 90 public buildings was available..
- Also, other 478 public buildings (provided by Basque Government) are georeferenced in another shape layer.

Finally, the GIS Project integrates the following information:

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Table 1. Sources of information integrated in GIS project.

TYPE	INFORMATION	YEAR	SOURCE	PROVIDER
Specific for the project	Residual industrial heat locations	2019	EVE	EVE
	Gas consumption (27 municipalities, domestic sector)	2018	EVE	EVE
	90 public buildings demand	2020	EVE	EVE
Public sources	Population per census track	2019	Municipal register	National Statistical Institute (INE)
	Elevation model	2016	Geoeuskadi	Basque Government
	Territorial planning	2018	Geoeuskadi	Basque Government

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3. Geoprocessing

Based on the criteria explained on the main body of the present deliverable, 5 km circles with centre on the waste heat source are applied to identify the area of influence of this source, this is, the municipalities included in a 5km area around the industrial residual heat locations (buffers from now on).

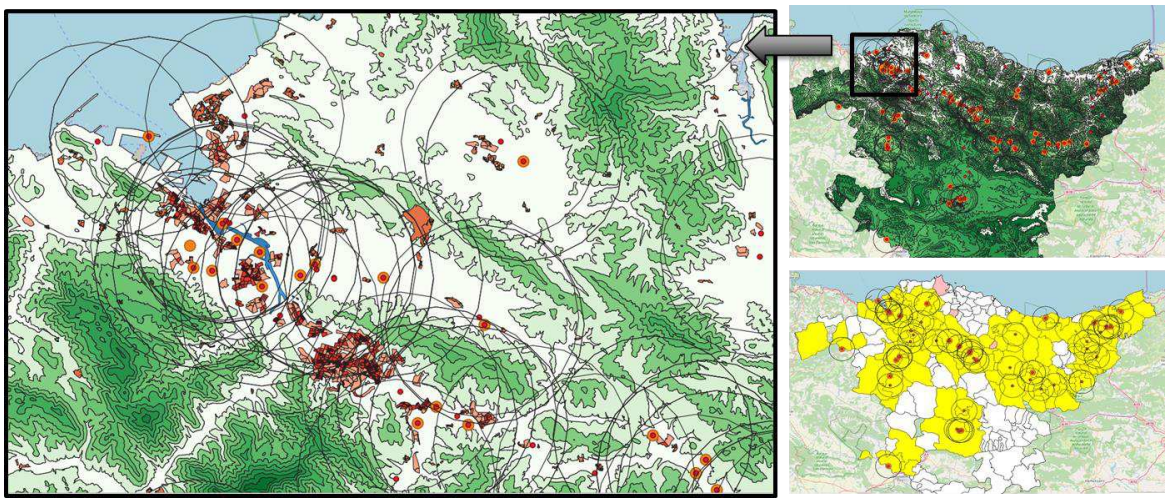

Figure 2. Application of a 5 km radius with centre on the industrial waste heat source.

The different buffers contain 566 interactions between heat sources and municipalities in their area of influence; the same municipality could interact with different buffers because of the proximity of the heat locations.

In order to filter these interactions and discard those less available for reuse of heat, different criteria were used until the most suitable one was found.

The first criteria considered to guarantee the exploitation of the residual heat location was to identify those interactions in which gas demand is at least 5 times higher than the offer of the industrial residual heat location. This filter reduces the interactions to 235, represented by 89 municipalities.

However, this approach based on the ratio gas consumption/waste heat available has been rejected since important heat producers were discarded of the study.

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Therefore, a different approach was analysed to include the biggest industrial sources of waste-heat, taking into account the interaction between the biggest urban areas and the biggest industrial sources of waste-heat, as explained in the next section.

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4. Prioritization and selection of municipalities with high potential of deploying waste heat DH networks.

4.1. Towns features

Main features of the towns and their natural gas consumption to satisfy heat (DHW and space heating needs) in the Basque region are:

- The highest populated areas are related with main cities (i.e. Bilbao, Vitoria and Donostia-San Sebastian) with an average population density of 28 - 12 kpeople/km^2) and population size of approx. 350 – 180 kpeople.
- Towns that are nearby these cities have lower population in total (100 - 20 kinhabitants), but population densities are similar, with around 40 -12 kpeople/km^2. The population densities decrease in the towns with 20k -10k inhabitants.
- Distances between towns in the Basque Country are rather small, which is positive when considering the potential population to be serviced by a DH.

These high population towns lead to high natural gas consumption in rather small areas where citizens are concentrated. The **natural gas consumption** has been estimated based on the data available from 27 municipalities. Those 3 municipalities with very low values in domestic or services gas consumption (Amezketa, Idiazabal and Urnieta) have been discarded. The consumption for the 24 remaining are related with their total population, calculating the average value (2.29 m^3 of natural gas per inhabitant). The rest of municipalities gas consumption is estimated using that calculation, this is, multiplying its population*2.29.

In general, the towns with population sizes higher than 20 kpeople, lead to annual average natural gas consumption rates of 51-36 MWh/km^2, while towns with

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population in the range of 20-10 kinhabitants have yearly ratios of 36-32 MWh/km^2.

Hence, taking in consideration that DH are benefitted for highly density and populated areas, the preferred targeted towns are going to be these with population sizes higher than 20k Inhabitants, with energy consumption densities of around 51-42 GWh/km^2.year, or overall energy consumption of >74 GWh.

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Table 2. Main features of the municipalities with regards to population and residential sector.

Population Size	Nº of towns	Average population	Avge. population density in populated (per/km^2)	City	NG avge. consump. (GWh/y)	NG avge. consump. density (GWh /km^2.y)
>100 kHab	3	255,069	17,735	Bilbao, Vitoria, Donostia	600	42
100-50 kHab	3	78,557	17,341	Barakaldo, Getxo, Irun	184	41
50-20 kHab	12	32,151	22,367	Portugalete, Santurtzi, Basauri, Errenteria, Leioa, Galdakao, Durango, Sestao, Eibar, Erandio, Zarautz, Arrasate/Mondragon	74	51
20-15 kHab	12	17,472	16,042	Hernani, Tolosa, Amorebieta-Etxano, Lasarte-Oria, Laudio/Llodio, Hondarribia, Mungia, Bermeo, Gernika-Lumo, Pasaia, Ermua, Bergara	40	36
15-10 kHab	12	12,216	14,010	Andoain, Azpeitia, Beasain, Sopela, Arrigorriaga, Azkoitia, Trapagaran, Elgoibar, Oñati, Etxebarri, Amurrio, Oiartzun	28	32

*densities referred to km^2 of residential areas.

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4.2. Waste heat Sources features

Industrial residual heat locations are analysed according the quality of the source. The analysis of the selected 73 sources is as follows:

4.2.1. Heat quality of the waste heat sources

The 73 residual industrial heat sources have been split in two groups according to their output temperature range in the process

- < 70 ºC: Heat Pump necessary *(24 locations).*
- 70-80 ºC: Direct Use of heat *(49 locations).*

4.2.2. Heat availability (operation hours and magnitude of the heat)

With regards to the magnitude of these sources, it can be seen that:

- More than 50% of the sources have a year round heat production lower than 3,000 MWh, i.e. the available heat is 10 times lower than the consumption of 15-10 k inhabitants.
- Only **25%** of the heat sources have higher annual heat production rates than **20 GWh**, i.e. 2 times lower than the average consumption of **medium sized cities (20-15 k. inhabitants).**
- There are 27 waste sources with a waste heat production higher than 10 GWh/year, belonging to 26 companies.
- The largest 6 heat sources, with heat production between 197 GWh and 100 GWh, are related to Kraft pulp mills, glass manufacturing, clinker and tires manufacturing heat waste, heat sources that are usually located in the town outskirts.
- These 6 sources are characterized by direct application heat, except the tires manufacturing company, which heat requires a HP for increasing the temperature.

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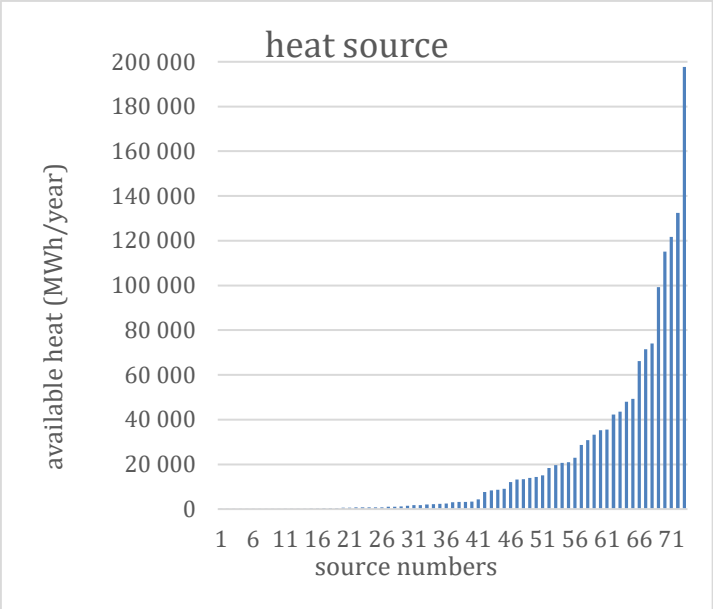
The following table summarizes the main features of the selected waste heat sources.

Table 3. Main features of the waste heat sources in the Basque Region.



Item	Heat production (MWh/year)
Max	197,631
Min	3.4
Median	3,002
Percentile 25 %	559.44
Percentile 50 %	3,001.56
Percentile 75 %	20,980.08

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4.3. Potential areas for waste heat DH network deployment

To select those areas with highest potential to reuse the waste heat, the following criteria is proposed:

- waste heat sources of **> 10 GWh** → 27 sources fulfil this criteria
- municipalities with higher population areas than **20 k inhabitants, this is,** the densest areas → 18 municipalities fulfil this criteria.

The vicinity between the selected waste heat sources and the densest municipalities is mandatory for a region to be considered of high potential. Therefore, buffers of **3 and 5 km are geoprocessed** around the 27 waste heat spots selected, resulting in the following:

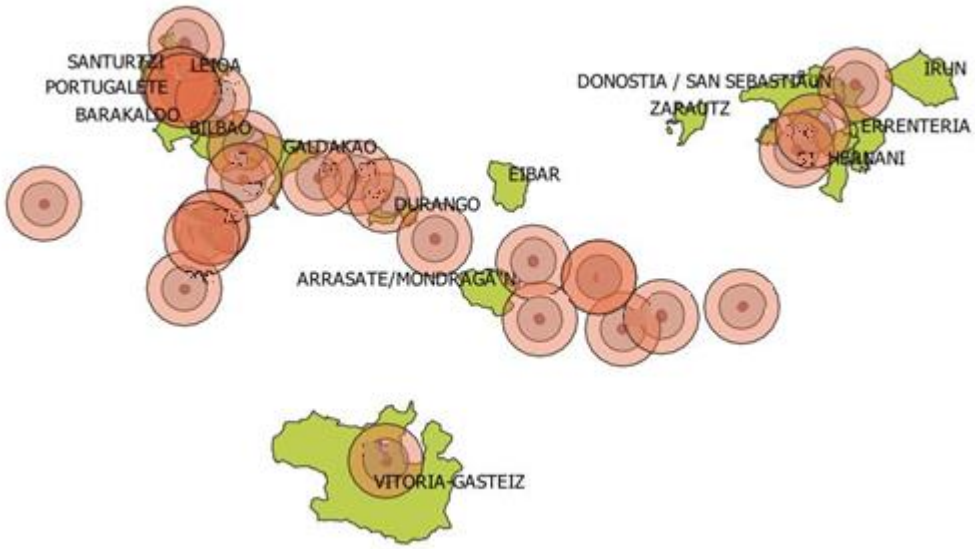

Figure 3. Waste heat sources with heat availability higher than 10 GWh, their areas of influence in 3 and 5 km around, and municipalities with population higher than 20,000 inhabitants.

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From the figure above it can be seen that there are waste heat sources that are not neighbouring highly populated cities/municipalities, and selection is basically concentrated in 4 areas, (1) Great Bilbao area (north-west), (2) Donostialdea area (north-east), (3) Vitoria (south) and (4) a more central area, located around Durango and Arrasate-Mondragon.

At the same time, when zooming and intersecting these buffers with the most populated areas in the municipalities, these highly populated areas of Great Bilbao and Donostialdea can further be split in subareas since there are several waste heat sources and highly populated neighbouring zones. This zoom results in 7 areas of potential interest for using waste heat source.

The following table and figures depict the potential municipalities and heat sources.

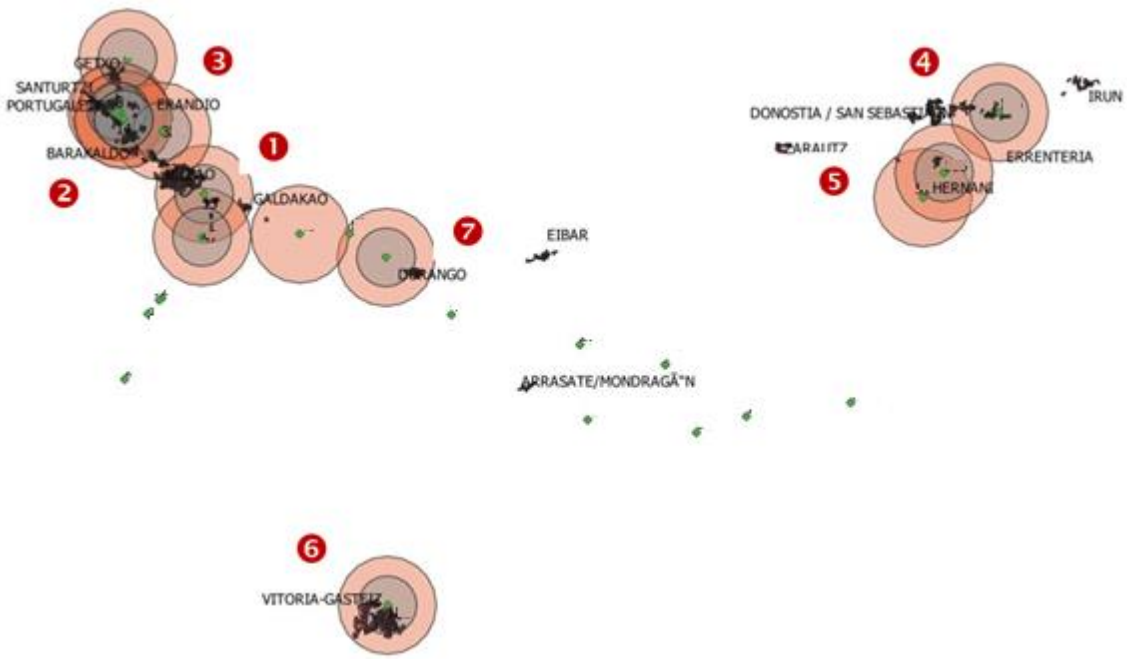

Figure 4. Selected interactions between waste heat sources with an annual heat production> 10 GWh/year and high/medium dense areas in cities with higher population than 20,000 inhabitants.

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Table 4. Potential areas for waste heat DH network in the Basque Region.

Ref	Municipalities
1.	Bilbao, Basauri, Galdakao
2.	Great area of Bilbao (river's left side) Sestao, Santurtzi, Portugalete, Barakaldo
3	Great area of Bilbao (River's right side) (Getxo, Leioa, Erandio)
4	Donostia-San Sebastian – Renteria
5	Donostialdea – Hernani
6	Vitoria-Gasteiz
7	Durango

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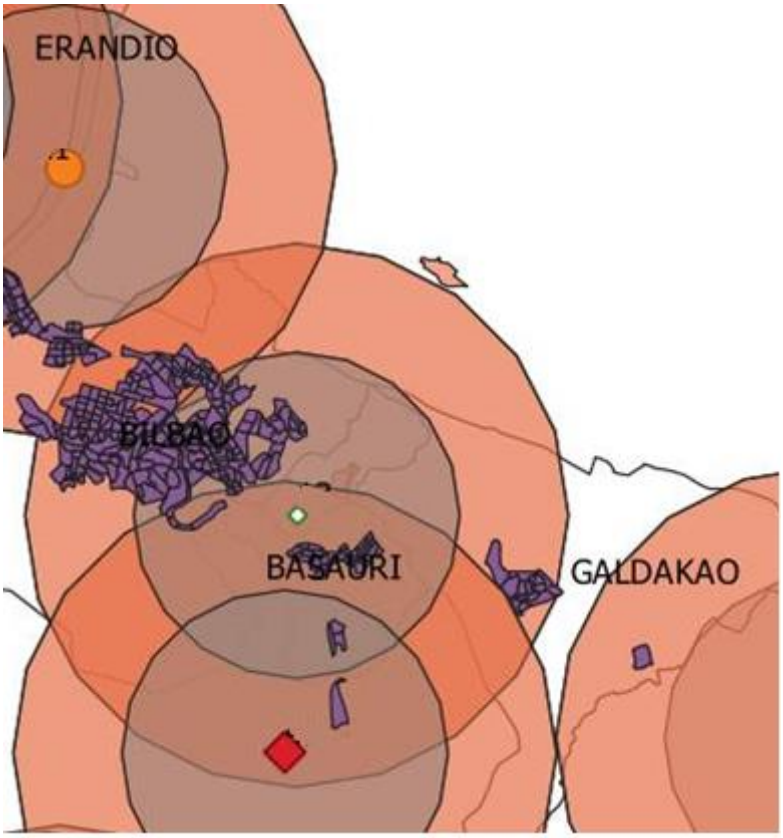
Table 5. Potential areas to deploy a waste heat DH network in the Basque Country (Zoom in).

Potential areas of interest to deploy a DHN with waste heat	
Location	**Municipalities**
	Bilbao, Basauri, Galdakao Sources: 118.8 GWh/year

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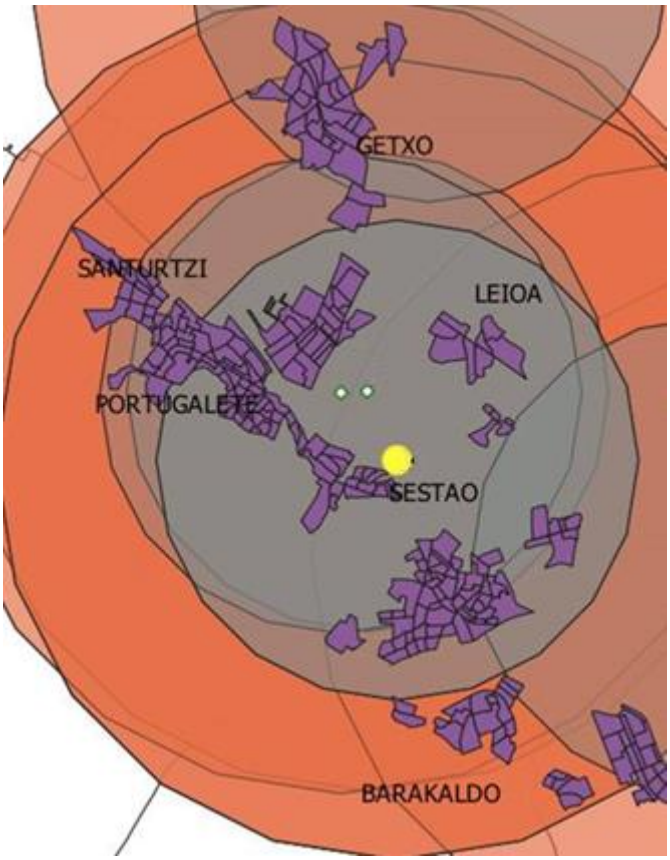
Potential areas of interest to deploy a DHN with waste heat	
Location	**Municipalities**
	Great area of Bilbao (river's left side) Sestao, Santurtzi, Portugalete, Barakaldo Sources: 48 GWh/year Great area of Bilbao (River's right side) Getxo, Leioa, Erandio Sources: 99.9 GWh/year

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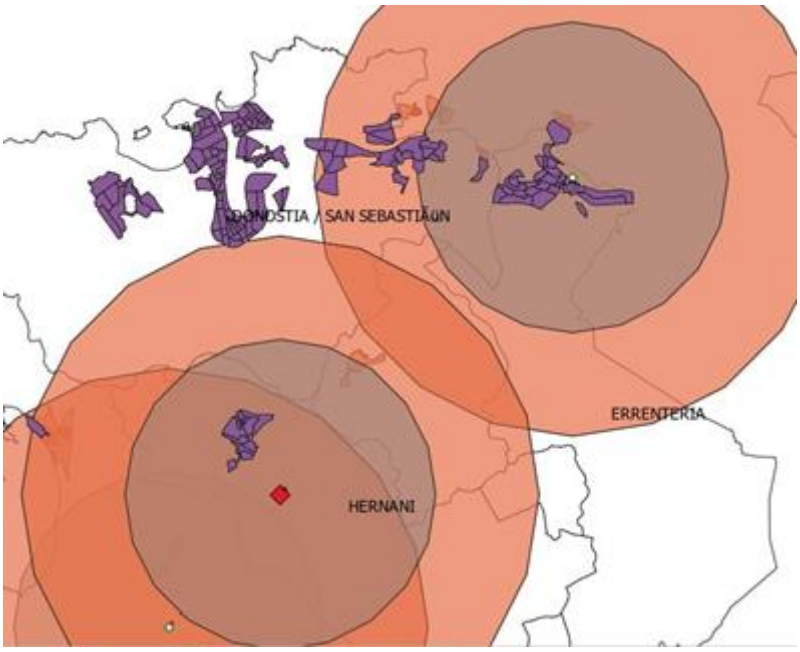
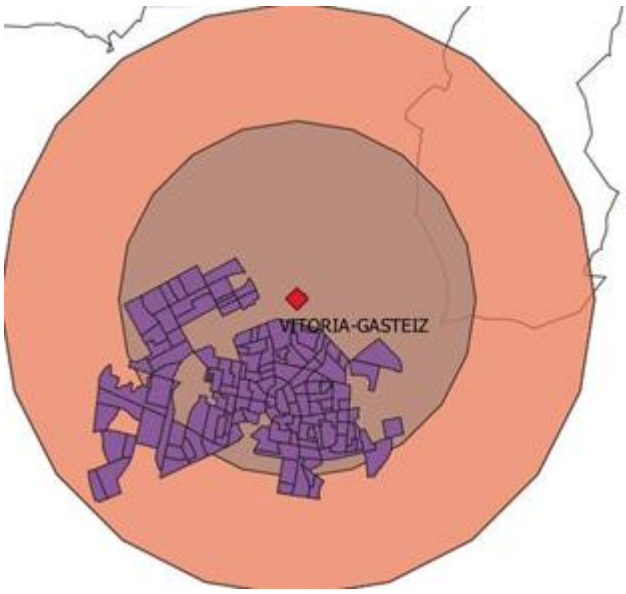
Potential areas of interest to deploy a DHN with waste heat	
Location	**Municipalities**
	Donostia-San Sebastian-Renteria-Hernani Sources: 215.9 GWh/year
	Vitoria-Gasteiz Sources: 115.1GWh /year

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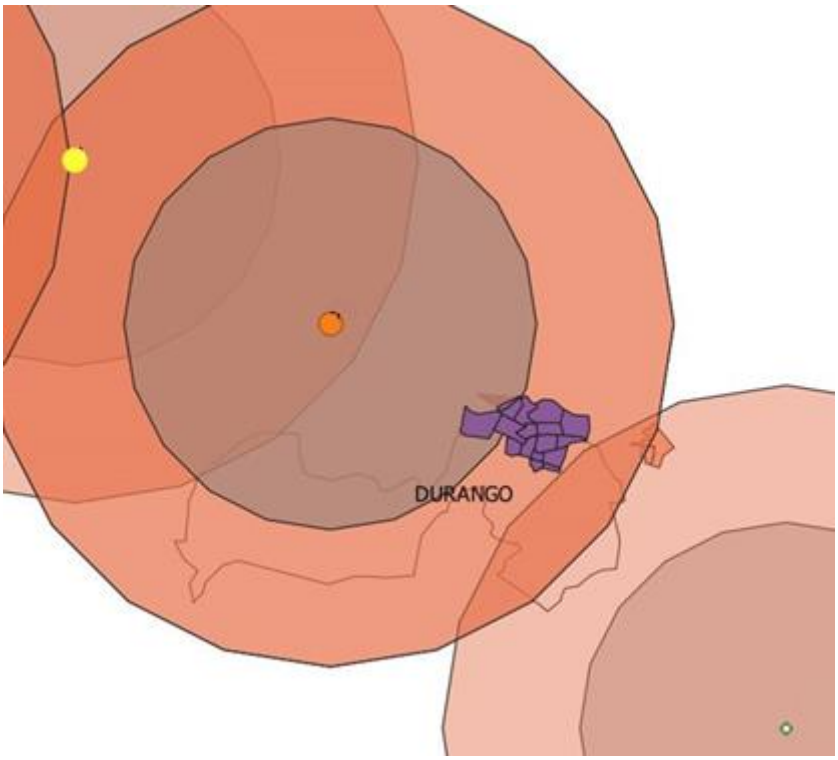
Potential areas of interest to deploy a DHN with waste heat	
Location	**Municipalities**
	Durango Sources: 71.4 GWh/year

From the first pre-selection of locations identified, different criteria are employed to prioritize and select the 2 best locations for further feasibility studies, as explained in annex C.

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Annex B: Regional feasibility studies of new DH in Mazovia

Date: 17/02/2022

Version:1.0

Deliverable	Annex B
Name	Regional feasibility studies of new DH in Mazovia
RELaTED website	www.relatedproject.eu
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Table 5. Pre-selected locations. The enterprise is represented with a number to anonymize the process. 16

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1. Introduction

This annex reports on the application for Mazovia of the methodology developed within Task 5.6. The application of this methodology has identified opportunities of waste heat reuse with the RELaTED configuration in Mazovia region on two phases:

- **Phase 1 (T 5.6):** a set of 2 locations are identified as suitable for the region, as described in the present annex B.
- **Phase 2 (T 5.7):** The identified locations are analysed in detail for the final selection of one suitable location for the deployment of a new DH network with the RELaTED configuration. Based on phase 1 and regional workgroups, potential sites for DH development are identified based on predefined key factors such as economic factors, available residual industrial heat or vicinity of urban areas, among others. Furthermore, the definition of implementation roadmaps is included for the selected areas.

The structure of the present annex meets the following:

- **Information compilation and georeferencing:** short explanation of the information collected and visual representation of it.
- **Geoprocessing:** analysis via GIS tools of the main waste heat sources' locations and nearby municipalities to identify the most interesting areas in terms of interactions between energy availability and highly populated areas.
- **Prioritization and selection of municipalities with high potential of deploying waste heat DH networks:** from the interactions identified, those areas with higher potential of waste heat DH deployments will be selected.

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2. Information compilation and georeferencing

Firstly all the information necessary for the analysis is gathered by MAE and processed by EVE to be integrated in a GIS project by TECNALIA. This information includes:

- The total number of flats in the Mazovia region is 2,302,881:
  - 1,998,934 flats are connected to the heating network. However, this does not include single-family houses as residential buildings, but only apartments in multi-family buildings.
  - 303,947 flats have individual heating systems based on coal, fuel oil, gas etc.
  - Number of single-family houses: 1,030,512.
  - Number of two-apartment buildings: 5,610.
  - Number of buildings with three or more apartments: 41,766.
- Geoinformation for 860 residential buildings for 42 counties, which are georeferenced in a specific shape layer.

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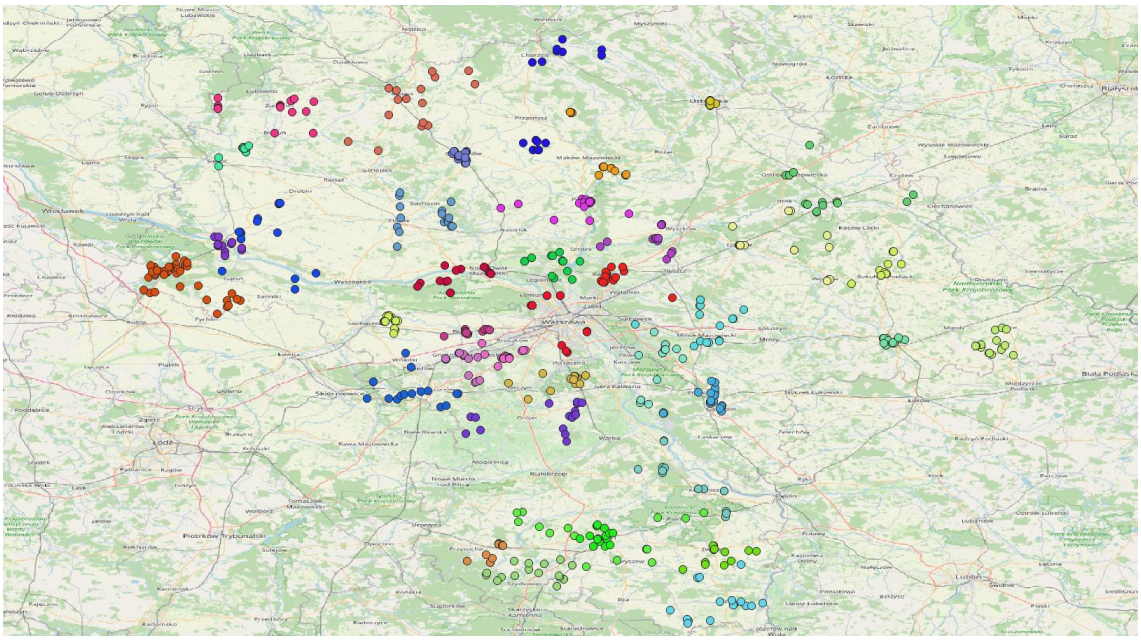

Figure 1. Spatial distribution of the residential buildings.

- The information regarding the number of buildings per region has been complemented with the free wiki world map OpenStreetMap [https://www.openstreetmap.org].

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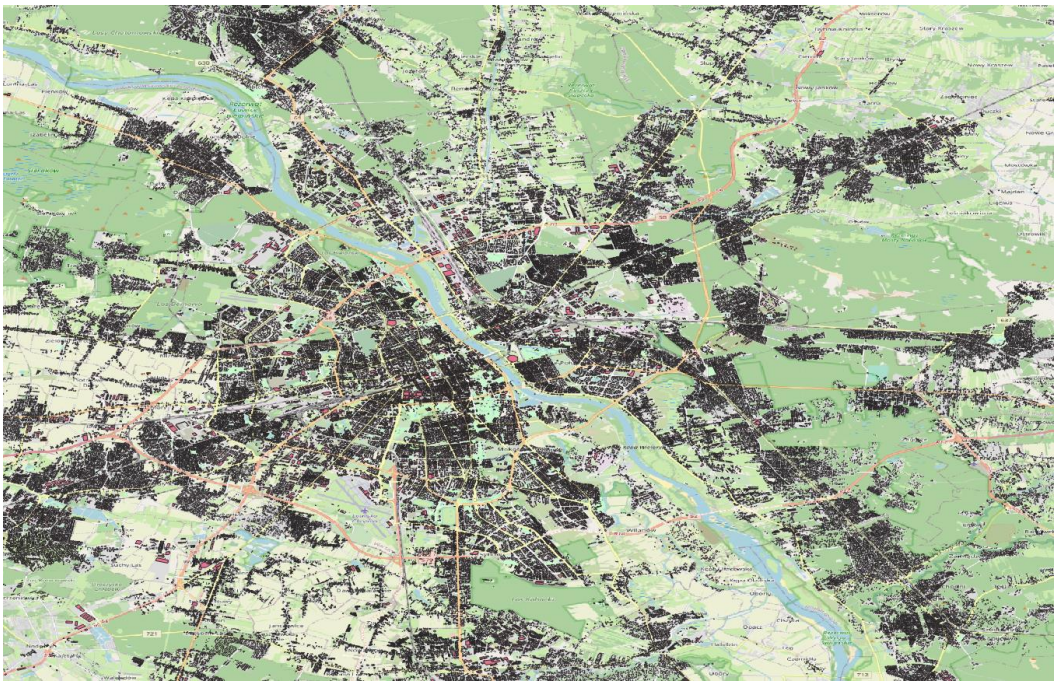

Figure 2. Spatial distribution of the buildings extracted with OpenStreetMap for the county of Warsaw.

- Heat energy consumption in domestic sector divided into the 42 counties and 435 municipalities, which are georeferenced in a specific shape layer (Figure 3). This information includes the consumption of over 2.3 million flats, with a total of 32.109 GWh/year as the overall addition of coal, heating oil, gas and DH consumption in the above mentioned houses, from which around 2 million are connected to the DH.

Table 1. Number of flats associated with the heat energy consumption.

Total number of flats	**2.302.881**	**32.109 GWh/year**
Number of flats equipped with central heating	**1.998.934**	

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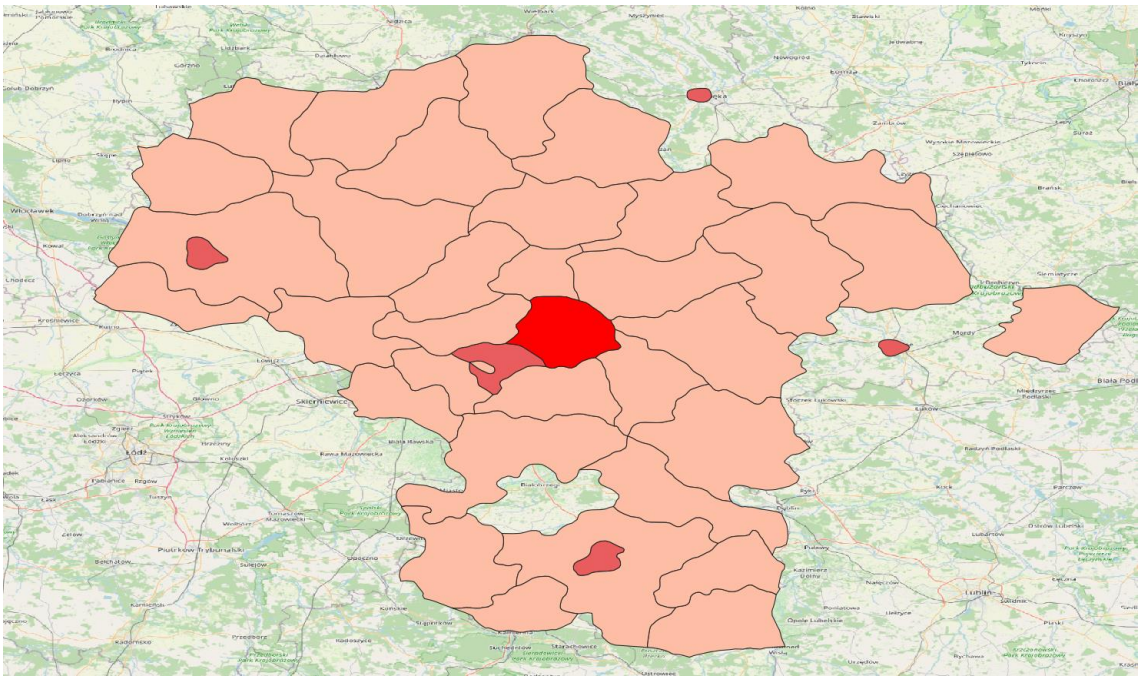

Figure 3. Heat energy consumption. The colours go from salmon red colour (670-91,893 MWh), Indian red colour (91.893-420 GWh), to scarlet (420-6,618 GWh).

- The share of each energy carrier in heating is not fully known, but it can be assumed that DH is based on:
    - coal in 78%, gas in 20% and biomass 2% as a general ratio.
    - DH of Radom is based only on hard coal (100%).
- Regarding the general heat consumption per energy vector, **Table 2** is included.

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Table 2. Heat energy consumption per fuel for all residential buildings in Mazovia.

Heat energy consumption in domestic sector (households) MWh	Energy vector
14.633.581	Hard coal
8.570.435	Natural gas
7.842.995	District heating
899.826	Liquefied petroleum gas
161.716	Light fuel oil

- Heat sales from DH networks:
    - Residential sector: 9,016 GWh/y in apartments in multi-family buildings.
    - Tertiary sector: 1,653 GWh/y.
    - Total: 10,669 GWh/y.

As a summary of the above information per county,

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- **Table 3** has been added, where the number of flats associated with the DH consumption are divided per county.

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Table 3. Number of flats associated with the DH consumption per county.

	Number of flats	County	MWh	kWh/flat year
1	31,828	ciechanowski	88,509.24	2,781
2	35,681	garwoliński	24,927.40	699
3	16,471	gostyniński	36,080.45	2,191
4	36,905	grodziski	41,937.80	1,136
5	37,386	grójecki	17,830.48	477
6	22,423	kozienicki	39,471.74	1,760
7	46,387	legionowski	91,893.01	1,981
8	13,373	Lipski	1,255.70	94
9	11,596	Łosicki	1,861.86	161
10	15,354	makowski	15,645.65	1,019
11	56,738	Miński	66,901.36	1,179
12	25,537	mławski	20,494.88	803
13	30,444	nowodworski	61,338.88	2,015
14	24,826	ostrowski	38,471.12	1,550
15	47,469	otwocki	39,483.42	832
16	77,946	piaseczyński	13,177.37	169
17	35,562	Płocki	670.41	19
18	30,713	płoński	35,410.87	1,153
19	63,510	pruszkowski	200,607.82	3,159

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20	16,299	przasnyski	34,588.85	2,122
21	14,884	przysuski	7,542.01	507
22	18,742	pułtuski	27,527.26	1,469
23	46,492	radomski	37,732.56	812
24	17,139	sierpecki	34,344.05	2,004
25	29,728	sochaczewski	50,322.69	1,693
26	21,374	sokołowski	27,075.50	1,267
27	13,493	szydłowiecki	15,462.33	1,146
28	46,123	warszawski zachodni	23,140.09	502
29	24,779	węgrowski	1,938.63	78
30	86,188	wołomiński	86,512.46	1,004
31	23,665	wyszkowski	44,178.81	1,867
32	12,428	zwoleński	6,504.12	523
33	12,236	żuromiński	22,776.23	1,861
34	31,308	żyrardowski	83,166.24	2,656
35	19,435	m, Ostrołęka	133,609.94	6,875
36	51,614	m, Płock	420,814.23	8,153
37	84,368	m, Radom	331,451.82	3,929
38	33,159	m, Siedlce	172,122.23	5,191
39	975,731	m, st, Warszawa	6,618,860.30	6,783

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- From the above information, the average consumption rises to 13.942,78 kWh/flat year (**Table 1**). Since Poland is a heating dominated climate, where space heating and DHW are the major consumption and cooling can be neglected for residential buildings, average heating consumption value for the whole residential area will be used as indicator of the energy use at municipal level.
- Geoinformation for potential waste heat sources, with 20 potential industrial points with 4 CHP plants and 29 chimneys associated. Figure 4 shows the distribution of the waste heat sources, where it can be observed that the central region of Warsaw has the highest density of these sources.

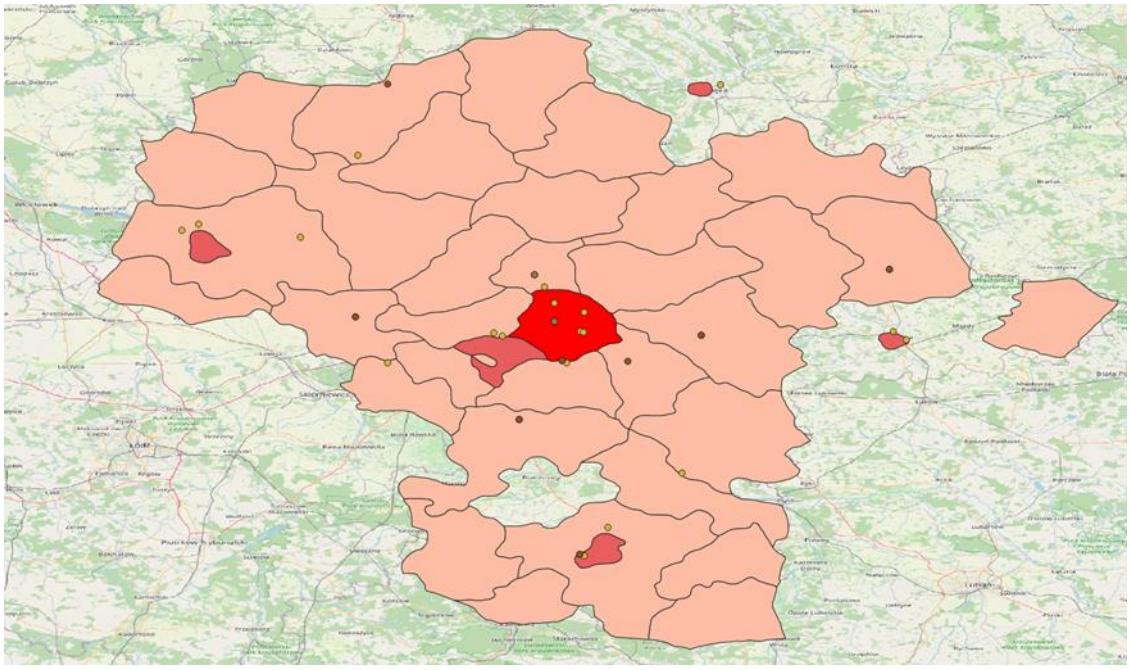

Figure 4. Potential heat sources: chimneys (yellow) and CHP (grey).

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- Georeferenced data for 683 public buildings divided by counties, within the Mazovia Region, with information of energy demand for 260 buildings.

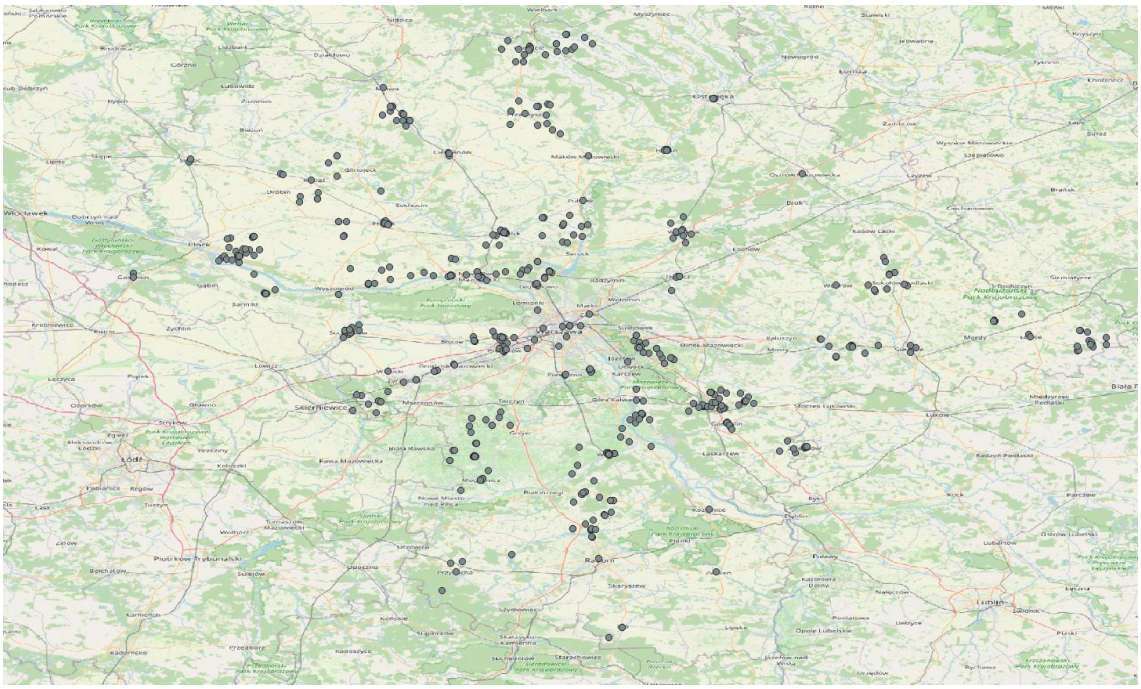

Figure 5. Heat energy consumption of the identified public buildings.

- District heating networks and the heat produced by them. There are 34 DH networks, but information only for 10 of them, which account for 983 GWh/year.

In 3 from the 42 counties (01 Białobrzeski, 15 Ostrołęcki, 26 Siedlecki) there is no generation plant or the heat is only sold to public buildings, so these counties are no taken into account.

Regarding economic information, the cost of DHW amounts to 21.44 PLN/m^3, assuming an exchange rate of 4.2 is 5.1 EUR/m^3. Taking into account the specific heat of water 4.19 kJ/kgK, density 1000 kg/m^3 and temperature difference 45 K, we can get 0.409 PLN/kWh, which is 0.097 EUR/kWh.

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Finally, the GIS Project integrates the following information:

Table 4. Sources of information integrated in GIS project.

TYPE	INFORMATION	YEAR	SOURCE / PROVIDER
Specific for the project	20 residual industrial heat locations	2020	MAE
	DH consumption for 39 counties	2020	MAE
	260 public buildings demand	2020	MAE
	683 public buildings location	2020	MAE
	860 residential buildings location	2020	MAE

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3. Geoprocessing

Based on the data explained on the previous chapter and the criteria explained on the main body of the present deliverable, 3km buffers with centre on the identified waste heat sources have been geoprocessed to identify the area of influence of this source, this is, the buildings included in a 3km area around the industrial residual heat locations (Figure 6). The legend shows the number of buildings contained in each buffer:

- [134 – 2503] buildings.
- [2503 - 6903] buildings.
- [6903 - 11,143] buildings.
- [11,143 - 14,131] buildings.

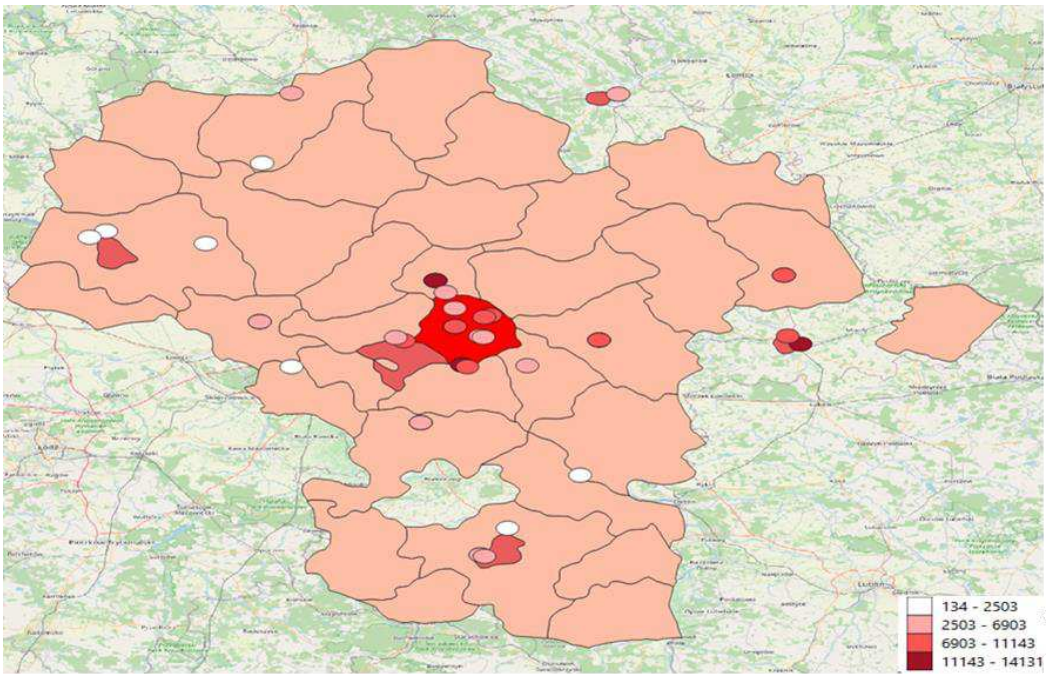

Figure 6. 3 kms buffers around the available waste heat sources. The legend shows the meaning of the buffer's colours.

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Figure 6 shows both the buffers and those areas with higher consumption (see Figure 3 for more references). From a visual inspection of the above included information, it can be concluded that Warsaw region is the county with higher potential since:

- It has the highest number of flats connected to the DH, with 975,731 flats.
- It is the highest consumption of DH, with over 6,600 GWh/year.
- It contains the highest number of identified waste heat sources for potential use in the DH.

Furthermore, from the visual inspection of Figure 6, three are the most interesting buffers, this is, those containing a higher number of buildings. Visual evidence shows that none of them are fully located in the Warsaw county, and therefore no interaction is fully satisfactory.

Since the criteria applied don't fully comply with expectations, the prioritization and selection of municipalities with high potential of deploying waste heat DH networks is based on those industries which have shown an interest on the study, as reflected in **Table 5**.

Table 5. Pre-selected locations. The enterprise is represented with a number to anonymize the process.

Cluster	Enterprises reference	Type of residual heat	Counties related
1	4	Direct use	**Pruszków**
2	7	Direct use	**Radom**

In Annex D, these clusters are analysed in detail.

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Annex C: Technical, financial and administrative roadmaps of new DH in consolidated urban environments in Basque Country.

Date: 17/02/2022

Version: 1.0

Deliverable	Annex C
Name	Regional feasibility studies of new DH in Basque Country.
RELaTED website	www.relatedproject.eu
Project Coordinator	Roberto Garay. TECNALIA roberto.garay@tecnalia.com
Author(s)	Jesús Mª Casado (EVE), jmcasado@eve.eus; Elena Usobiaga Ferrer (TEC), elena.usobiaga@tecnalia.com; Antonio Garrido Marijuan (TEC), antonio.garridomarijuan@tecnalia.com.

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1. Introduction

This annex reports on the application for Basque Country of the methodology developed within Task 5.6. The application of this methodology has identified opportunities of waste heat reuse with the Basque country region on two phases:

- **Phase 1 (T 5.6):** a set of 2 locations are identified as suitable for the region, as summarised in the annex A.
- **Phase 2 (T 5.7):** The identified locations are analysed in detail for the final selection of suitable locations for the deployment of a new DH network with the RELaTED configuration in Basque Country, as described in the present annex C. Based on phase 1 and regional workgroups, potential sites for DH development are identified based on predefined key factors such as economic factors, available residual industrial heat or vicinity of urban areas, among others, as explained in the present annex.

The structure of the present annex meets the following:

- **Selection of areas:** short explanation of the pre-selected areas coming from the analysis of Annex A.
- **Available residual industrial heat:** quantification of the available energy, taking into account main characteristics:
    - Continuity of heat production.
    - Quality.
- **Analysis of the selected urban areas:** the urban areas are evaluated in terms of density of population; typology of dwellings and heating system (power, energy carrier); distribution of consumption (kWh/year, heating&DHW); estimated heat production & re-use levels.

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- **Technical analysis**: the deployment of a DH is proposed, including:
    - Definition of the pipe: size, path…
    - Losses (kWh/year).
- **Economic analysis:** a cost model for the DH network is proposed, taking into account:
    - Investment for the pipe as well as additional equipment.
    - Estimated cost of heat and electricity.

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2. Pre-selected areas

As described in annex A, the pre-selection of locations identified the potential areas for waste heat DH network deployment, based on the criteria of availability of waste heat sources of **> 10 GWh** and a high dense populated area on buffers of **3 and 5 km** around the waste heat spot.

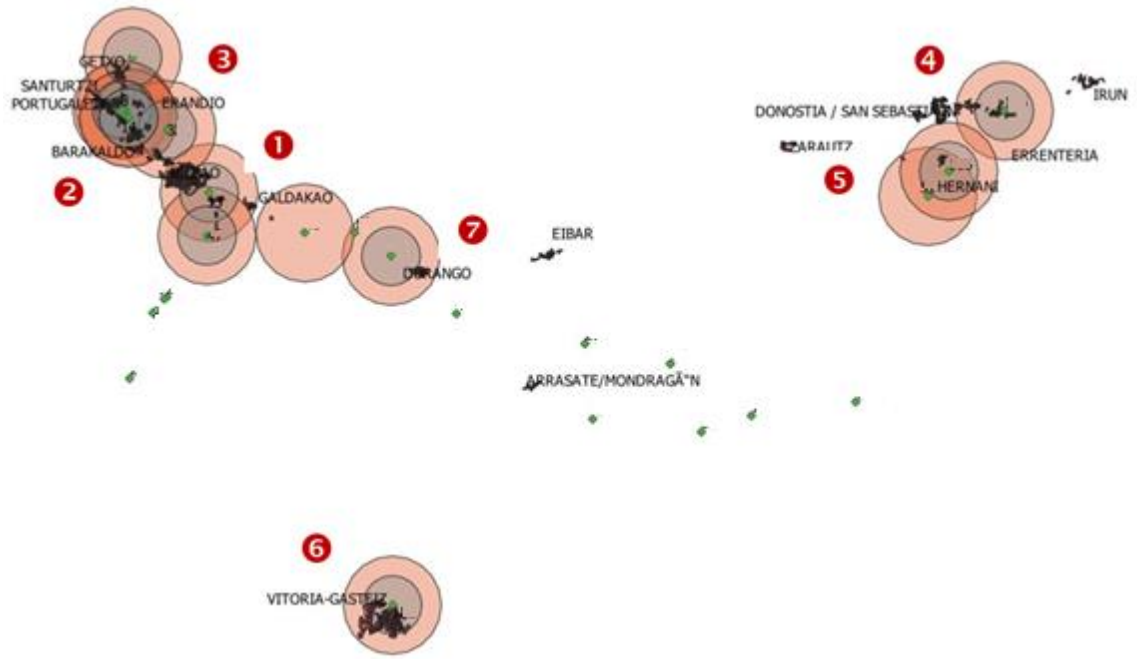

Figure 1. Selected interactions between waste heat sources with an annual heat production> 10 GWh/year (represented with a green diamonds and numbered), and high/medium dense areas in cities with higher population than 20,000 inhabitants (identified with the name).

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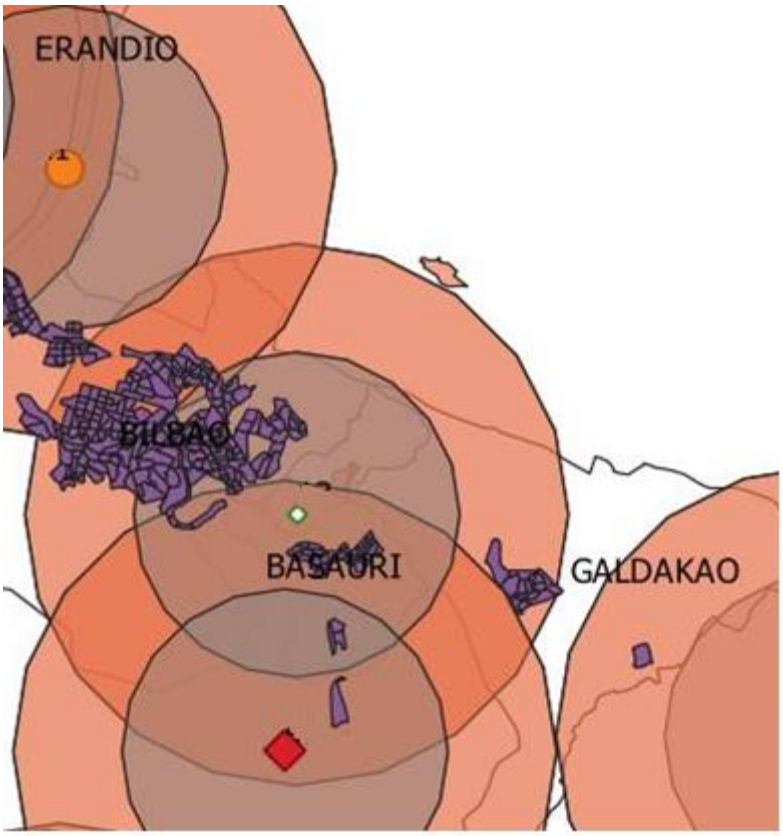
In the case of the Basque Country, two companies with large cooling towers and with high dense populations are identified:

- Heat source in Basauri: already defined as one of the potential areas, as follows:

Table 1. Zoom in the vicinity of the analysed heat source to deploy a waste heat DH network in the Bilbao, Basauri, Galdakao area.

Location	Municipalities
	Bilbao, Basauri, Galdakao Sources: 19.6 GWh/year.

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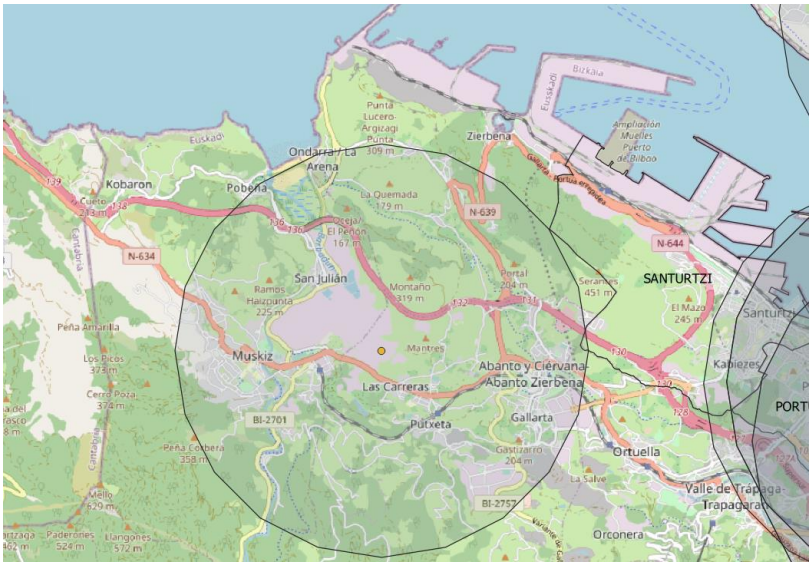
- Waste heat source not contemplated before in Abanto Zierbena: although this area has not been selected as potential areas of interest to deploy a DH thermal network with waste heat (due to the lack of information), the interest and the provision of data from the waste heat source owners in subsequent parallel meetings, makes it a potential source.

Table 2. Zoom in the vicinity of the pre-selected heat source to deploy a waste heat DH network in the area of Abanto Zierbena (Bizkaia).

Location	Municipalities
	Abanto Zierbena area (Bizkaia) Sources: 319.0 GWh/year

These two locations are the basis for phase 2, which conclude in the final selection of one suitable location for the deployment of a new DH network with the RELaTED configuration in Basque Country. In the following section, these interactions heat source-DH network are analysed in detailed.

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3. Available residual industrial heat

The present section studies the two selected industrial heat sources, with in depth analysis of the continuity and quality of heat production.

3.1. Heat source at Basauri

The energy available in this area is related to the cooling tower of the industrial source, with an available power of 16.4 MW and available energy equal to 19.6 GWh/year. Both Power (kW) and available energy (kWh) are higher than power and energy demand.

It can be pointed out that the continuity of heat production includes 8,760 working hours, with 24 hours of availability. Regarding the quality, and according to the quality classification criteria defined in previous sections of the present document, the source quality is considered as C.

Table 3. Source quality classification criteria.

Source quality	Hours	T_{source}
A	Hours ≥ 6,000 h	$T_{gases} \geq 400°C$
B	3,000 h ≤ Hours < 6,000 h	$150°C \leq T_{gases} < 400°C$
C	Hours < 3,000 h	$T_{gases} < 150°C$

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3.2. Heat source at Abanto Zierbena

The energy available in this area is related to the cooling tower of the industrial source, with an available power of 36.4 MW and available energy equal to 319 GWh/year.

Both Power (kW) and available energy (kWh) are higher than power and energy demand.

It can be pointed out that the continuity of heat production includes all year long, with 8,760 hours of availability. Regarding the quality, and according to the quality classification criteria defined in previous sections of the present document, the source quality is considered as C.

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4. Analysis of the selected urban areas close to the available residual industrial heat

The potential urban areas in the vicinity of the industrial sources selected are evaluated in the present section.

4.1. Basauri

When a buffer of 3-5 kms is applied to the heat source, Basauri is one of the municipalities that could be considered for DH deployment (see **Table 1. Zoom in the vicinity of the analysed heat source to deploy a waste heat DH network in the Bilbao, Basauri, Galdakao area.**

A further analysis of Basauri results in the pre-selection of the San Miguel quarter as case study:

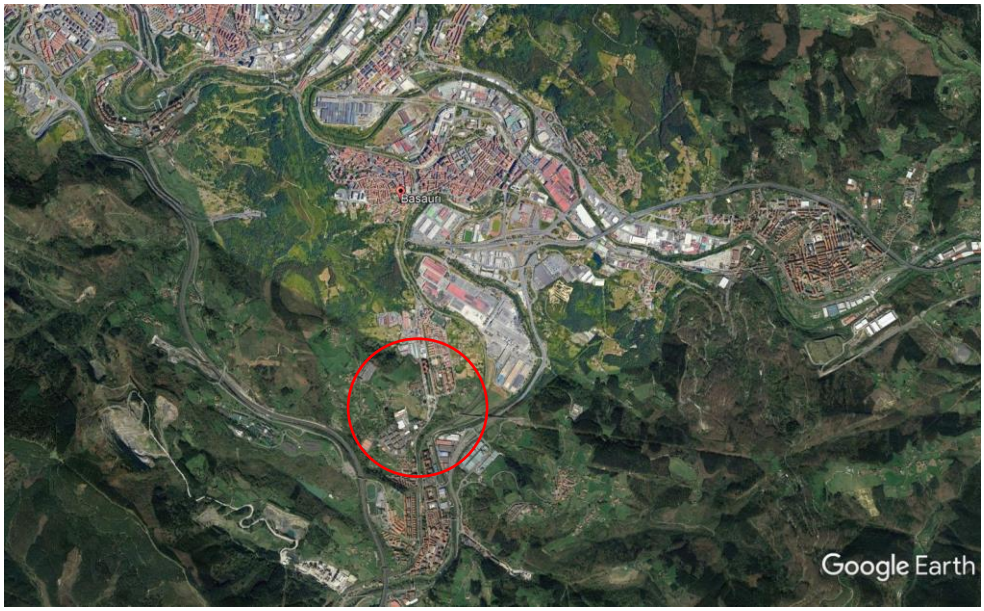

Figure 2. Aerial view of Basauri quarter highlighted (edited from Google Earth).

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To understand the suitability for the DH deployment, the heating demand is estimated for the buildings with potential to be integrated in the DH network, which in principle are all of them. Those are the buildings that are in the buffer area of the heating source. Moreover, it is also estimated the capacity needed for each building.

4.1.1. Typology of dwellings and heating system

Detailed evaluation of the buildings in the area has been carried out based on cadastre and Google Earth. The demand is estimated for each building in the area, with a total of 191 buildings and 1,360 dwellings. This analysis includes the year of construction, the heating area and the estimation of the ratio windows/envelope. With these estimations, the heating demand is calculated based on heating degree days (15/15) and the typology of the buildings and typical u-values for the year of construction. Regarding the DHW estimation, it is based on an average consumption per m^2.

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REFERENCIA	1			AÑO CATASTRO	2009
DIRECCION	ELEXALDE 01				
USO	1	VIVIENDAS		TOTAL EDIFICIO	
SUPERFICIE PLANTA	133,4	m2		400 m2	
PERIMETRO EXTERIOR	18,1	m		1.200 m3	
SUPERFICIE VENTANAS	20	%		133 m2/vivienda	
ALTURA PLANTA	3,00	m		POTENCIA	
TIPO VENTANAS	3	CTE		14.497 W	
AISLAMIENTO TERMICO	3	CTE		4.832 W/vivienda	
SUELO	2	SUELO LNC		36 W/m2	
Nº PLANTAS	3			DEMANDAS (kWh/m2·año)	
Viviendas/planta	1,0			29,2 CALEFACCION	
Viviendas Total	3			22,2 ACS	
OCUPANTES	12	32		51 TOTAL	

DATOS DEMANDA TERMICA

MES	Nº DIAS	GD 15,15	Tª Agua Red	DEMANDA (kWh) CALEFACCION	ACS	TOTAL
ENE	31	189	6	2.365	818	3.182
FEB	28	159	7	1.989	725	2.714
MAR	31	133	9	1.664	772	2.436
ABR	30	102	11	1.276	718	1.994
MAY	31	40	12	500	727	1.227
JUN	30	6	13	75	689	764
JUL	31	0	14	0	697	697
AGO	31	0	13	0	712	712
SEP	30	4	12	50	703	753
OCT	31	29	11	363	742	1.105
NOV	30	105	9	1.314	747	2.061
DIC	31	166	6	2.077	818	2.895
AÑO	**365**	**933**	**10**	**11.674**	**8.867**	**20.541**
PORCENTAJE DE DEMANDA DE CADA SERVICIO				57%	43%	
DEMANDA MEDIA POR USUARIO.....				3.891	2.956	**6.847**

ESTIMACION POTENCIA CALEFACCION

CERRAMIENTO	SUPERFICIE (m2)	U (W/m2·K)	ΔT	W
MURO EXTERIOR	130	0,50	21	1.355
VENTANAS	33	2,80	21	1.897
CUBIERTA	133	0,50	21	1.387
SUELO EXTERIOR	0	0,50	21	0
SUELO LNC	133	0,50	10	694
		CARGA POR TRANSMISION		5.333
VENTILACION	1.200	0,335	21	8.364
		CARGA POR VENTILACION		13.697
		POTENCIA TOTAL		14.497

Figure 3. Example of the data compiled for the study, including year of construction, surface, ratio windows to envelope and an estimation of the thermal transmittance according to the construction period for the demand calculation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567

The study shows that 64% of the users rely on individual gas boilers for both SH and DHW, while the rest uses electricity for SH and butane gas for DHW.

4.1.2. Distribution of demand (kWh/year, heating & DHW)

A summary of the total demand is included in **Table 5**.

Table 4. Total demand of the buildings in the area.

Connected buildings	Total dwellings	1,360
	Total buildings	191
	Total area (m^2)	104,159
	Average surface (m^2/dwelling)	77
	Total power (kW)	7,669
	Average power (W/m^2)	74
Energy demands	Heating (MWh/year)	5,722.8
	DHW (MWh/year)	3,224.6
	Total (MWh/year)	8,947.4
	Average demand (kWh/year/m^2)	86

As stated in **Table 4**, the total power to cover the building demand is 7.7 MW, with an annual demand of 8.95 GWh. Regarding the average numbers, the values are 74 W/m^2 and 86 kWh/year/m^2. These values are considered as conservative according to similar buildings in the region and, therefore, the values are used in the further calculations.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567

4.1.3. Estimated heat production & re-use levels

Based on the industrial source considered, 24 working hours with a total heating power of 16.4 MW are available. Therefore, this waste heat source is able to cover 100% of the energy demand estimated at null cost.

4.2. Abanto Zierbena

When a buffer of 3-5 kms is applied to the heat source, Las Carreras is one of the districts within the municipality that could be considered for DH deployment (see **Table 2. Zoom in the vicinity of the pre-selected heat source to deploy a waste heat DH network in the area of Abanto Zierbena (Bizkaia).**

A further analysis of the Carreras results in the pre-selection of the following quarters or consumption points:

- Barrio de La Trinidad.
- Barrio San Lorenzo.
- Barrio Los Llanos.
- El Minero
- Grupo Mª Auxiliadora.
- Grupo Gure Etxea.
- Bloques I and II.
- School, church and social center.
- Unifamiliar I, II and IV.
- Road II.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567

Figure 4. Potential areas (edited from Google Earth).

To understand the suitability for the DH deployment, the heating demand is estimated for the buildings with potential to be integrated in the DH network, which in principle are all of them. Those are the buildings that are in the buffer area of the heating source. Moreover, it is also estimated the capacity needed for each building.

4.2.1. Typology of dwellings and heating system

Detailed evaluation of the buildings in the area has been carried out based on cadastre and Google Earth. The demand is estimated for each building in the area, with a total of 261 buildings and 839 dwellings plus the school as public buildings. This analysis includes the year of construction, the heating area and the ratio windows/envelope. With these estimations, the heating demand is calculated based on heating degree days and the typology of the buildings and typical u-values for the year of construction. Regarding the DHW estimation, it is based on an average consumption per m^2.

Regarding the school, the consumption is estimated from the energy bills.

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REFERENCIA	15			AÑO CATASTR 1910
DIRECCION	AMBROSIO DE LOS HEROS 49			
USO 1	VIVIENDAS		TOTAL EDIFICIO	
SUPERFICIE PLANTA	96,8	m2	97 m2	
PERIMETRO EXTERIOR	18,7	m	291 m3	
SUPERFICIE VENTANA	20	%	97 m2/vivienda	
ALTURA PLANTA	3,00	m	POTENCIA	
TIPO VENTANAS	1	SENCILLO	12.968 W	
AISLAMIENTO TERMIC	1	NO	12.968 W/vivienda	
SUELO	1	SUELO EXTE	134 W/m2	
Nº PLANTAS	1		DEMANDAS (kWh/m2·año)	
Viviendas/planta	1,0		101,6 CALEFACCION	
Viviendas Total	1		7,6 ACS	
OCUPANTES	1	70	109 TOTAL	

DATOS DEMANDA TERMICA							
	MES	Nº DIAS	GD 15,15	Tª Agua Red	DEMANDA (kWh) CALEFACCION	ACS	TOTAL
	ENE	31	189	6	1.992	68	2.061
	FEB	28	159	7	1.676	60	1.737
	MAR	31	133	9	1.402	64	1.466
	ABR	30	102	11	1.075	60	1.135
	MAY	31	40	12	422	61	482
	JUN	30	6	13	63	57	121
	JUL	31	0	14	0	58	58
	AGO	31	0	13	0	59	59
	SEP	30	4	12	42	59	101
	OCT	31	29	11	306	62	368
	NOV	30	105	9	1.107	62	1.169
	DIC	31	166	6	1.750	68	1.818
	AÑO	**365**	**933**	**10**	**9.836**	**739**	**10.575**
PORCENTAJE DE DEMANDA DE CADA SERVI					93%	7%	
DEMANDA MEDIA POR USUARIO.....					9.836	739	**10.575**

ESTIMACION POTENCIA CALEFACCION				
CERRAMIENTO	**SUPERFICIE (m2)**	**U (W/m2·K)**	**DT**	**W**
MURO EXTERIOR	45	1,50	21	1.400
VENTANAS	11	5,00	21	1.167
CUBIERTA	97	2,00	21	4.029
SUELO EXTERIOR	97	1,45	21	2.921
SUELO LNC	0	1,48	10	0
			CARGA POR TRANSMISION	**9.516**
VENTILACION	291	0,335	21	2.024
			CARGA POR VENTILACION	**11.541**
			POTENCIA TOTAL	**12.968**

Figure 5. Example of the data compiled for the study, including year of construction, surface, ratio windows to envelope and estimation of the thermal transmittance according to the year of construction for the demand calculation.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768567

The study shows that 76% of the users rely on individual gas boilers for both SH and DHW, while the rest uses electricity for SH and butane gas for DHW.

4.2.2. Distribution of demand (kWh/year, heating&DHW)

A summary of the total demand is included in **Table 5**.

Table 5. Total demand of the buildings in the area.

Connected buildings	Total dwellings	839
	Total buildings	261
	Total area (m^2)	93,202
	Average surface (m^2/dwelling)	104
	Total power (kW)	6,831
	Average power (W/m^2)	73
Energy demands	Heating (MWh/year)	4,966.7
	DHW (MWh/year)	1,830.6
	Total (MWh/year)	6,797.3
	Average demand (kWh/year/m^2)	73

As stated in Table 5, the total power is 6.83 MW, with an annual demand of 6.79 GWh. Regarding the average numbers, the values are 73 W/m^2 and 73kWh/year/m^2. These values are considered as conservative according to similar buildings in the region and, therefore, the values are used in the further calculations.

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4.2.3. Estimated heat production & re-use levels

Based on the industrial source considered, 24 working hours with a total heating power of 36.4 MW are available. Therefore, this waste heat source is able to cover 100% of the energy demand estimated at null cost.

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5. Technical analysis

For both cases, and since the DH network would operate at low temperature, non-insulated steel pipes have been selected.

For the sizing of the buried pipes, the power previously estimated is used with a simultaneity factor of 100%, in order to oversized the network in the worst case scenario. Regarding the network, a seasonal performance of 4 is used to calculate the power for the network, this is, 25% of the heating demand is provided by electricity and 75% of the demand from the heating network.

In spite of the existence of DHW storage associated to the heat pumps, the total DHW has been considered.

The next assumptions are made for the sizing of the pipes:

- Impulsion temperature: 33 ºC.
- Return temperature: 24 ºC.
- Temperature gradient: 9 ºC.
- Density: 996 kg/m^3.
- Viscosity: 0.88 cST.

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5.1. Definition of the pipe: size, path… for Basauri

The proposed distribution is included in Figure 6:

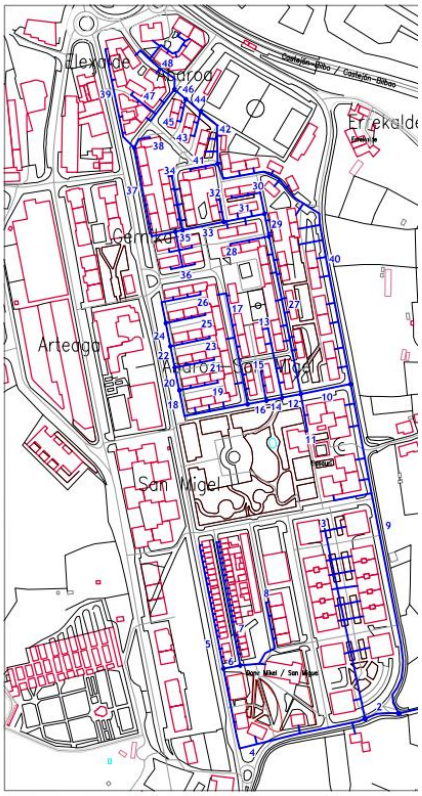

Figure 6. Network layout.

The total power of the proposed network and the assumptions allow the calculation of the pipe dimensions per section. With the dimensions and total lengths for each sector, the heat losses can be obtained based on the losses per meter long based on own know-how based on the distribution temperature (0.5 W/m).

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5.1.1. Losses (kWh/year)

For the estimation of losses in the distribution network and subnetworks, the ratio of losses over the total building demand is available. The total energy lost is calculated with the total number of operating hours of the installation, being this number estimated in 24 hours. A calculation for the case of 18 working hours is also included for further information:

Table 6. Summary of losses.

Total working hours/day	18	24
Total working days/year	365	365
Losses kWh/season	58,105	46,923
Distribution losses (%)	1%	1%
Distribution losses (W)	5,356	5,356
Design flow through pipes (l/h)	549,601	549,601
ΔT due to heat losses (ºC)	0.01	0.01
Network water volume (l)	215,906	215,906
ΔT due to heat losses during non-working periods (ºC)	1	0
ΔT due to heat losses during non-working periods (ºC)	1	0
Total heat losses during non-working periods (kWh/period)	63	0

The monthly heat losses are:

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Table 7. Summary of monthly heat losses.

	Distribution losses (%)
January	0%
February	0%
March	1%
April	1%
May	1%
June	2%
July	2%
August	2%
September	2%
October	1%
November	1%
December	0%

It can be concluded from the table that losses during winter are low, being in summer close to 2%.

A summary of the information here presented is included in **Table 8**.

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Table 8. Summary of the network.

Total network power (kW), as 75% of the total buildings' energy demand	5,751,639
Total flow (l/h)	549,601
Water volume (l)	215,906
Losses (W)	5,356
Total length (m)	10,713
ΔP (mmCA)	118,298

5.1.2. Pumps consumption

The calculation is made for steel pipes, deployed one meter deep. This kind of pipes allow for low electrical consumption of the pumps (lower pressure losses than other type of pipes), and good behaviour under pressure.

For the estimation of the electric consumption of the pipes, the following equation is used:

$$W = M \cdot Pa \cdot \eta$$

Being:

W: electric consumption [kWh]

M: volume Flow in [m^3/s]

Pa: pressure difference.

η : pump efficiency.

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The calculation of the pump consumption is summarised per month and add up for the year consumption in the following table:

Table 9. Summary of pump consumption (kWh), for constant (C) and variable (V) flow for both 24 and 18 working hours.

	C 24 hours	C 18 hours	V 24 hours	V 18 hours
January	291,558	218,669	95,419	87,468
February	263,343	197,507	86,185	79,003
March	291,558	218,669	95,419	87,468
April	282,153	211,615	92,341	84,646
May	291,558	218,669	95,419	87,468
June	282,153	211,615	92,341	84,646
July	291,558	218,669	95,419	87,468
August	291,558	218,669	95,419	87,468
September	282,153	211,615	92,341	84,646
October	291,558	218,669	95,419	87,468
November	282,153	211,615	92,341	84,646
December	291,558	218,669	95,419	87,468
Total (kWh/year)	3,141,307	2,355,980	1,028,064	942,392

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The first two rows summarise the consumption for constant flow pumps with 18 and 24 working hours. Third and fourth row includes the calculations for variable flow pumps for the same working hours.

The total electric consumption used for pumping is:

- Constant flow and 24 working hours: 3,141,307 kWh/year.
- Constant flow and 18 working hours: 2,355,980 kWh/year.
- Variable flow and 24 working hours: 1,028,064 kWh/year.
- Variable flow and 18 working hours: 942,392 kWh/year.

5.2. Definition of the pipe: size, path… for Abanto Zierbena

The proposed distribution is included in Figure 7:

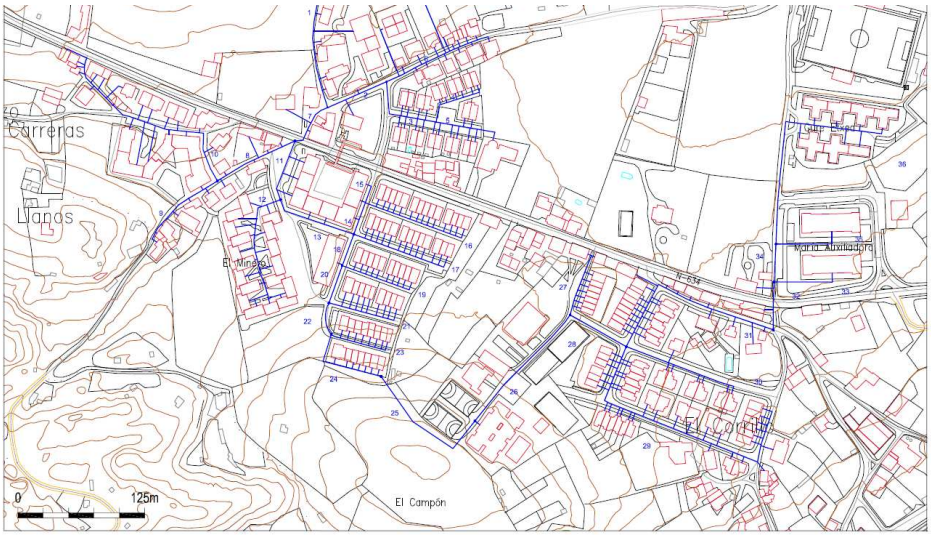

Figure 7. Network layout.

The total power of the proposed network and the assumptions allow the calculation of the pipe dimensions per section. With the dimensions and total lengths for each sector, the heat losses can be obtained based on the losses per

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meter long based on own know-how based on the distribution temperature (0.5 W/m).

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5.2.1. Losses (kWh/year)

For the estimation of losses in the distribution network and subnetworks, the ratio of losses over the total building demand is available. The total energy lost is calculated with the total number of operating hours of the installation, being this number estimated in 24 hours. A calculation for the case of 18 working hours is also included for further information:

Table 10. Summary of losses.

Total working hours/day	18	24
Total working days/year	365	365
Losses kWh/season	54,736	48,907
Distribution losses (%)	1%	1%
Distribution losses (W)	5,583	5,583
Design flow through pipes (l/h)	489,548	489,548
ΔT due to heat losses (ºC)	0.01	0.01
Network water volume (l)	170,140	170,140
ΔT due to heat losses during non-working periods (ºC)	1	0
ΔT due to heat losses during non-working periods (ºC)	1	0
Total heat losses during non-working periods (kWh/period)	49	0

The monthly heat losses are:

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Table 11. Summary of monthly heat losses.

	Distribution losses (%)
January	**0%**
February	**0%**
March	**1%**
April	**1%**
May	**1%**
June	**3%**
July	**3%**
August	**3%**
September	**3%**
October	**1%**
November	**1%**
December	**0%**

It can be concluded from the table that losses during winter are low, being in summer close to 3%.

A summary of the information here presented is included in **Table 12**.

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Table 12. Summary of the network.

Total network power (kW), as 75% of the total buildings' energy demand	5,123,173
Total flow (l/h)	489,548
Water volume (l)	170,140
Losses (W)	5,583
Total length (m)	11,166
ΔP (mmCA)	97,424

5.2.2. Pumps consumption

The calculation is made for steel pipes, deployed one meter deep. This kind of pipes allow for low electrical consumption of the pumps (lower pressure losses than other type of pipes), and good behaviour under pressure.

The estimation of the electric consumption of the pipes follows the logic from 5.1.2 and is summarised per month and add up for the year consumption in the following table:

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Table 13. Summary of pump consumption (kWh), for constant (C) and variable (V) flow for both 24 and 18 working hours.

	C 24 hours	C 18 hours	V 24 hours	V 18 hours
January	214,513	193,753	214,513	207,593
February	160,884	145,315	160,884	155,695
March	70,204	63,410	70,204	67,939
April	64,354	58,126	64,354	62,278
May	214,513	193,753	214,513	207,593
June	160,884	145,315	160,884	155,695
July	70,204	63,410	70,204	67,939
August	64,354	58,126	64,354	62,278
September	214,513	193,753	214,513	207,593
October	160,884	145,315	160,884	155,695
November	70,204	63,410	70,204	67,939
December	64,354	58,126	64,354	62,278
Total (kWh/year)	2,311,200	1,733,400	756,393	693,360

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The first two rows summarise the consumption for constant flow pumps with 18 and 24 working hours. Third and fourth row includes the calculations for variable flow pumps for the same working hours.

The total electric consumption used for pumping is:

- Constant flow and 24 working hours: 2,311,200 kWh/year.
- Constant flow and 18 working hours: 1,733,400 kWh/year.
- Variable flow and 24 working hours: 756,393 kWh/year.
- Variable flow and 18 working hours: 693,360 kWh/year.

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6. Heat pumps

For the analysed districts, specific w/w heat pumps are included with the following characteristics to reach the comfort temperature as well as safety thermal levels for DHW:

Table 14. Heat pump characteristics.

	Minimum power (W)	Maximum power (W)
1	1,500	6,000
2	3,000	12,000
3	4,000	16,000
4	4,000	22,800
5	10,700	44,600
6	17,100	59,600
7	21,100	86,700
8	25,100	109,500
9	35,800	154,100
10	52,900	213,700
11	74,000	300,400

The heat pumps are part of the building HVAC systems, being connected to the distribution network with a dedicated heat exchanger.

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7. Total energy balance

7.1. Basauri

The summary of the thermal consumption, heat losses and electric consumption associated to flow distribution are summarised in **Table 16**:

Table 15. Energy balance.

Thermal consumption		
Total heating demand (MWh/year)		8,947
Total network heating demand (MWh/year)		6,710
Distribution losses (MWh/year)	24 H	59
	18 H	47
Total network heating consumption (MWh/year)	24 H	6,769
	18 H	6,757
Electric consumption		
Constant flow (MWh/year)	24 H	3,141
	18 H	2,355
Variable flow (MWh/year)	24 H	1,028
	18 H	942

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Electric consumption on the heat source is not taken into consideration in the energy balance. This electric consumption is part of the pre-existing system before energy re-use, and therefore is not part of the DH injection.

7.2. Abanto Zierbena

The summary of the thermal consumption, heat losses and electric consumption associated to flow distribution are summarised in **Table 16**:

Table 16. Energy balance.

Thermal consumption		
Total heating demand (MWh/year)		6,797
Total network heating demand (MWh/year)		5,097
Distribution losses (MWh/year)	24 H	48.9
	18 H	54.7
Total network heating consumption (MWh/year)	24 H	5,146
	18 H	5,153
Electric consumption		
Constant flow (MWh/year)	24 H	2,311
	18 H	1,733
Variable flow (MWh/year)	24 H	756
	18 H	693

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Electric consumption on the heat source is not taken into consideration in the energy balance. This electric consumption is part of the pre-existing system before energy re-use, and therefore is not part of the DH injection.

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8. Economic analysis

In the present case study for the Basque Country, it is assumed that both the industry and users are responsible for the investment.

It is also necessary to account the associated revenues from supplying waste heat to DHN that must ensure a suitable RoI for both of them.

Firstly, the process starts with the avoided costs due to the substitution of gas boilers and DHW produced by electricity with a HP which uses waste heat, for the final user

Other avoided cost that is not a real economic flow or revenue but must be taken into account is the reduction on the use of auxiliary processes for waste heat treatment such as cooling towers (reduction of water treatment, electricity etc).

The avoided costs are not a real economic flux, but a simulated figure used to represent the improvement on operational costs due to the injection of waste heat.

8.1. Cost model for the DH network for Basauri

8.1.1. Total investment

The total investment for both the network and the individual installations is:

Table 17. Total investment, estimated from average market prices

Installation type	CONCEPT	Cost per unit	Units in the installation	**INVESTMENT (€)**
Network and substations	Heat exchanger	4 €/kW	5,752 kW	**22,680**
	PUMPS & associated costs	10 €/kW	5,752 kW	**55,000**

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	Special pipes elements (elbows, etc.)	28 €/m	8,246 m	**231,091**
	Valves	32 €/m	8,246 m	**288,864**
	Buried pipes	130 €/m	8,246 m	**1,155,456**
	Ditches	135 €/m	4,123 m	**556,578**
	Other construction works			**5,500**
	Total installation			**2,315,169**
Connection to the buildings	Special pipes elements (elbows, etc)	11 €/m	2,467	**27,091**
	Valves	14 €/m	2,467	**33,864**
	Buried pipes	55 €/m	2,467	**135,455**
	Ditches	135 €/m	2,467	**166,543**
	Substations, heat pumps and connection	12.149 €/building	2,467	**2,320,532**
	Total installation			**2,683,484**
TOTAL				**4,998,653 €**

An investment of nearly 5M€ is needed to reuse the waste heat as a substitute of individual heating.

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8.1.2. Savings

The total savings are divided among:
the individual consumers, which replace gas costs by electric costs (heat pumps and distribution costs) (**Table 18**).

Table 18. Total yearly costs for the situation pre (upper part) and after intervention (lower part). Cost for after intervention are highlighted in red.

Item	Cost per unit [c€/kWh]*	Efficiency [%]	Demand [kWh/ year]	Distribution [kWh/ year]	Heat pump [kWh/ year]	Consumption [kWh/ year]	Total cost [€/year]
Natural gas	**6**	90	5,690,564			7,025,388	**421,523**
Electricity for heating	**17**		2,083,104			2,083,104	**354,128**
Butane gas	**9**	85	1,173,760			1,380,895	**124,281**
Total savings							**899,931**
Electricity used for HP boosting	**17**	100			2,236,857	2,236,857	380,266
O&M		35					133,093
Total costs after intervention							513,359
Total savings							386,573

*Estimated figures.

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The economic savings to be obtained will be the difference between the fossil energy that the user stops consuming and the electricity consumption associated with the new heat pump installation.
The total avoided costs by the user would be revenues for the heat producer, ensuring an attractive price for the user as the cost equals the previous scenario. Savings for the industrial source, which reduces the cooling towers costs (**Table 19**).

Table 19. Total yearly costs for the situation pre (upper part) and after intervention (lower part). Cost for after intervention are highlighted in red.

Item	Cost per unit *	Units	Total [€/year]
Electricity for DH distribution	7 [c€/kWh]	1,028,064 kWh	71,964
Water (consumption and treatment)			195,536
Fan consumption	7 [c€/kWh]	356,844 kWh	24,979
Total savings			**148,551**

*Estimated figures.

In this case, the economic saving is based on the difference between the electricity consumption avoided in the cooling tower, plus costs associated with water treatment, and the new consumption of electricity in the pumping.

Therefore, the total savings thanks to the waste heat recovery is the addition of both savings: 535,124 euros/year. Taking into consideration the investments needed, **the payback is 10 years.**

8.2. Cost model for the DH network for Abanto Zierbena

8.2.1. Total investment

The total investment for both the network and the individual installations is:

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Table 20. Total investment.

Installation type	CONCEPT	Cost per unit	Units in the installation	**INVESTMENT (€)**
Network and substations	Heat exchanger	4 €/kW	5,123 kW	**20,202**
	PUMPS & associated costs	8 €/kW	5,123 kW	**40,000**
	Special pipes elements (elbows, etc)	26 €/m	7,177 m	**186,380**
	Valves	32 €/m	7,177 m	**232,975**
	Buried pipes	130 €/m	7,177 m	**931,901**
	Ditches	135 €/m	3,589 m	**484,475**
	Other construction works			**4,000**
	Total installation ……..			**1,899,932**
Connection to the buildings	Special pipes elements (elbows, etc)	10 €/m	5.176 m	**27,091**
	Valves	14 €/m	5,176 m	**33,864**
	Buried pipes	55 €/m	5,176 m	**135,455**
	Ditches	135 €/m	2,588 m	**166,543**
	Substations, heat pumps and connection	10.299 €/building	261	**2,687,932**
	Total installation ……..			**3,416,845**
TOTAL……..				**5,316,777 €**

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An investment of 5,3M€ is needed to reuse the waste heat as a substitute of individual heating.

8.2.2. Savings

The total savings are divided among:

- the individual consumers, which replace gas costs by electric costs (heat pumps and distribution costs) (**Table 21**).

Table 21. Total yearly costs for the situation pre (upper part) and after intervention (lower part). Cost for after intervention are highlighted in red.

Item	Cost per unit [c€/kWh]*	RTO [%]	Demand [kWh/ year]	Distribution [kWh/ year]	Heat pump [kWh/ year]	Consumption [kWh/ year]	Total cost [€/year]
Natural gas	**6**	90	5,165,965			6,377,735	382,664
Electricity for heating	**17**		1,192,004			1,192,004	202,641
Butane gas	**9**	85	439,353			516,886	46,520
Total savings							**631,825**
Electricity used for HP boosting	17	100			1,699,331	1,699,331	288,886
O&M		35					101,110
Total costs after intervention							389,996
Total savings							**241,828**

*Estimated figures.

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The economic savings to be obtained will be the difference between the fossil energy that the user stops consuming and the electricity consumption associated with the new heat pump installation.

The total avoided costs by the user would be revenues for the heat producer, ensuring an attractive price for the user as the cost equals the previous scenario.

- and the industrial source, which reduces the cooling towers costs (**Table 22**).

Table 22. Total yearly costs for the situation pre (upper part) and after intervention (lower part). Cost for after intervention are highlighted in red.

Item	Cost per unit*	Units	Total [€/year]
Electricity for DH distribution	7 [c€/kWh]	756,393 kWh	52,948
Water (consumption and treatment)			174,218
Fan consumption	7 [c€/kWh]	306,055 kWh	21,424
Total savings			**142,695**

*Estimated figures.

In this case, the economic saving is based on the difference between the electricity consumption avoided in the cooling tower, plus costs associated with water treatment, and the new consumption of electricity in the pumping.

Therefore, the total savings thanks to the waste heat recovery are is the addition of both savings: 384,523 euros/year. Taking into consideration the investments needed, **the payback is 14 years.**

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9. Environmental analysis

Following the methodology included in the *Tool to support the calculation of GHG emission avoidance from renewable electricity, renewable cooling and renewable heating projects under the Innovation Fund (v2.0 - 24.03.2021)*, the GHG emission avoided with the waste heat recovery are estimated for both cases. For the estimation of the CO_2 emissions associated to butane gas there is no value provided by this tool, and therefore the "*Well to tank Report, version 4.0*" from the Joint Research Institute has been used as reference. It is worth mentioning that the GHG conversion factors provided by this tool are lower than the factors from Spanish official sources, which propose 0.357 kgCO2/kWh. Therefore, the environmental positive impact from the substitution of fossil fuels by electricity would be lower.

Regarding the primary energy reduction achieved by the proposed case studies, the method for calculating the primary energy factors (PEF) for fuels is straightforward, while the calculation of PEF for the electricity is more complex because different energy sources and generation technologies are involved. Since there is no PEF proposed by the mentioned tool, the PEF suggested by Spanish official sources are used, as shown in **Table 23**.

Table 23. Primary energy factors for different energy resources. Source: Eguiarte, O. et at. (2020).

Energy Resource	Individual PEF (kWh/kWh)
Natural gas boiler	1.1
Gas butane boiler	1.1
Electric mix in Spain	2.403

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9.1. Basauri

In this case, the total emissions avoided are:

Table 24. Total emissions avoided.

Item	[kWh/ year]	Emission factor [kgs CO_2e / kWh]	Total [tonnes CO_2e / year]
Gas consumption	- 7,025,388	0.202	-1,419
Avoided electricity (heating, cooling towers, etc.)	- 2,439,948	0.15	-365
Gas butane	- 1,380,895	0.254	-351
Electricity for the HPs	2,236,857	0,15	336
Electricity for DH distribution	1,028,064	0,15	154
Total			**-1,645**

The amount of GHG emissions avoided would be higher in future scenarios, as the electric grid will have lower emissions factor in the future, which benefits the electrification of the demand. The assumption proposed on the above mentioned tool is 0 kgs CO_{2e} per electric kWh in 2050.

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Table 25. Total primary energy avoided.

Item	[kWh/ year]	PEF [kWh/kWh]	Total [kWh / year]
Gas consumption	- 7,025,388	1.1	-7,727,927
Avoided electricity (heating, cooling towers, etc.)	- 2,439,948	2.403	--5,863,195.04
Gas butane	- 1,380,895	1.1	-1,518,985
Electricity for the HPs	2,236,857	2.403	5,375,167.37
Electricity for DH distribution	1,028,064	2.403	2,470,437.79
Total			**-7,264,501.18**

The amount of primary energy avoided would be higher in future scenarios, as the electric grid will have lower PEF factor in the future, which benefits the electrification of the demand.

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9.1. Abanto Zierbena

In this case, the total emissions avoided are:

Table 26. Total emissions avoided.

Item	[kWh/ year]	Emission factor [kgs CO_2e / kWh]	Total [kg CO_2e / year]
Gas consumption	- 6,377,735	0.202	-1,288
Avoided electricity (heating, cooling towers, etc.)	-1,498,059	0.15	-225
Gas butane	- 516,886	0.254	-131
Electricity for the HPs	1,699,331	0.15	255
Electricity for DH distribution	756,393	0.15	113
Total			**-1,276**

The amount of GHG emissions avoided would be higher in future scenarios, as the electric grid will have lower emissions factor in the future, which benefits the electrification of the demand. The assumption proposed on the above mentioned tool is 0 kgs CO_{2e} per electric kWh in 2050.

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Table 27. Total primary energy avoided.

Item	[kWh/ year]	PEF [kWh/kWh]	Total [kWh / year]
Gas consumption	- 6.377.735	1.1	-7,015,509
Avoided electricity (heating, cooling towers, etc.)	-1,498,059	2.403	-3,599,835.77
Gas butane	- 516,886	1.1	-568,575
Electricity for the HPs	1,699,331	2.403	4,083,492.39
Electricity for DH distribution	756,393	2.403	1,817,612.38
Total			**-5,282,814.11**

The amount of primary energy avoided would be higher in future scenarios, as the electric grid will have lower PEF factor in the future, which benefits the electrification of the demand.

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10. Conclusions

The main outcomes from the study are:

- Due to the lack of interest on some of the identified areas, directly implying lack of reliable data, a new criteria is applied: the interest of the owners of the heat sources to further analyse the potential of injecting the waste stream into a nearby DH network. This new criteria has shown its importance during the execution of this task, as available data as open source is almost inexistent for most of the sources. If the owners of the potential facilities are not interested in the assessment, lack of information implies an inconclusive study.

- The use of heat pumps is mandatory as the heat quality is considered as C, being not possible the direct use of heat due to its low thermal level in comparison with DHW and SH requirements.

- Paybacks could advise against reuse of waste heat, as the periods estimated for the return of the investment can be considered too high for industrial purposes (over 10 years).

- The use of individual heat pumps has been considered as the preferred option. The substitution of the individual gas boilers for individual heat pumps, of bigger size, could represent a problem for the costumer.

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Regarding the specific outcomes for the two quarters analysed as study cases are:

10.1.1. Basauri

- The total investment is close to 5M€, being the cost on the network piping (1.1M€) and the substations and connection (2.3M€) the items with the highest investment needs.
- The total savings are 535,124 € per year.
- This results on a payback period of 10 years.
- Regarding the GHG emissions avoided, the total number amounts to -1,645 tons of CO_2 per year.
- Regarding the primary energy, 7,264 MWh are avoided per year.

10.1.2. Abanto Zierbena

- The total investment is 5,3M€, being the cost on the network piping (0.9M€) and the substations and connection (2.7M€) the items with the highest investment needs.
- The total savings are 142,695 € per year.
- This results on a payback period of 14 years.
- Regarding the GHG emissions avoided, the total number amounts to 1,276 tons of CO_2 per year.
- Regarding the primary energy, 5,283 MWh are avoided per year.

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Annex D: Technical, financial and administrative roadmaps of new DH in consolidated urban environments in Mazovia.

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Deliverable	Annex D
Name	Regional feasibility studies of new DH in Mazovia
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1. Introduction

This annex reports on the application for Mazovia of the methodology developed within Task 5.6. The application of this methodology has identified opportunities of waste heat reuse with the RELaTED configuration in the Mazovia region on two phases:

- **Phase 1 (T 5.6):** a set of 2 locations are identified as suitable for the region, as summarised in the annex B.
- **Phase 2 (T 5.7):** the identified locations are analysed in detail for the final selection of suitable locations for the deployment of a new DH network with the RELaTED configuration in Mazovia, as described in the present annex D. Based on phase 1, potential sites for DH development are identified based on predefined key factors such as economic factors, available residual industrial heat or vicinity of urban areas, among others, as explained in the present annex.

The structure of this annex meets the following:

- **Selection of areas:** short explanation of the pre-selected areas coming from the analysis of Annex B.
- **Available residual industrial heat:** quantification of the available energy, considering main characteristics:
    - Continuity of heat production.
    - Quality.
- **Analysis of the selected urban areas:** the urban areas are evaluated in terms of density of population; typology of dwellings and heating system (power, energy carrier); distribution of consumption (kWh/year, heating&DHW); estimated heat production & re-use levels.
- **Technical analysis**: the deployment of a DH is proposed, including:
    - Definition of the pipe: size, path…

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- Losses (kWh/year).

- **Economic analysis:** a cost model for the DH network is proposed, considering:
  - Investment for the pipe as well as additional equipment.
  - Estimated cost of heat and electricity.

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2. Pre-selected areas

As described in annex B, the methodology developed within RELaTED identifies interesting interactions between heat sources and high dense areas, but fails to encounter fully successful outcomes.

As it is the case in Basque Country (check annexes A and C), a new criteria is applied: the interest of the owners of the heat sources to further analysis the potential of injecting the waste stream into a nearby DH network. This new criteria has shown its importance during the execution of this task, as available data as open source is almost inexistent for most of the sources. If the owners of the potential facilities are not interested in the assessment, lack of information implies an inconclusive study.

In the case of the Mazovia region, two companies have shown the interest and have provided data:

- Heat source with reference number 4, in the region of Pruszków.
- Heat source with reference number 7, in the region of Radom.

Therefore, the prioritization and selection of municipalities with high potential of deploying waste heat DH networks are based on those industries which have shown an interest on the study, as reflected in **Table 1**.

Table 1. Pre-selected locations. The enterprise is represented with a number to anonymize the process.

Cluster	Enterprises reference	Type of residual heat	County
1	4, Thermal Power generation	Direct use	**Pruszków**
2	7, Thermal Power generation	Direct use	**Radom**

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Figure 1. Aerial view of the analysed heat source and vicinity area to deploy a waste heat DH network in the Pruszków area.

Figure 2. Aerial view of the analysed heat source and vicinity area to deploy a waste heat DH network in the Radom area.

These two locations are the basis for phase 2, which conclude in the final evaluation of these suitable locations for the reuse of waste heat into existing DH networks in Mazovia. In the following sections, these interactions heat source-DH network are analysed in detailed following the methodology explained in the main body on the present document.

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3. Available residual industrial heat

The present section studies the two selected industrial heat sources, with in depth analysis of the continuity and quality of heat production (temperature range and heat availability).

3.1. Heat source at Pruszków

Due to confidential issues, the data provided by the industrial source regarding the available waste heat source at Pruszków cannot be disclosed. Therefore, the viability analysis takes as assumption that the available heat is enough to double the energy demand already provided by the DH, both in power and energy, with a thermal level adequate to be injected directly into the DH. The assumptions also include that no cooling towers are available at this location, being the waste heat a secondary product with an availability of 24/7 for all year long.

Heat quality of the waste heat sources (temperature [ºC] and availability [hours])

As introduced in Annex A of the present document, three quality classification groups are identified according to their output temperature and available hours range, as reflected in **Table 2**:

Table 2. Source quality classification criteria.

Source quality	Hours	T_{source}
A	Hours ≥ 6,000 h	T_{gases} ≥ 400 °C
B	3,000 h ≤ Hours < 6.000 h	150°C ≤ T_{gases} < 400 °C
C	Hours < 3,000 h	T_{gases} < 150 °C

Furthermore, the level temperature of the waste heat can be also classified as:

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- < 30 ºC: Heat Pump necessary.
- 70-80 ºC: Direct Use of heat.

In the case of this waste heat source, the assumption is that the quality can be considered as B, being possible the direct use of heat.

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3.2. Heat source at Radom

The available waste heat source at Radom counts with 166,908 MWh of waste heat available, no cooling towers, being the waste heat a secondary product of boilers. From the information provided from the industrial source, and considering a specific heat capacity of 1.097 kJ/kgC for the exhaust gases and a reduction of the temperature of exhaust gases of 10ºC, the total available waste heat is 875MWh/year for one of the boilers which has the highest availability in terms of working hours with 3,500 of operating hours per year.

Heat quality of the waste heat sources (temperature [ºC] and availability [hours])

The temperature of the exhaust gases is 160ºC, being possible the direct use for DH purposes. The quality of the heat can be considered as B according to their output temperature and available hours range.

In this sense, and as opposite to the cooling towers case taken into consideration in Annex C, it is important to remark that the proposed improvement of energy efficiency through the recovery of heat from flue gas is not technologically possible in every case. The flue gas temperature behind the boiler is an important parameter, the value of which determines the calculation results and the selection of devices and materials for the flue gas (dew point, duct cross-sections, selection of exhaust fans, filters, chimney height). It should also be assessed to what extent the reduction of the flue gas temperature will deteriorate the efficiency of the flue gas treatment installation, mainly the desulphurization installation, as the effectiveness of the desulphurization process in the semi-dry method is closely related to the temperature.

Furthermore, it should be assessed if the reuse of this waste heat would imply that additional energy is used in the primary process. In this case, where the flue gas is already being cooled down, it is not the case.

In the present case, the 10K temperature reduction is considered as feasible with no further implication on the primary process.

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4. Analysis of the selected urban areas close to the available residual industrial heat.

The potential urban areas in the vicinity of the industrial sources selected are evaluated in the present section.

4.1. Pruszków

According to the information provided in annex B, Pruszków counts with the following urban configuration:

Table 3. Number of flats associated with the DH consumption.

Number of flats	DH consumption	
	[MWh]	Coal
63,510	200,607.82	3,159

The available waste heat is considered to cover new customers. For the availability analysis, it is considered that the potential reuse of waste heat could cover 60,000 new customers, being the real one confidential.

Figure 3. Zoom on the vicinity of the analysed heat source.

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4.2. Radom

The municipal heating system in Radom (M.S.C.) relies on a DHN that provides heat to 84,368 apartments for a total of 331,452 MWh per year, what means an average yearly consumption of 3,929 kWh/flat. This number will increase according to the plans of the operator.

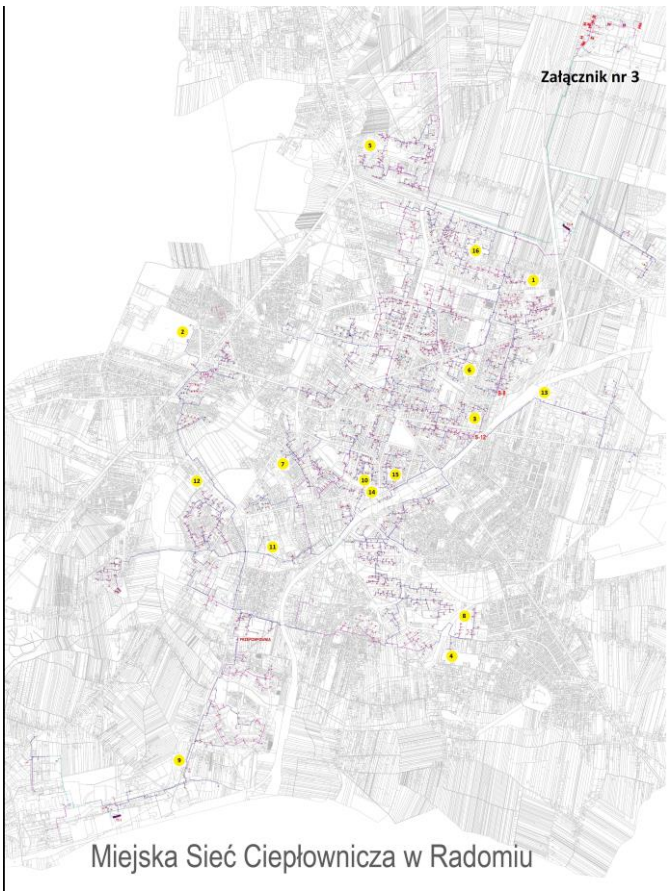

Figure 4. DH network at Radom. The numbers circled in yellow show the locations of the facilities to be connected in the plan for 2021 on the RADPEC heating network diagram.

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This DH is 176.4 km of network, delivering heat in the form of hot water with temperature parameters of 130°C / 70°C, supplied from two heat sources:

- TC-I Południe heat plant with installed capacity of 169.5 MW,
- TC-II heat plant Północ with installed capacity of 116.3 MW.

Figure 5. Location of the production plants at the network.

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This means that the capacity of the installed boilers in the M.S.C. amounts to a total of 285.8 MW, while the contractual power demand reported by heat recipients connected to M.S.C. as of February 28, 2021 amounts to 279.6 MW.

The total heat sales are summarised in the following table:

Table 4. Production, heat supplied to the network, heat sale – 2019/2020

Year		**2019**			**2020**		
Heat source		TC-I	TC-II	SUM	TC-I	TC-II	SUM
Heat production	GJ	979,380	813,236	**1,792,616**	823,866	948,216	**1,772,082**
Heat supplied to the network	GJ	962,903	808,472	**1,771,374**	805,827	942,959	**1,748,787**
Heat sale	GJ			**1,559,203**			**1,510,908**

The heating plant of Radom is planning the expansion of the system as result of connection agreements concluded by the company. The company's 3-year plan includes items related to the expansion of the system resulting from concluded contracts only for the current year (currently for 2021), which includes an increase in the demand for heat (ordered power) and the length of the network as a result of the implementation of connections.

The remaining items of the plan are only modernization tasks aimed at maintaining or improving the technical condition of the network infrastructure.

Since the total DH consumption equals 3,929 kWh/flat, the 875 MWh of waste heat available could cover the demand of 270 flats.

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5. Technical analysis

For both cases, and since the DH network would deliver heat in the form of hot water with temperature parameters of 130°C / 70°C, insulated polyethylene pipes have been selected.

For the sizing of the buried pipes, the power previously estimated is used with a simultaneity factor of 100%, in order to oversize the network in the worst case scenario.

The next assumptions are made for the sizing of the pipes:

- Impulsion temperature: 130 ºC.
- Return temperature: 70 ºC.
- Temperature gradient: 60 ºC.
- Density: 996 kg/m^3.
- Viscosity: 0.88 cST.
- Length: 200 m.

5.1. Definition of the pipe for Pruszków

The total power of the proposed injection and the assumptions allow the calculation of the pipe dimensions. It is important to remark that the industrial source at Pruszków already delivers energy to the DH, so the new pipes would run in parallel to the existing ones. With the dimensions and total lengths for each sector, the heat losses can be obtained based on the losses per meter long based on own know-how based on the distribution temperature (0.5W/m).

5.1.1. Losses (kWh/year)

The total energy lost is calculated with the total number of operating hours of the installation, being this number estimated in 24 hours.

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Table 5. Summary of losses.

Total working hours/day	24
Total working days/year	365
Losses kWh/season	1,752
Distribution losses (%)	<1%
Design flow through pipes (l/h)	307,312

It can be concluded from the table that losses are low (1,752 kWh), below 1% of the total energy delivered.

5.1.2. Pumps consumption

The calculation is made for insulated polyethylene pipes, deployed one meter deep.

For the estimation of the electric consumption of the pipes, the following equation is used:

$$W = M \cdot Pa \cdot \eta$$

Being:

W: electric consumption [kWh]

M: volume Flow in [m^3/s]

Pa: pressure difference.

η : pump efficiency.

The calculation of the pump consumption is summarised per month and add up for the year consumption in the following table:

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Table 6. Summary of pump consumption (kWh), for constant (C) and variable (V) flow for 24 working hours.

	C 24 hours	V 24 hours
Total (kWh/year)	4,460,655.94	1,459,850.88

The first row summarises the consumption for constant flow pumps and 24 working hours. The second row includes the calculations for variable flow pumps for the same working hours.

5.2. Definition of the pipe for Radom

As it was the case for Pruszków, the total power of the proposed injection and the assumptions allow the calculation of the pipe dimensions.

5.2.1. Losses (kWh/year)

The total energy lost is calculated with the total number of operating hours of the installation, being this number estimated in 24 hours.

Table 7. Summary of losses.

Total working hours/day	24
Total working days/year	365
Losses kWh/season	1,752
Distribution losses (%)	<1%
Design flow through pipes (l/h)	1.380

It can be concluded from the table that losses are low (1,752 kWh), below 1% of the total energy delivered.

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5.2.2. Pumps consumption

The calculation is made for insulated polyethylene pipes, deployed one meter deep.

The calculation of the pump consumption is summarised per month and add up for the year consumption in the following table:

Table 8. Summary of pump consumption (kWh), for constant (C) and variable (V) flow for 24 working hours.

	C 24 hours	V 24 hours
Total (kWh/year)	20,082.33	6,572.40

The first row summarises the consumption for constant flow pumps and 24 working hours. The second row includes the calculations for variable flow pumps for the same working hours.

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6. Total energy balance

6.1. Pruszków

The summary of the thermal consumption, heat losses and electric consumption associated to flow distribution are summarised in **Table 9**:

Table 9. Energy balance.

Thermal consumption	
Total network heating consumption (MWh/year)	189,162
Electric consumption	
Constant flow (MWh/year)	4,461
Variable flow (MWh/year)	1,460

Electric consumption on the heat source is not taken into consideration in the energy balance. This electric consumption is part of the pre-existing system before energy re-use, and therefore is not part of the DH injection.

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6.2. Radom

The summary of the thermal, heat losses and electric consumption associated to flow distribution are summarised in **Table 10**:

Table 10. Energy balance.

Thermal consumption	
Total network heating consumption (MWh/year)	874
Electric consumption	
Constant flow (MWh/year)	20
Variable flow (MWh/year)	6.6

Electric consumption on the heat source is not taken into consideration in the energy balance. This electric consumption is part of the pre-existing system before energy re-use, and therefore is not part of the DH injection.

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7. Economic analysis.

In the present case study for the Mazovia region, it is assumed that the industry is the responsible for the investment. To account the associated revenues from supplying waste heat to DHN that must ensure a suitable RoI for the heat producer (industrial waste heat source) while offering an attractive price for the user, the price of the heat sold to the network is fixed to the price of the conventional heat of source used in the previous scenario.

Therefore, the proposed methodology in the case of Pruszków is to adjust the price of the heat sold to the network to the simulated economic output of avoided costs due to the substitution of gas boilers with waste heat by the final user. The avoided costs are not a real economic flux, but a simulated figure used to represent the improvement on operational costs due to the injection of waste heat. The cost paid by the user previously equals the revenues on the new scheme to pay off the investment by the industrial heat source.

In the case of Radon, there are no avoided costs by the user as they were already connected to the DH. In this case, the avoided costs are by the DH operator that would use less fuel (coal). The avoided costs of the operator are assumed to be revenues for the investor (either the industrial heat source or the DH operator).

Other avoided cost that is not a real economic flow or revenue but must be taken into account is the reduction on the use of auxiliary processes for waste heat treatment such as cooling towers (reduction of water treatment, electricity etc).

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7.1. Cost model for the heat injection in Pruszków

7.1.1. Total investment

The total investment needed for the heat injection:

Table 11. Total investment.

CONCEPT	**INVESTMENT (€)**
Heat exchanger	4,200
Economizer	12,000
PUMPS & associated costs	55,000
Piping	36,000
Ditches	27,000
Other costs (valves, etc)	40,000
Total cost	174,200

An investment of 174k€ is needed to reuse the waste heat as a substitute of the existing plants. Regarding the connection of the new costumers, five thousand new substations are estimated for an individual cost of 5,000€, which adds up to 25M€.

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7.1.2. Savings

The total savings are concentrated on the individual consumers, which replace gas costs by DH costs (**Table 12**).

Table 12. Total yearly costs for the situation pre (upper part) and after intervention (lower part). Cost for after intervention are highlighted in red.

Item	Cost per unit [c€/kWh]	Efficiency [%]	Demand [MWh/ year]	Distribution [MWh/ year]	Consumption [MWh/ year]	Total cost [k€/year]
Natural gas	**11**	90	189,540		210,600	**23,166**
Total avoided costs						**23,166**
DH	**4.2**	100	189,540		189,540	7,961
Electricity for DH distribution	**15.1**	100		1,460		220.5
Total costs after intervention						8,181.5
Total savings						14,984.5

The total avoided costs by the user would be revenues for the heat producer, ensuring an attractive price for the user as the cost equals the previous scenario.

Therefore, the total savings thanks to the waste heat recovery are ≈15,000 k euros/year. Taking into consideration the investments needed, **the payback is 1.68 years.**

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7.2. Cost model for the heat injection in Radom

7.2.1. Total investment

In the case of Radom, the total investments are the same as for Pruszków for the heat injection:

Table 13. Total investment.

CONCEPT	**INVESTMENT (€)**
Heat exchanger	4,200
Economizer	12,000
PUMPS & associated costs	55,000
Piping	36,000
Ditches	27,000
Other costs (valves, etc)	40,000
Total cost	174,200

An investment of 174k€ is needed to reuse the waste heat as a substitute of the existing plants. No further investment is needed as the buildings are connected to the existing DH network.

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7.2.2. Savings

The total savings are concentrated in the industrial source since the individual customers don't replace any costs as they were already connected to the DH.

In the case of the DH operator, it replaces coal cost per waste heat (free), plus the electric cost for distribution.

Table 14. Total yearly costs for the situation pre (upper part) and after intervention (lower part). Cost for after intervention are highlighted in red.

Item	Cost per unit [c€/kWh]	Efficiency [%]	Demand [MWh/ year]	Distribution [MWh/ year]	Consumption [MWh/ year]	Total cost [€/year]
Coal	**11**	70	875		**1,250**	**137,500**
Total avoided costs						**137,500**
Electricity for DH distribution	**15.1**	100		6.9		1042
Total costs after intervention						1042
Total savings						136,459

Therefore, the total savings thanks to the waste heat recovery are 136,459 euros/year. Taking into consideration the investments needed, **the payback is between one and two years.**

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8. Environmental analysis

Following the methodology included in the *Tool to support the calculation of GHG emission avoidance from renewable electricity, renewable cooling and renewable heating projects under the Innovation Fund (v2.0 - 24.03.2021)*, the GHG emission avoided with the waste heat recovery are estimated for both cases. For the estimation of the CO_2 emissions associated to coal there is no value provided by this tool, and therefore the "*Well to tank Report, version 4.0*" from the Joint Research Institute has been used as reference.

Regarding the primary energy reduction achieved by the proposed case studies, the method for calculating the primary energy factors (PEF) for fuels is straightforward, while the calculation of PEF for the electricity is more complex because different energy sources and generation technologies are involved. Since there is no PEF proposed by the mentioned tool, the PEF suggested in Eguiarte, O. et at. (2020) are used, as shown in **Table 15**.

Table 15. Primary energy factors for different energy resources. Source: Eguiarte, O. et at. (2020).

Energy Resource	Individual PEF (kWh/kWh)
Natural gas boiler	1.1
Coal power plant	2.88
Electric mix in Poland	**2.78**

8.1.

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8.2. Pruszków

In this case, the total emissions avoided are:

Table 16. Total emissions avoided.

Item	[MWh/ year]	Emission factor [kgs CO_2e / kWh]	Total [tonnes CO_2e / year]
Gas consumption	-189,162	0.202	-38,211,724
Electricity for DH distribution	1,460	0.15	219,000
Total			**-37,992,724**

The amount of GHG emissions avoided would be higher in future scenarios, as the electric grid will have lower emissions factor in the future, which benefits the electrification of the demand. The assumption proposed on the abovementioned tool is 0 kgs CO_{2e} per electric kWh in 2050.

Table 17. Total primary energy avoided.

Item	[MWh/ year]	PEF [MWh/MWh]	Total [MWh / year]
Gas consumption	-189,162	1.1	-208,078.2
Electricity for DH distribution	1,460	2.78	4,058.8
Total			**- 204,019.04**

The amount of primary energy avoided would be higher in future scenarios, as the electric grid will have lower PEF factor in the future, which benefits the electrification of the demand.

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8.1. Radom

In this case, the total emissions avoided are:

Table 18. Total emissions avoided.

Item	[MWh/ year]	Emission factor [kgs CO_2e / kWh]	Total [tonnes CO_2e / year]
Coal consumption	- 875	0.356	**-311**
Electricity for DH distribution	15.1	0.15	2.3
Total			**-308.7**

The amount of GHG emissions avoided would be higher in future scenarios, as the electric grid will have lower emissions factor in the future, which benefits the electrification of the demand. The assumption proposed on the abovementioned tool is 0kgs CO_{2e} per electric kWh in 2050.

Table 19. Total primary energy avoided.

Item	[MWh/ year]	PEF [MWh/MWh]	Total [MWh / year]
Coal consumption	- 875	2.88	**-2520**
Electricity for DH distribution	15.1	2.78	**42**
Total			**-2478**

The amount of primary energy avoided would be higher in future scenarios, as the electric grid will have lower PEF factor in the future, which benefits the electrification of the demand.

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9. Conclusions

The main outcomes from the study are:

- Due to the lack of interest on some of the identified areas, directly implying lack of reliable data, a new criteria is applied: the interest of the owners of the heat sources to further analyse the potential of injecting the waste stream into a nearby DH network. This new criteria has shown its importance during the execution of this task, as available data as open source is almost inexistent for most of the sources. If the owners of the potential facilities are not interested in the assessment, lack of information implies an inconclusive study.
- Two cases are analysed:
    - Pruszków: waste heat injection to an existing DHN to provide service to new customers.
    - Radom: waste heat injection to an existing DHN to substitute heating based on coal production.
- Paybacks are lower than 3 years, which advise towards the reuse of waste heat, as the periods estimated for the return of the investment can be considered adequate for industrial purposes.

The specific outcomes for the two regions analysed are as follows.

9.1.1. Pruszków

- The total investment is close to 25M€.
- The total savings are ≈15,000 k€ per year.
- This results on a payback period of <2 years.
- Regarding the GHG emissions avoided, the total number amounts to 38 Mtons of CO_2 per year.

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- Regarding the primary energy, 204,019 MWh are avoided per year.

9.1.2. Radom

- The total investment is 174k€.
- The total savings are 136,459 € per year.
- This results on a payback period of less than two years.
- Regarding the GHG emissions avoided, the total number amounts to 308.7 tons of CO_2 per year.
- Regarding the primary energy, 2478 MWh are avoided per year.
- The recovery of heat from flue gas is not technologically possible in every case. The flue gas temperature behind the boiler is an important parameter, the value of which determines the calculation results and the selection of devices and materials for the flue gas (dew point, duct cross-sections, selection of exhaust fans, filters, chimney height). It should also be assessed to what extent the reduction of the flue gas temperature will deteriorate the efficiency of the flue gas treatment installation, mainly the desulphurization installation, as the effectiveness of the desulphurization process in the semi-dry method is closely related to the temperature.

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