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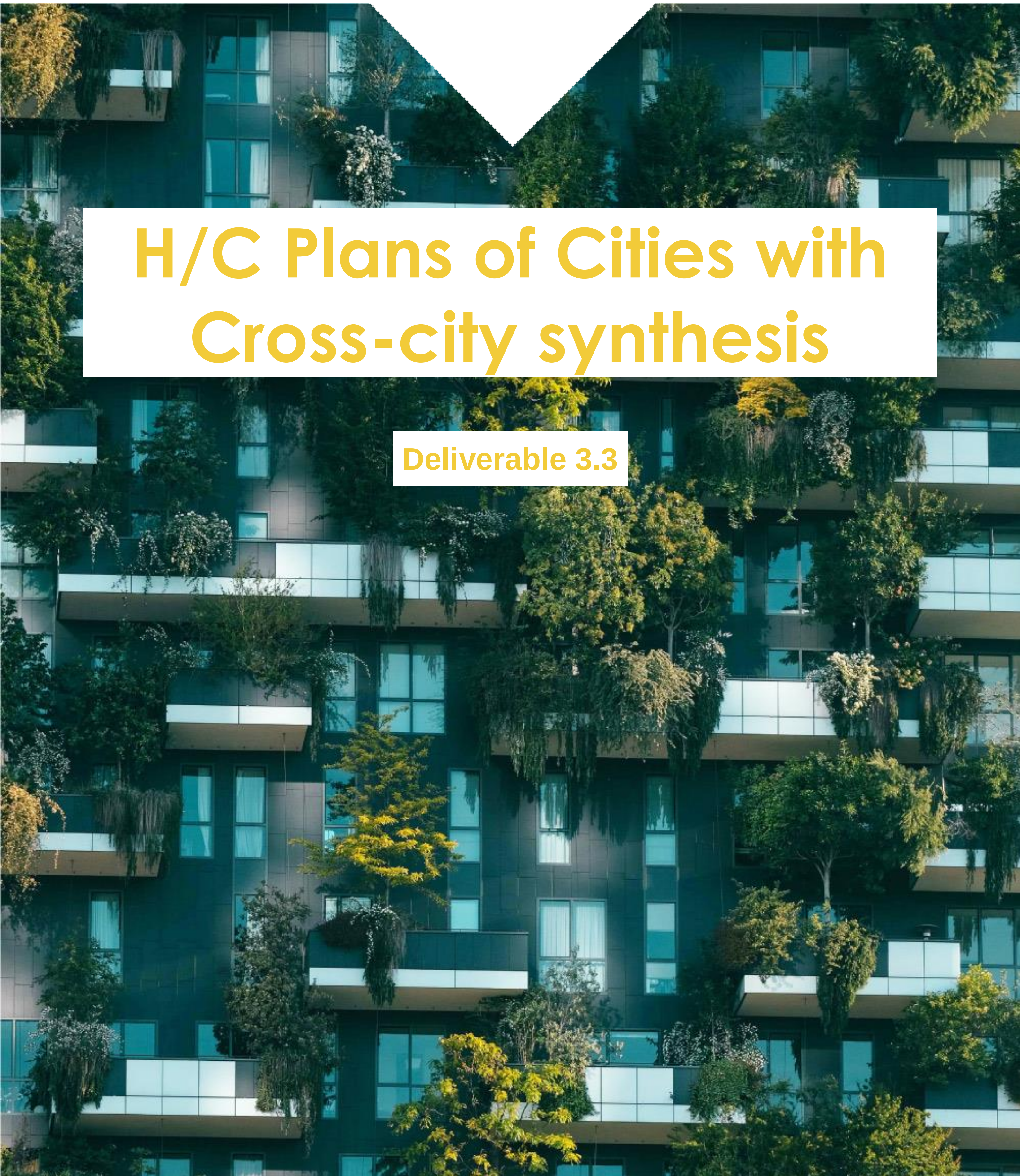
H/C Plans of Cities with Cross-city synthesis

Deliverable 3.3



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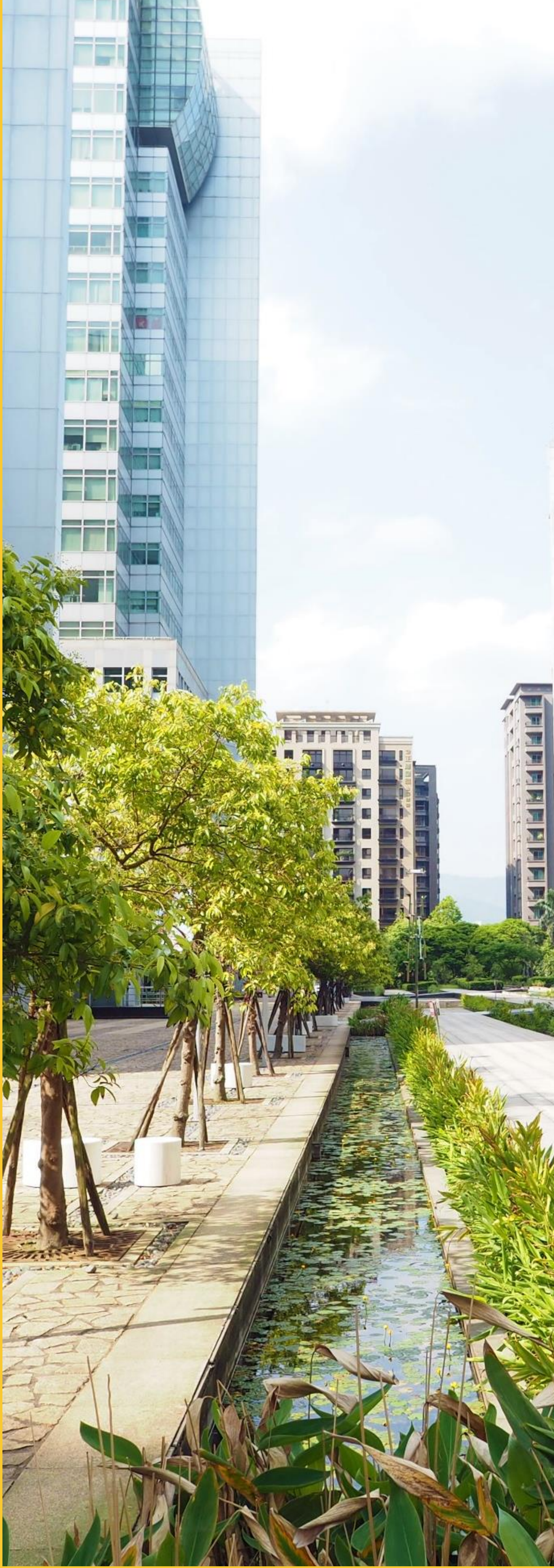


Table of Content

Cross-city synthesis

Introduction

All cities have a big challenge ahead in changing the way their building stock is heated and cooled based on fossil-free alternatives. The solutions at hand differ per city.

As part of this project, each of the participating city[1] - Bilbao, Dublin, Munich, Rotterdam, Vienna and Winterthur – has had to create its own H/C plan. These plans are all presented in detail in this report.

Furthermore, this report is preceded by a summary as well as a comparison of all plans. The purpose of this summary is to highlight some elements and get an overall overview of how to make an H/C plan.

The summary will show **differences** between the cities, such as in terms of size and amount of district heating grids available within the cities, and **similarities**, for example, regarding their approach of using heat-density as a method to decide where district heating is a logical alternative for natural gas heating.

[1] Except for the city of Bratislava, given its reduced role in the project.

Facts & figures

Current situation & goals

A first comparison between the cities can be found in the table below.

		Bilbao	Dublin	Munich	Rotterdam	Vienna	Winterthur
Inhabitants		350,000	550,000	1,460,000	650,000	1,910,000	110,000
Energy mix in H/C market	Gas	85%	72%	50%	72%	42%	41%
	DH	0%	0%	30%	18%	39%	20%
	Oil	5%	17%	0%	0%	4%	29%
	Other	10%	10%	20%	10%	15%	10%

TABLE 1: COMPARISON BETWEEN CITIES

As can be seen from the table, the cities differ in size and in the way heating is organized.

As part of this project, all cities had to create a heating and cooling plan that creates a future picture of the city in which the heating and cooling sector is decarbonized. In doing so, the cities are working toward "carbon neutrality," "climate neutrality," "carbon neutrality," "zero emissions," or "natural gas-free heating." Although all cities define their goals in different terms, they are all working to decarbonize the heating system for their building stock. In doing so, they are clearly moving away from fossil fuels for heating. The H/C plans represent a vision of how this decarbonization can be realized.

Like the target, the end date to achieve it differs from city to city, e.g., from 2035 to 2050. The table below summarizes the cities' targets.

City	Goal	End year	Other values & heat transition goals
Bilbao	Carbon neutrality	2050	2030: reduction of 40% GHG emission. Goal for buildingstock is translated to zero fossil fuel use in 2050.
Dublin	Net zero	2050	National Climate Action Plan target: 10% of all residential and commercial heating to be supplied via district heating by 2030.
Munich	Climate neutral	2035	Identify potential energy savings for the efficient, climate-friendly provision of energy for the heating and cooling of the building stock.
Rotterdam	Natural gas free heating	2050	Work towards sustainable energy (incl. air quality) , smart, energy justice, resilient (e.g. affordable, reliable, inclusive etc.)
Vienna	Carbon neutrality	2040	Phase-out of fossil fuels for heating, cooling and hot water production; reducing the carbon emissions per capita about -55% till 2030 and neutral in 2040 (compared to 2005); reducing the final energy

City	Goal	End year	Other values & heat transition goals
			consumption -45% till 2040 (compared to 2005) – for heating/cooling -30%
Winterthur	Net zero	2040	These goals are translated: various parts of the gas network will be decommissioned. Gas is used for peak supply. By 2033 green gas should replace fossil natural gas. .

Despites these differences in definiton, all cities aim for decarbonizing the heating and cooling of the built environment. It is clear that in order to decarbonise, there is a need for heating and cooling plans to give direction to the city's transformation paths.

Please note: The H/C Plans of the cities are not final plans. New insights, innovation and more accurate data will be used to update and improve the H/C plans constantly.

Cooling

Cooling is considered being important. All cities paid attention to cooling to a certain level, it is, however, not yet integrated into the H/C plans. The cities aim to make cooling part of the updated versions of the H/C plans, since the city´s cooling demand might influence the preferred heat option.

Most cities already analysed their cooling demand (density), e.g. Vienna looked at expansion of cooling networks (as separate system) and Bilbao used the heating/cooling ratio to decide in which places the use of heat pumps would be preferred. Rotterdam analysed its cooling demand and a made plan on how to deal with it. Munich integrated cooling for non residential buildings in the H/C plan, outlining potential district cooling. Winterthur analysed its cooling demand by regarding the data about industry affiliation from company statistics. Areas with high cooling[2] demand are identified in the H/C plan. These are to be considered in future district heating planning.

Heat demand

The estimated energy use for heating is known in all cities. Thecities also calculated potential heat demand reduction in time. Most cities have information regarding the type of buildings and calculated potential reductions based on assumptions how the building stock can be retrofitted. The retrofitting rate in most cities currently is about 1% per year. The cities`she ambitions, however, are higher.

All cities use standard building data to calculate the heat demand and potential reductions (retrofit). The different types of buildings (e.g. building year, ground bound / apartment flats and ownership) are taken into account. Dublin incorporated behavioral aspects in the energy demand calculations. It was found that the reboud effect (the percentage of theoretical savings compared to the actual savings) was 26.7% for homeowners and 41.3% for tenants. This difference between theoretical and actual energy consumption (also called preformance gap) is caused by behavioural aspects. For example, rooms in well insulated homes are heated more often than in badly insulated homes. Bilbao warns in their H/C plan

[2] A detailed paragraph on cooling can be found in the H/C Guideline (D3.2).

against overestimatng the potential impact of (retrofit) measures. Old buildings often have lower energy consumption then calculated, not only due to the behavioural aspects mentioned, but also because retrofitting measures have taken place in many of these buildings but have not yet been included in the calculations.

The cities of Vienna and Dublin expect significant population growth over the next decade(s), which will lead to an increase in heating demand. However,this will be limited compared to the existing building stock, as most buildings are expected to be built to near zero emission standards.

Energy supply

For the decarbonisation of the heating and cooling demand, fossil-free energy sources are needed. All cities still use more than 50% of fossil fuels in their heating system, especially natural gas. Natural gas is used for the heating of the building stock, either directly via gas boilers in the buildings or via CHP and peak and back up systems to produce heat for the existing district heating systems.

To meet the cities goals, the energy supply for heating needs to become fossil free. Still, for the coming years (natural) gas is oftenseen as a means to meet the heat demand and specifically the peak and back-up demand in district heating systems. In time, this natural gas either needs to be exchanged to alternative energy carriers or needs to become green (either H_2 or biogas). However, all of the cities asssume that there is not going to be enough green gas to replace natural gas in full.
So the bigger part of current gas based heating systems needs to be replaced by heating systems that can use other heat sources[3]. This is either with (individual) heat pumps or district heating networks This transformation of heating system enables the use of a wide range of (local) energy sources to heat the building stock.

Munich, Rotterdam, Vienna and Winterthur already have a district heating system in place, Bilbao and Dublin not (yet). Most of the cities still use natural gas as the main energy source for their district heating system. However, not all cities are completely dependent on it, e.g. Rotterdam, Vienna, Munchen, Winterthur also use heat from waste incinerators. Rotteram and Vienna also use waste heat from the industry (first connections have already been built, e.g. with a refinery; more are planned in the future).

Each city looks at district heating as one of the solutions for decarbonisation of the heating sector. CHP which uses natural gas is widely used to, besides electricity, also produce heat for the district heating systems. Dublin stated in their H/C plan that the amount of CHP enabled power plants will decrease due to the expected growth of green electricity production.

[3] This will be distric heating using geothermal heat, aquathermal heat and/or waste heat, heatpumps using electricity or a combination of district heating and heatpump using both the heat sources as well as electricity.

There are many different heat sources for district heating, the most important ones are summarized in the table below.

Heat source for district heating systems	Remarks
(deep) geothermal heat	All cities except Bilbao looked at the potential of geothermal heat.
Industrial waste heat	Cities with industrial complexes nearby, like Rotterdam, use or are planning to use this kind of heat. The future availability of waste (or recoverable) heat due to decarbonisation of the industry itself is, however, a point of attention. How much heat and at what temperature will be available in the future, needs to be analysed.
Waste incinerator	Most cities use or are planning to use heat from waste incinerators (Dublin, Munich, Rotterdam, Vienna, Winterthur). Circular economy aspects (no-waste strategy) are expected, however, to influence the future amount of available heat. How fast this no-waste future will unfold and what impact it will have on waste-to-energy plants is yet unknown.
Lower temperature waste heat *(e.g. heat from data centre, local industry)*	Especially heat from data centres are being considered. Not all cities have this potential, though. A lot of low temperature sources are also available in urban fabric areas (e.g. bakeries, supermarkets) – alltogether the have a high potential for low temperature networks or for direct use in neighbouring buildings.
Aqua thermal energy *(e.g energy from surface water, waste water, ground water)*	This type of heat needs to be upgraded by heat pumps, either by individual or large-scale heat pumps. All cities are looking at different types of aquathermal heat, but availability is most often low compared to heat demand.
Electricity	Cities will not be able to produce enough electricity within the city (excluding offshore wind) to fully meet the electricity demand. Cities are primarily looking for solar solutions (rooftop installations) within the built environment and win-win solutions, using PV elements for shading public spaces or combining green elements with PV installatioins on buildings. The rest of the electricity generation will come from wind (both onshore and offshore) and hydro power, mostly generated outside of cities. Electricity can be used to generate heat through heat pumps (both, on a large scale as part of district heating, as well as through individual heat pumps to heat individual buildings).
Green gas (H_2, biogas)	All cities expect to have a limited amount of green hydrogen[4] and biogas available by 2030. This high-value energy carrrier and source is preferably used for industry (requiring high temperatures) or serving as feedstock, heavy transport and/or balancing the energy system. This balancing is needed for both, the electricity as well as district heating systems. Munich as well as Vienna, for example, are examining whether there is enough green gas to meet current peaks in heating and electricity demand as well as for back up purposes in theses systems. .

[4] H_2 is, unlike biogas not an energy source but an energy carrier, it is made in an electrolyser using (green) energy sources.

Process, framework settings & principles used

Process

The creation of an H/C Plan can contribute significantly to the decarbonization of the city. However, it is important to obtain appropriate political support for this. This political support can be given at the beginning (e.g., council or board calls for an H/C plan) or later in the proces (e.g., the city council and administration approve the (draft) H/C plan). Political support is especially important during the implementation phase of an H/C plan.

In the course of the project, all participating cities (except Bratislava) drafted an H/C plan by following (some of) these steps:

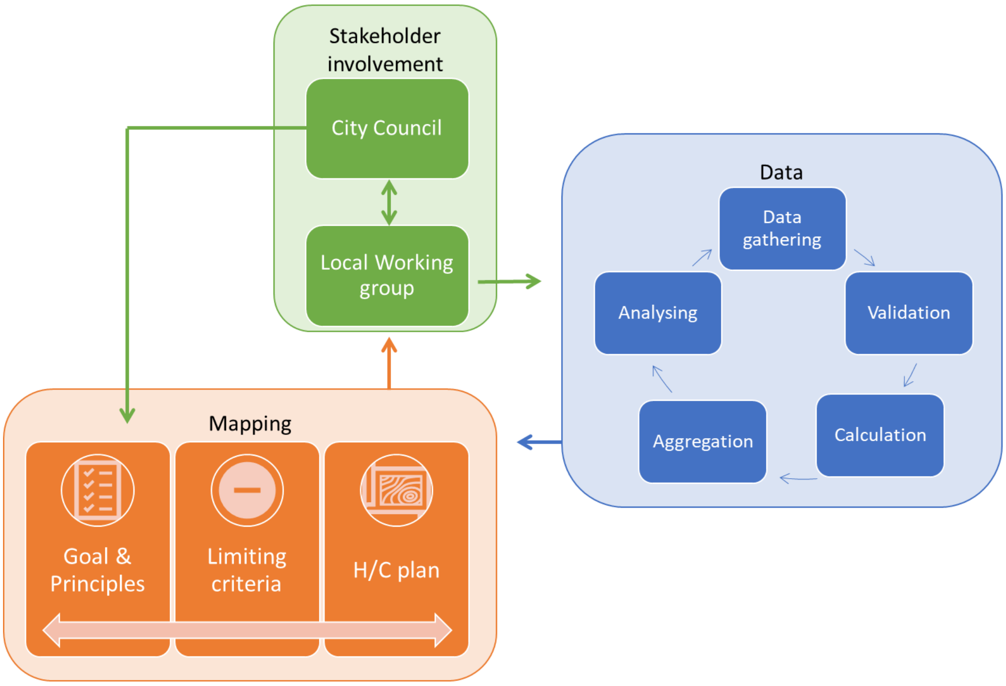


TABLE 2: SCHEMATIC ILLUSTRATION OF THE PROCESS FOR DEVELOPING AN H/C PLAN

Typically, the City Council establishes goals, principles and criteria. A local working group then gathers and collects data and aggregates information for later analysis and mapping. The results are presented to the City Council for approval. This process can be iterative, soliciting feedback and new input throughout the various steps.

The stakeholders involved in the local working group vary from city to city. Sometimes the city is the lead and other stakeholders, such as energy companies or grid owners, are involved later in the process. Other cities worked from the beginning with a local working group involving all stakeholders.

Limiting criteria in the decision process of a H/C plan may concern the availability of alternative heat sources, which in turn also restrict the type of solutions. Spatial constraints based on land-use planning decisions or social principles may also be an obstacle, e.g., if the energy supply must remain affordable and reliable for end users.

Reduction of heat demand

All cities considered reducing the heat demand by insulating the buildings as an important step in the transition towards (almost) zero-emission heating.

The level of insulation, however, depends on what is possible and needed. The options of refurbishment are, for example, in historic monumental buildings rather limited. Also, not all levels of refurbishment are cost efficient. Different heating solutions result in different temperature levels and provide direction for the level of insulation required.
In the cost analyses, the (costs and) level of insulations are taken into account.

Framework settings & principles used

The H/C plans are created by analysing and plotting available data and using different kinds of framework calculations. The most important frameworks & principles cities used to create their H/C plan are listed below.

Heat density

One of the main classification criteria used for mapping H/C potentials refers to heat density. Several studies show[5] that heat density is an opportune method to decide, for which areas district heating is an economically efficient fossil free alternative. Cities have used this method in different ways.

Winterthur uses 400 MWh/ha*a as an economical profitable threshold for district heating systems. The future heat demand is calculated based on the current heat demand, taking into account a decrease of heat demand due to retrofitting. Bilbao calculated both, the heat demand per m^2 usable floor area as well as the heat demand per area. The first criteria indicates the potential for retrofitting, the second the potential for district heating systems.

Cost calculations

Besides heat density, cost calculations are also made to decide what type of solution is the best one in an area. These calculations allow for a comparison of the required investments in the buildings[6] and in the energy system[7] as well as the annual costs of different solutions. Both, Dublin as well as Rotterdam have performed such calculations, both showing high potential for district heating in dense urban areas. The city of Dublin first conducted a heat density analyses and then a cost analyses, with the latter method showing even greater potential for district heating systems.

The best (most cost-effective) combination of measures at building level (insulation) and neighbourhood level (energy system) leads to the best solutions per area. Calculations can

[5] See D3.2. H/C guidelines
[6] Costs regarding the building: insulation, change of heating system & electrical cooking.
[7] Costs regarding the energy system : decommissioning of gas grid, reinforcement of electrical grid and/or realisation of new district heating network as well as the explorations of new energy sources.

be performed to find the best economically viable combination. Rotterdam and Dublin have performed such calculations.

Solutions for middle and high temperatures usually involve connecting buildings to a district heating system. This supplies buildings with a temperature of 70 degrees Celsius or more. Insulation measures are then not required, but still desirable to reduce energy demand. Low temperature solutions connect buildings to the electricity grid (using heat pumps) or to low temperature district heating systems. These options use heat at a temperature below 50 degrees Celsius. This type of low temperature heating is most efficient when buildings are well insulated and airtight.

Temperature	Above 70 degrees	Below 50 degrees
Cost at building level	Low (cost efficient)	High
Costs at system level	High	Low

Current system

Current energy systems provide direction for the H/C plan. In areas with district heating networks, district heating is, of course, to remain. In some cities, buildings already connected to district heating also still have gas connections (for heating and hot water production and/or for cooking, e.g. in Vienna). Other buildings are not yet connected to the district heating network at all (e.g. Rotterdam, Munich). For these areas, disconnection from the gas grid is incorporated into the H/C plans.

Energy availability

All cities do not see hydrogen and biogas as playing a major role in decarbonizing the heating sector. Both the limited (future) availability of any type of green gas and the fact that these types of high-value energy sources can be better used in sectors in which high-value energy is the only option, are reasons for the cities to focus on district heating and (individual) electric heating using heat pumps. Which of these solutions are possible depend on the potential availability of energy sources suitable for these specific systems.

The city of Bilbao looked at both the availability as well as the proximity of heat sources for the development of district heating networks. The city does not have a high temperature heat potential, so all district heating solutions are mid or low temperature.
The city of Munich calculated that 80% of the future heat demand in the current district heating system can be covered by geothermal heat. Since an expansion of the district heating network thus does not make sense, the city of Munich focuses on the existing district heating network in its H/C plan.

Sector coupling and system integration have currently not yet been analysed in the context of the H/C plans. The cities consider this to be a next step. In general, a district heating system will improve the resilience of the energy system by utilizing more energy sources and allowing more types of conversions. However, how this will be implemented in the heating and cooling plans is not yet part of the current heating and cooling plans.

Building stock

Not all buildings can be easily retrofitted, especially old and historic buildings. These buildings are given special consideration in deciding on the best option, e.g. the development of district heating solutions in cities. The city of Munich, for example, applies a building-oriented approach for buildings where retrofitting is not possible. Especially buildings near areas with (planned) district heating are connected to district heating (even if the heat density is low).
Building ownership is also taken into account. In Dublin areas with the lowest percentage of ownership and high number of apartments are considered difficult to retrofit.

Spatial aspects

Every choice also has a spatial impact (under and above the ground). And not all solutions fit easily into the built environment. The city of Bilbao explicitly used urban planning restrictions to weigh the different strategies, such as limitating the placement of heat pumps on rooftops in certain areas.
Other cities have not included this type of restriction in their H/C plans. In Rotterdam this will be part of the next step: the H/C plan represents the WHAT map (what solutions seems to fit best in what area). In a next step a WHEN map is created (which area will be transformed first). In this WHEN map spatial constraints or opportunities are also taken into account.

Other aspects

All cities consider the legal framework to be of great importance for the implementation of the H/C plans. Cities, however, do not yet have a complete set of regulatory and financial instruments to successfully implement their H/C plans. Therefore, after finalizing their H/C plans, cities will develop transition roadmaps as the next step in the project.

H/C plans

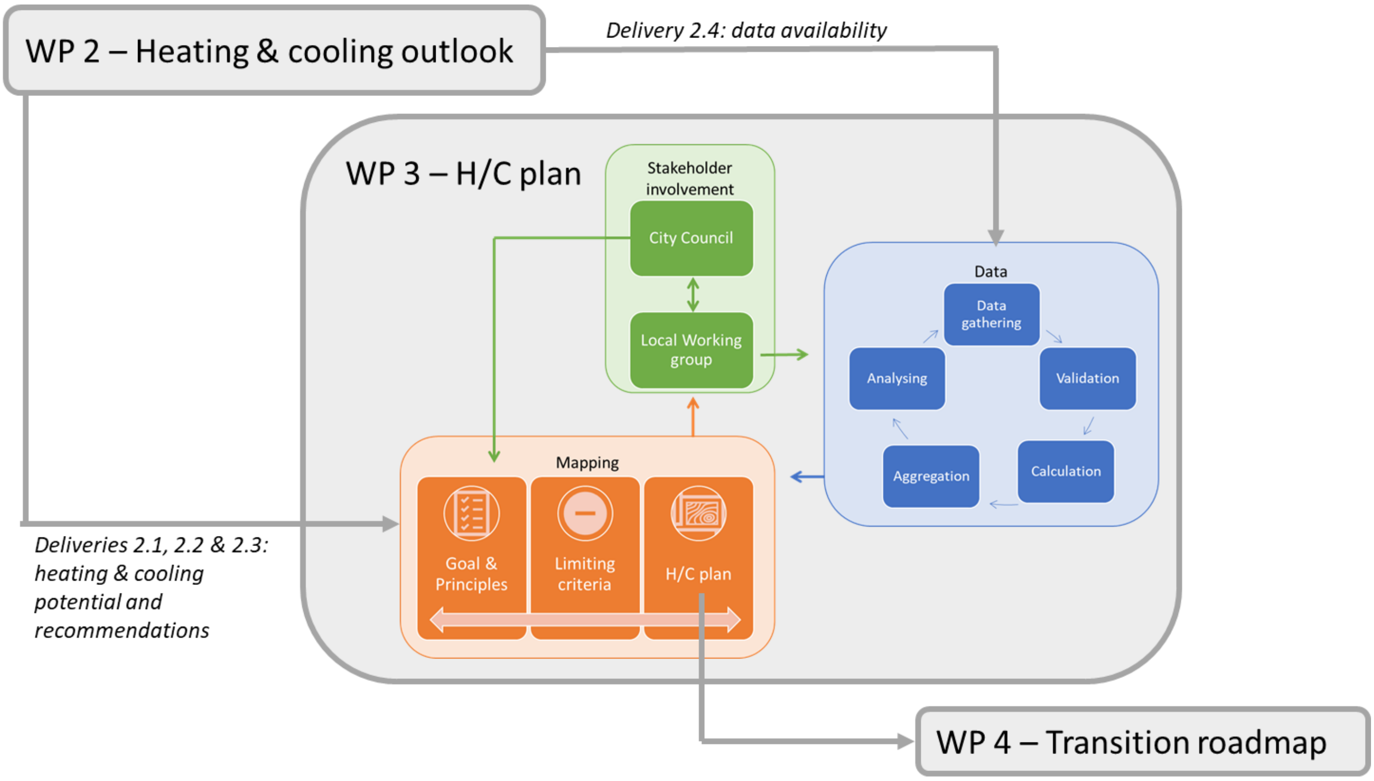
The H/C plans vary from city to city. The cities of Dublin and Rotterdam mapped preferred heating solutions per area compared to alternatives The city of Bilbao, on the other hand, has developed three strategies and, based on these, three potential maps.

Most cities focused on mapping future heat supply technology. Cooling is not yet fully integrated into all plans, even though all cities consider cooling an important element of the energy transition which needs to be taken into account for future H/C plans.
Nonetheless, some cities have already looked at cooling demand and potential solutions: Bilbao, for example, studied cooling demand for non-residential buildings. Munich analysed the expansion of current district cooling system (using ground water) to replace individual air conditioning systems for non-residential buildings. Winterthur’s map shows which areas are expected to have a significant cooling demand, as information for the utility to decide whether or not to install a cooling system. Rotterdam has created a separate map of cooling demand and heat island effects in the city.

Cities do see potential for low temperature systems that use heating and cooling from the same system (heat/cold storage). Currently this is, however, mainly installed in new buildings.
In cities where the grid owners are publicly owned, and especially where the electricity, gas and heating networks are owned by a single company (e.g., Winterthur and Vienna), it seems easier to create future integrated systemic H/C plans than in places where there are more owners and energy companies without strong public ownership and core values.

Data use

The data use and the outcome of the H/C plans as part the Decarb City Pips project are related to the other work packages in this project. Direct connections can be found between WP 2 (heating and cooling outlook) and WP 4 (transition roadmap). This delivery is one of the steps a cities needs to take.



The outcome and date used are relevant for all steps in the process. For the spatial planning data is used and processed. For more detailed information on data availability, data sovereignty, quality and exchange in the participating cities please see the deliverable 2.4.

Two points of attention are mentioned related to the use of data for making H/C plans, 1) the definitions used and 2) the availability and quality of data.

Definitions

It is important to have clear definitions that will be used during the whole process. For example, how is the heat demand defined? Is it in MWh or in GJ. Are the plans made per building? Is one building also one household? Or has one building one energy grid connection? So is an appartment building with one connection the same as a ground bound house? Are you using “average heat demand per household”? Etc. etc.

Every definition has pro’s and cons and in time consequences. It is good to be clear on the definitions that are used and for what specific defintions will be used. Some defintions are useful for monitoring but not for explaining the impact of the transition for the people involved.

H/C plans: Summary

Bilbao

Bilbao mapped three scenarios and created three different maps. The maps are not yet incorporated into one H/C plan. This will be done in a next step which will also require more detailed analyses. Bilbao focuses on building refurbishments with high energy efficiency requirements. 50% of the buildings are to be "nearly-zero" in 2050. In order to have no direct use of fossil fuels by 2050 in the building sector, natural gas needs to be replaced. The usage of green gas is considered highly unlikely.

TABLE 3: MAP OF BILBAO SHOWING STRATEGY 1

Strategy 1: Deep renovation of building blocks.

No other area has a higher potential for refurbishment than the inner city (marked in red). Almost 40% of the buildings in the city are, however, protected by conservation law due to their building characteristics.

TABLE 4: MAP OF BILBAO SHOWING STRATEGY 2

Strategy 2: Individual heat pumps

For the implementation of aerothermal systems, urban planning as well as building characteristics were considered in detail. New construction areas are weighed higher since interventions are much simpler, since they are not part of heritage areas.

Although there are no areas with a particularly high score, the neighbourhoods of San Francisco and Bilbao la Vieja do have the largest potential, since they are within an area of existing urban redevelopment plans and without any type of protection.

Strategy 3: district heating and cooling networks

In this strategy, the protection of buildings was not considered a constraint, as connection to district heating networks should be possible in most cases. Greater importance was given to the availability of resources and the distance to them, as well as the space available for the construction of infrastructure, if necessary.There are some areas that stand out: Casco Viejo, Bilbao la Vieja and Zorrozaurre. The first two areas are classified as Integral Rehabilitation Areas and are mainly dominated by old buildings with low thermal efficiency. Zorrozaurre, on the other hand, is an area that is currently being developed and where a low-temperature geothermal network is planned.

TABLE 5: MAP OF BILBAO SHOWING STRATEGY 3

Dublin

The H/C plan of Dublin shows areas most suited for each technology till 2050. The areas coloured blue are most suited for heat pumps; the areas coloured red for district heating. The darker the colour the more suited the area is for either technology. The priority areas are based on the lowest non-discounted carbon abatement cost.

The prices of alternatives were compared, taking into account the costs of new district heating infrastructure (production, distribution and substations), an upgrade of the existing electricity grid, and a medium fabric upgrade deemed necessary for both, district heating and heat pumps. It is likely that heat pumps will be more cost intensive. Furthermore, emissions were calculated including equivalent emissions (CH_4 leaks, NO_x emissions, refrigerant leaks; scaled down over time based on F-gas phase-down).

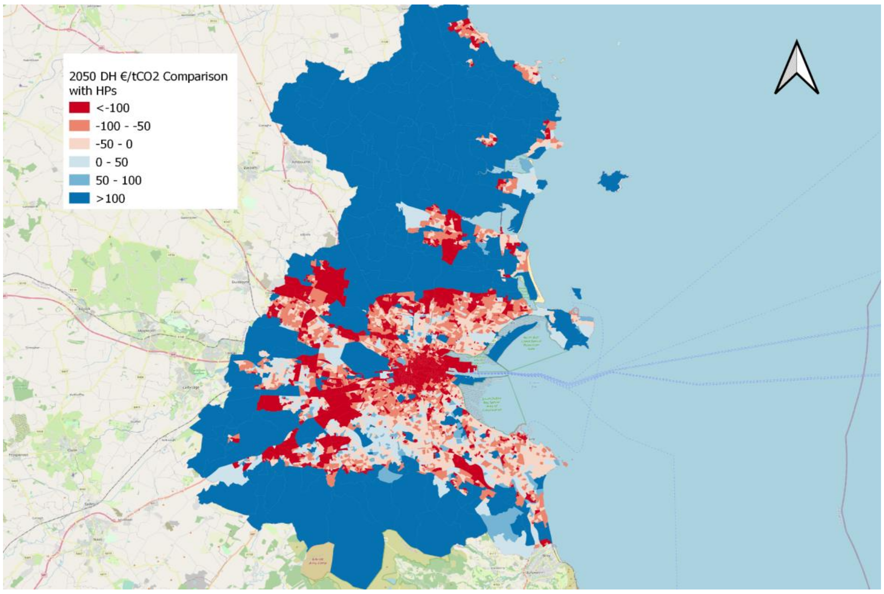


TABLE 6: H/C PLAN OF DUBLIN

District heating is an important part of Dublin's goal towards being net-zero by 2050, as laid out in the Dublin Region Energy Masterplan. District heating is the preferred solution for meeting up to 87% of the cities heat demand in 2050.

New buildings will be built as nearly-zero emissions buildings.

High-exergy fuels should not be used for low-exergy uses like space heating & hot water production. To meet the heat demand, less and less fossil fuels and gradually more local sources are to be used via district heating and heat pumps.

Munich

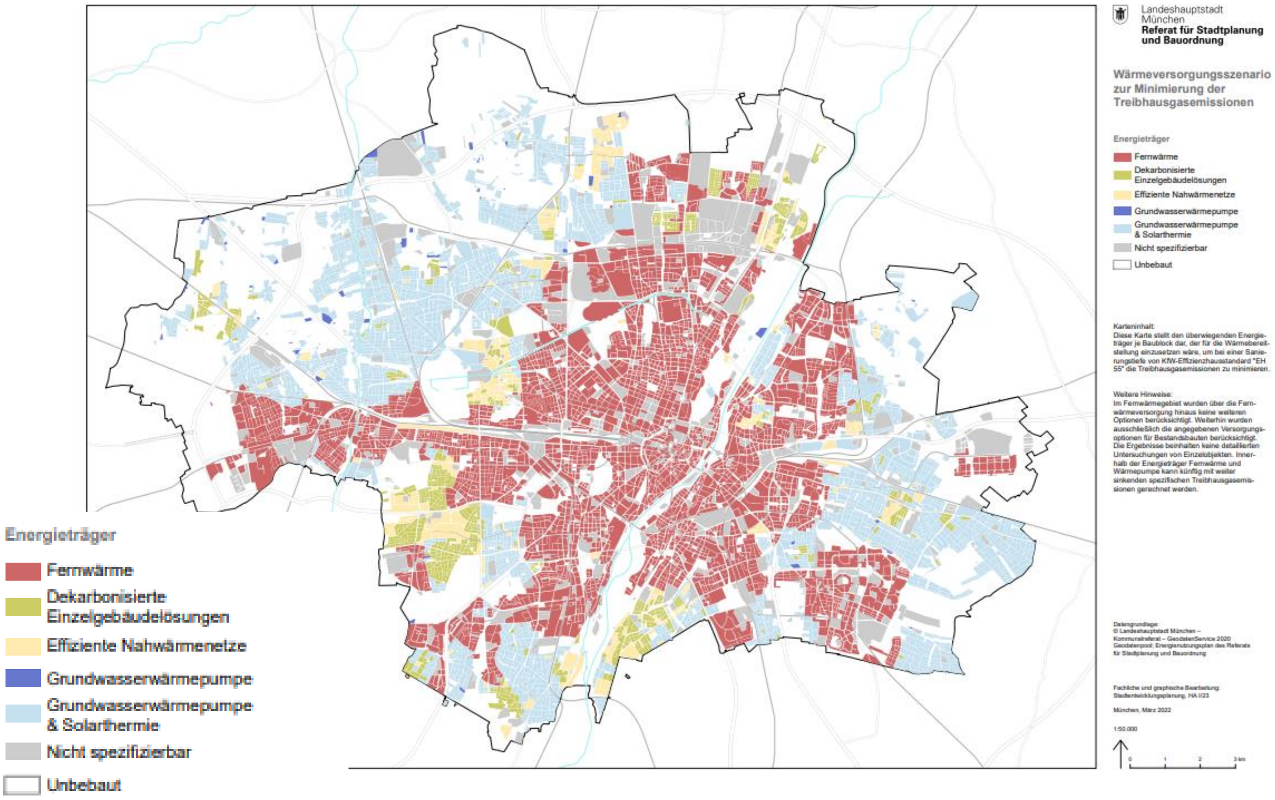


TABLE 7: H/C PLAN OF MUNICH

Munich aims towards climate neutrality by 2035. This requires the gradual abandonment of oil and gas in the heating of buildings. To organise this, a spatial heating and cooling strategy based on the current building stock and district heating network is being created.

Munich has built up a digital building database and already identified potentials of renewable energy sources for each building. The reduction of heat demand and GHG reduction potential for each building (in different retrofit scenarios) has been calculated.

Starting point of the H/C map is an increase in the number of district heating connections within the existing district heating area. Outside the current district heating area, the use of heat pumps (groundwater) is advised. The district heating operators are working on a strategy to make the heat supply from the district heating network renewable (geothermal is one of the options).

The H/C plan identifies options outside of the current D/C network areas. Retrofits are considered an essential part of the solution. Most buildings will need to be retrofitted.

Rotterdam

The H/C plan of Rotterdam is called WHAT map. It indicates what kind of solutions are most economically attractive in each area. In large parts of the city, collective heating solutions are an attractive alternative to natural gas because they are affordable for residents, landlords and businesses. A medium- or high-temperature heat network is the cheapest alternative for most of Rotterdam's districts. The advantage of a heat network is that it is suitable for the use of other heat sources in the future, making it a no-regret investment.

Another sustainable alternative to natural gas is electric heating with heat pumps (all-electric). This is an individual solution per house, which is relatively expensive. Most existing houses in Rotterdam need to be heavily insulated for this type of heating, which often makes this solution more expensive on the bottom line. This is evident from the WHAT map.

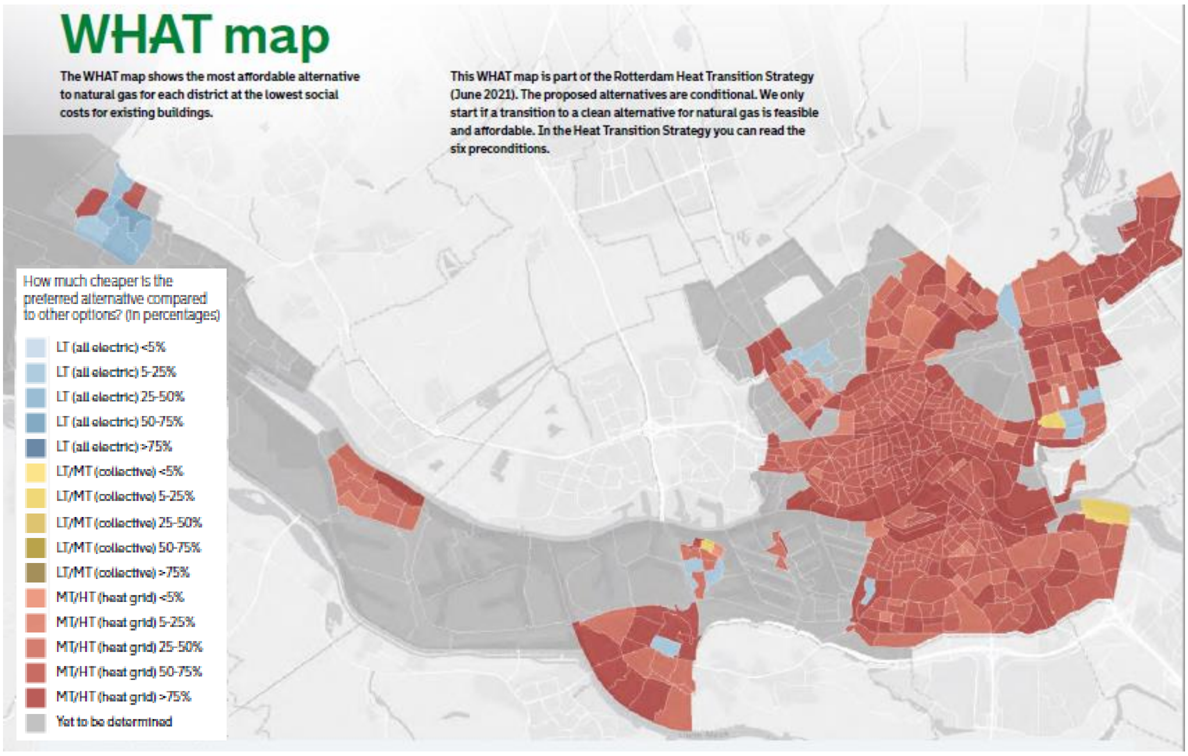


TABLE 8: WHAT-MAP OF ROTTERDAM

The WHAT map outlines a long(er)-term strategy for potential solutions in various districts. This map, however, it does not predetermine a decision on a particular type of solution, but rather provides a starting point for district oriented approach. It does show, which solution is preferred based on a detailed total costs calculations.

Furthermore, the city of Rotterdam stated that district heating networks should be used where already available (so no other calculation was needed). In cases where district heating is not close by, calculations are to be done.
The costs of the heat source are not explicitly included in calculations, but can be partially found in the energy use costs (based on actual energy costs by the energy/heating companies).

The WHEN map forms the next step: It shows where to start with the district-oriented approach. In this next step external effects are also considered (e.g. spatial impact, unlimited heat supply etc).

Vienna

The H/C plan of the city of Vienna identifies areas where a distinction is made between district heating densification, district heating expansion, micro grids and individual solutions. It is an initial concept plan that will be updated and improved over time based on new data and findings.

In areas where district heating networks already exist, the focus is on disconnecting buildings from gas grid and densifying the district heating network. The first focus is on buildings located next to existing district heating pipelines.

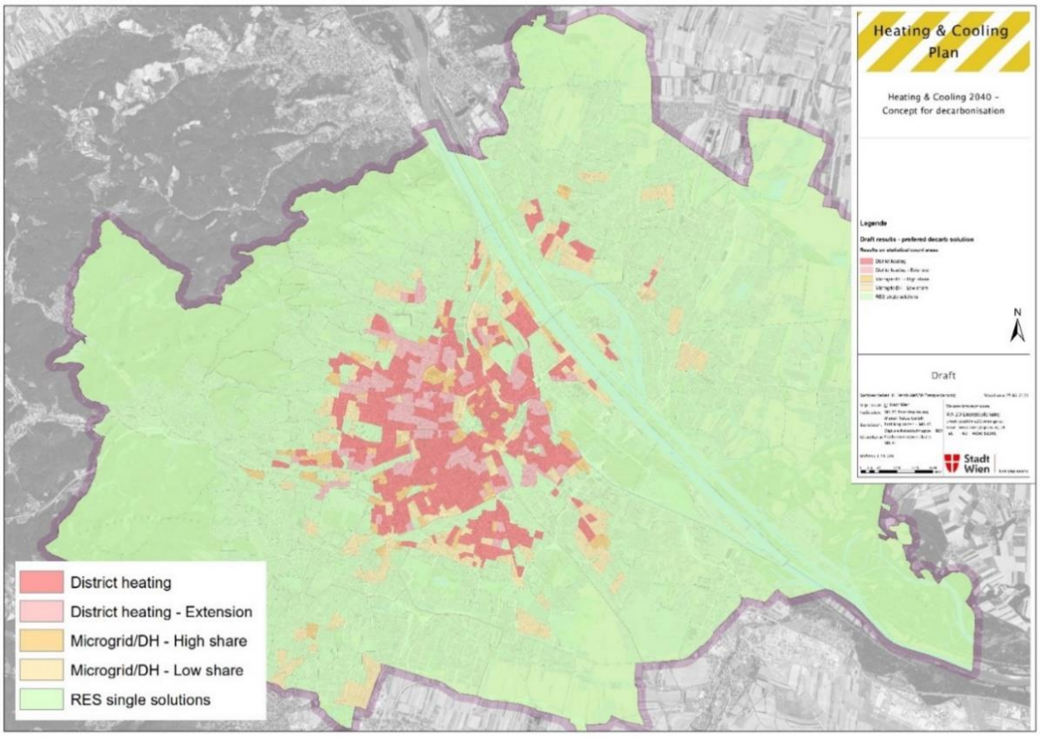


TABLE 9: H/C PLAN OF VIENNA

At the same time, district heating needs to be decarbonised. New heat sources are (deep) geothermal energy and the use of large central heat pumps that use ambient heat e.g. from the Danube (Donau). The expected limited amount of green gas available in Vienna in future, is to be used to meet peaks in heating and electricity demand and/or for industrial high-temperature processes as well as in heavy-duty transport.

In areas where central district heating is not possible, decentralised solutions are planned. The possibility of low-temperatures district heating networks is being examined (e.g. using aqua thermal heat from the Danube river or from data centers). If this is not possible, individual solutions are needed. Due to the increased use of heat pumps (as well as due to increasing amounts of PV systems and fast-charging stations for e-mobility), the capacity of the electricity grid is also taken into account

Furthermore, building typologies as well as the refurbishment rate[8] were part of the scenario analyses. For each building type, the best decarbonisation option (decarbonisation type) was examined, and the number of buildings and gross floor area for each category calculated.

Possible aspects to optimize the system are also part of the H/C plans, e.g. using the return flow of the district heating network for new buildings to reduce the temperature in the whole district heating network.

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[8] The current renovation rate is estimated between the 1 and 2%, the ambition is 3% per year.

Winterthur

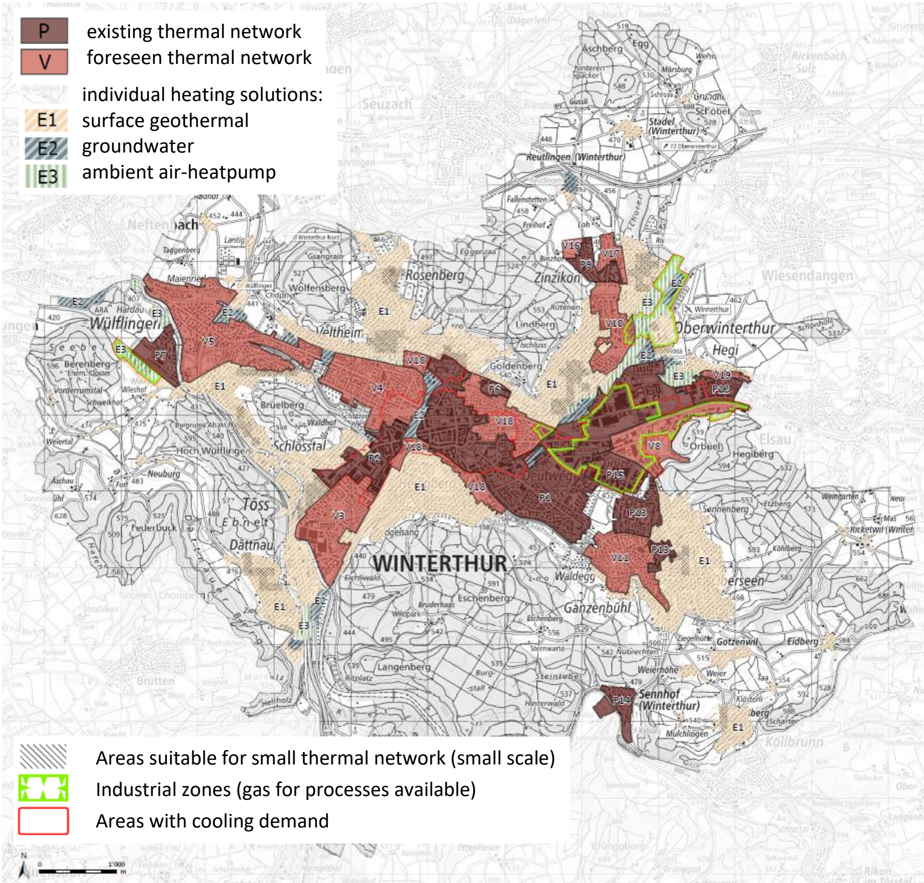


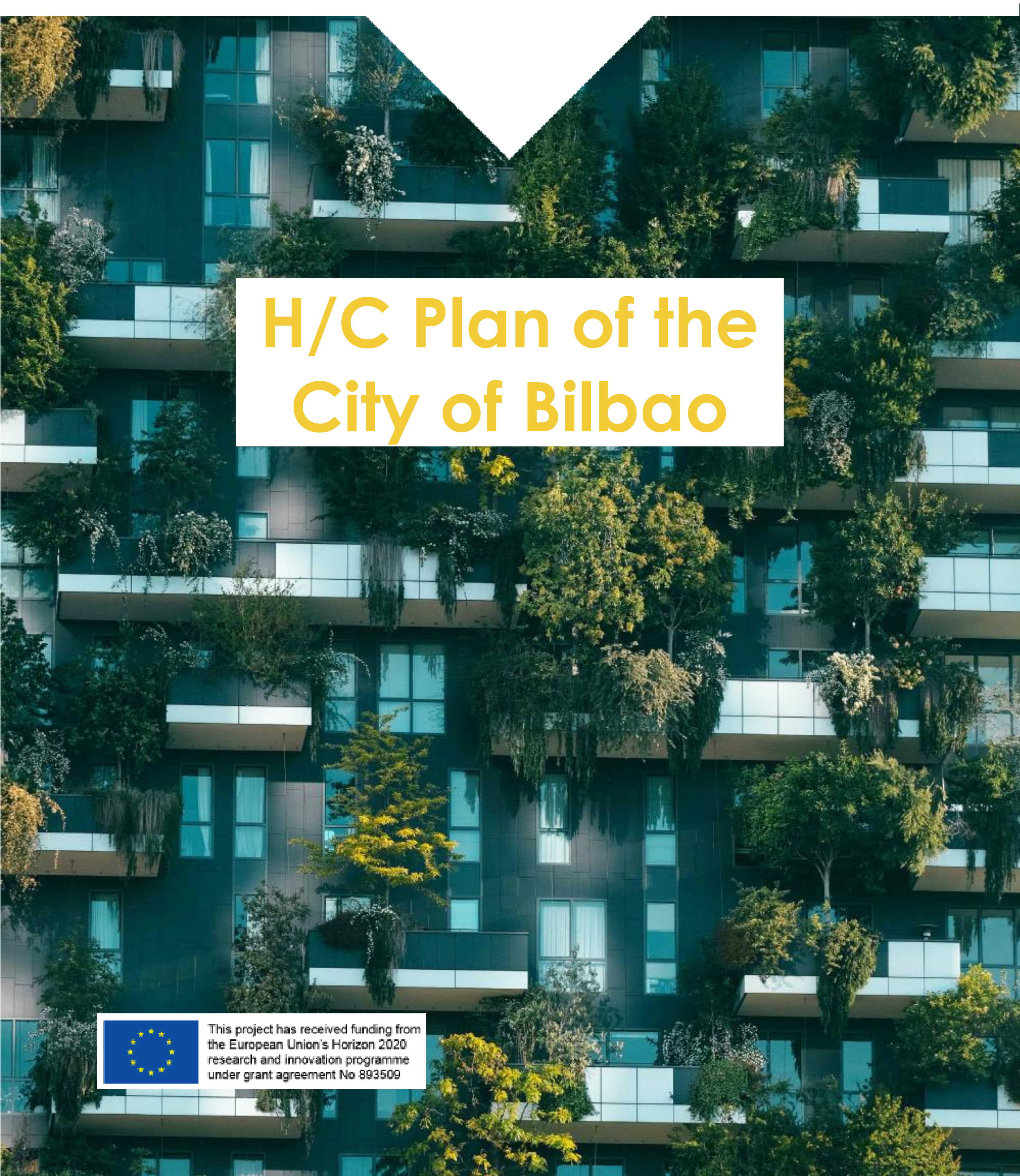
TABLE 10: H/C PLAN OF WINTERTHUR

The net-zero-goal to achieve in 2040 is confirmed by voting population in November 2021. This is translated into 1 ton CO_2/person in 2033, for heat-supply 300 kg/person.

Key elements of the H/C plan are:

- Retrofitting areas
- Reduction of gas infrastructure (closure of parts of the grid) and use of gas only in industrial processes and for peak capacity (as of 2033 this will through forms of green gas).
- District heating in areas with heat-density of more than 400 MWh/ha/a
- Other areas: heat pumps with near-surface geothermal heat or ambient air

The H/C plan was created in collaboration with utilities and grid owners (as part of the city’s local working group). New ways of thinking were introduced (mind opener/ cross-thinker / thinking outside the box). This led to utility buy-in and conviction that the transition will work. This energy plan is only the first step (vision). Subsequently, feasibility studies, financial viability, studies of resource potentials, etc. will be carried out. Overall, the current legal framework supports planning and achieving the city´s goals, e.g. property owners can be forced to connect to district heating, but this legal instrument has not been used in recent years.



H/C Plan of the City of Bilbao

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H/C Plan of the City of Bilbao

Introduction

Bilbao, as many cities in Europe, is working towards reducing the damage caused by COVID-19 pandemic on its socioeconomic situation, while also getting over the remaining consequences of the last economic and financial global crisis. Bilbao possesses some tools which contribute positively to social cohesion and, therefore, to alleviate the consequences of the crisis. These make Bilbao's social services system more efficient and help to generate work opportunities for people at risk of exclusion. Bilbao now relies on a strong civil society basis which contributes to building a city firmly related to people's wellbeing.

Currently, Bilbao is focused on the economic and employment challenge, and investments are being made in new businesses with better job quality conditions. Bilbao is also immersed in the social and urban rejuvenation challenge: an effort is being made to attract new young students and workers, so that they can choose Bilbao as a place to live and develop their personal and professional projects.
In the last few decades Bilbao has undergone a large restructuring and regeneration process, moving the industrial network outwards municipal limits, and with large infrastructure investments such as a subway net, treating the sea inlet or rebuilding a tram line. Building developments such as Euskalduna music house, the refurbished La Rivera market and the iconic opening of the Guggenheim Museum in 1997 have greatly changed the city's physiognomy. Now, Bilbao is engaged in projects related to the reconfiguration, digitalisation and modernisation of the tourism sector, which is expected to be one of Bilbao's main income sources.

In 2012, Bilbao published an **Action Plan for Sustainable Energy** which laid down city's commitment to sustainability from then on. Aligned with more than 4.000 European cities, Bilbao committed to reduce by 2020 at least a 20% the CO_2 emissions with regard to 2005 levels.

Bilbao also subscribed to other local and national initiatives, such us an **Action Plan against Noise**, a **Sustainable Urban Mobility Plan**, the creation of **green zones** in urban area, a **Climate Change Adaptation Plan**, and many more.

More recently, Bilbao published its **Environmental Strategy 2050** to achieve carbon neutrality by that date, and to improve life quality in the city in a one-year QALY (Quality Adjusted Life Years). The **Sustainable Energy and Climate Action Plan 2030**, which Bilbao is now developing on the framework of Covenant of Mayors, will commit the city to reduce at least 40% GHG by that date.

Within this framework, the project Decarb City Pipes 2050 is expected to play an important role with regard to planning the decarbonisation of the Heating and Cooling sector within the city. The following pages describe Bilbao´s efforts to create the city's first "Heating & Cooling Plan".

Facts & figures for Bilbao

The city of Bilbao has 347,000 inhabitants and is located on the eastern Atlantic side of the Iberian Peninsula, surrounded by mountainous areas. The capital of Bizkaia is the heart of a metropolis of more than 1 million inhabitants and considered the main factor of economic and social development as well as modernisation within the province. Its important transport infrastructure connects the city with the main capitals of Europe, by land, air, and sea, thanks to the easy access to the sea through the port. Additionally, Bilbao is a clear example of a successful case of urban reconversion, having undergone a great transformation from a completely industrial city to an attractive, design and service-focused city. Although it does not have a great expertise in the energy field, the background of such an important transformation shows the city's capacity to undertake forefront projects.

FIGURE 1 IMAGE OF THE CITY OF BILBAO

Focusing on data and particularly on the building stock, the vast majority are residential buildings. The city, however, also has a considerable number of non-residential buildings used by businesses of the tertiary sector (shops, educational centres, offices etc.). Figure 2 shows the type of use of buildings in Bilbao. Most of them are buildings with multiple ownership, which in some cases hinders the refurbishment and energy efficiency actuations at building level, since a consensus of the community of owners is required.

There is also a considerable number of municipal housing buildings for residential use.

FIGURE 2 BUILDING STOCK PER USE OF BUILDING

At present, natural gas is by a wide margin the main source of heating and cooling. Gas infrastructures are deployed all over the city. Bilbao has no district heating system yet. A low temperature district heating and cooling pilot is being developed on the city island of Zorrozaurre, as part of the area´s urban development from brownfield to a new city centre.

In this Heating and Cooling plan, the different approaches to replace gas supply in existing urban developed districts of Bilbao is evaluated.

According to 2018 data, a total of 807 GWh amount of heating consumption was reported for the total building stock in Bilbao (543 GWh for space heating and 264 GWh for domestic hot water). About 70% of this consumption is supplied by natural gas .Cooling has a very low impact on the city, with 136 GWh stated as mainly consumed in tertiary buildings.
With regard to the residential sector, a total final consumption heat demand is stated at 260 GWh for space heating and 185 GWh for domestic hot water, which results in a total final consumption of 445 GWh/a. The distribution of different equipment and types of heating in the residential sector is depicted in Figure 3. It shows a very low penetration of individual heat pumps (below 1%), 15% considerable direct use of electricity (Joule) and more than 50% of individual gas boilers. Around 30% of the systems are centralised, an important data when considering centralised DH systems. The existence of old oil boilers has to be also taken into account.

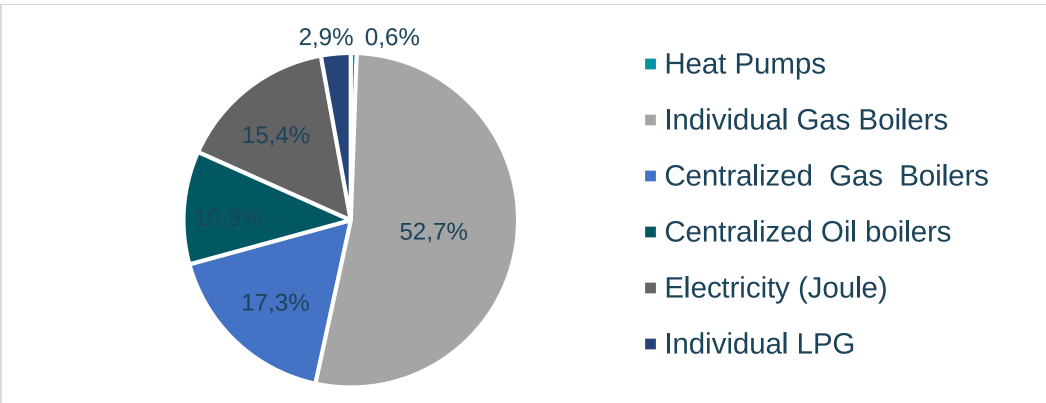


FIGURE 3 TYPE OF HEATING SYSTEMS IN RESIDENTIAL BUILDING (BY % OF HEATED AREA)

For the non-residential sector a similar analysis has been done. In this case, 282 GWh of consumption were reported for space heating and 79 GWh for domestic hot water. Figure 4 depicts the current breakdown of heating system types. Natural gas boilers are still the most common system. Remarkably, heat pumps, either individual or centralised, already make up 30%. Figure 5 shows the distribution of heating systems by building use in the non-residential sector.

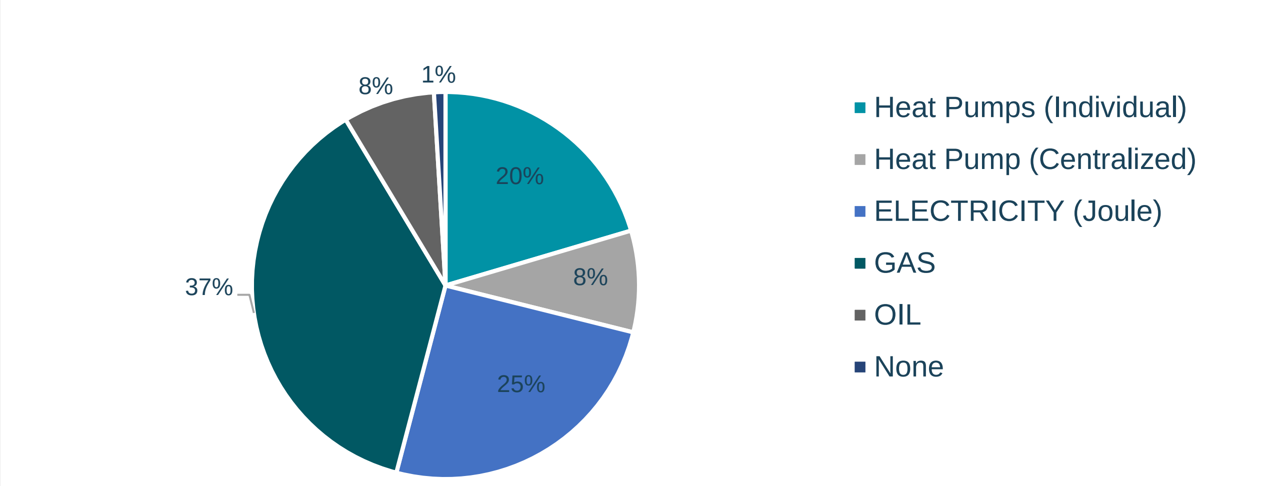


FIGURE 4 TYPE OF HEATING SYSTEMS (% OF ALL NON-RESIDENTIAL HEATED AREA)

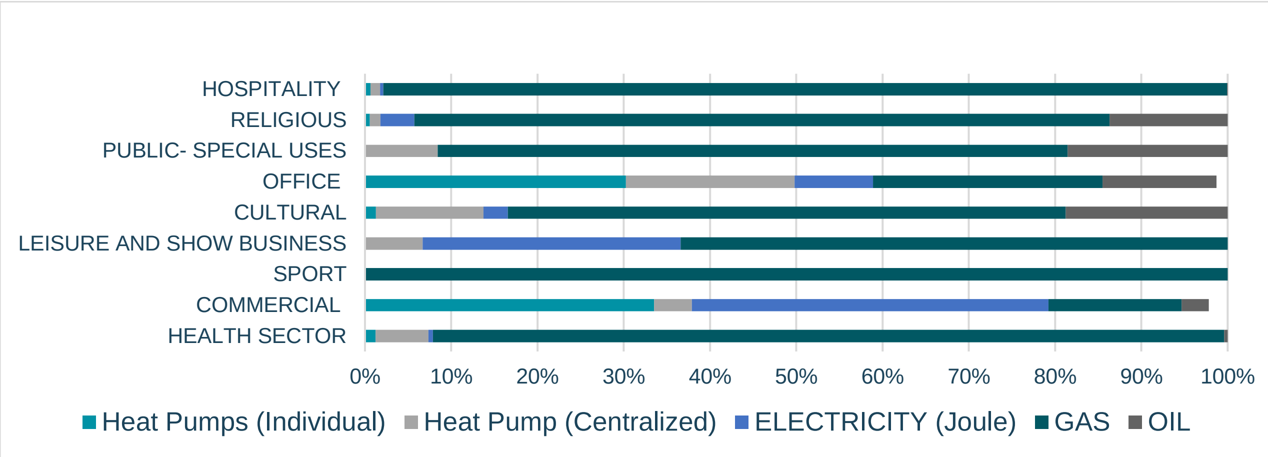


FIGURE 5 TYPE OF HEATING SYSTEMS IN NON-RESIDENTIAL BUILDINGS (% OF HEATED AREA)

An initially created outlook for heating and cooling for the year 2050 (task under WP2 in the course of Decarb City Pipes 2050) was based on the assumption that the current systems are to be transformed to be fully electric. In addition, some assumptions of heat savings were foreseen as well as the possibility to obtain reductions in final consumption demand through behavioural changes.

To achieve an electrification in the residential sector, individual combustion systems based on natural gas and on liquefied petroleum gas (LPG) are expected to be replaced with individual aerothermal heat pumps, water-to-water heat pumps connected to district networks, or direct electric heating systems based on the Joule effect. Centralised heat pumps are expected to substitute all current centralised gas and oil boilers, and would then supply both, heating and hot water. 75% of current individual domestic hot water (DHW) systems are expected to be replaced with individual heat pumps. 25% in turn are expected to be replaced with direct electric systems based on the Joule effect.

Process

In the process of developing the H/C Plan in the city of Bilbao, the technical part of the Local Working Group (LWG) was mainly involved. This consists primarily of technicians from the Sustainability Commission as well as from municipal departments, regional institutions, utilities, etc.

The H/C Plan forms a fundamental component of an existing process for generating Bilbao´s Vision. Energy is seen as an essential driver in the next years, which is why a set of strategies and objectives are needed. The first step was to develop a Vision for the city for 2050, but this raised some uncertainties in setting specific goals for this long period of time. This preliminary 2050 Vision helped in examining required actions till 2030, and will also feed into the Sustainable Energy and Climate Action Plan (SECAP), which the City of Bilbao is currently working on. During this process, meetings as well as workshops have been arranged with technicians from different areas of the City Council and representatives of local and regional companies and institutions.

In a first step, a SWOT analysis of the city has been done to get a full overview of the current situation of the city. This first step was important to inform about the starting point for potential future strategies. This also facilitated and set up a dynamic working process between local agents involved in the energy transition and the decarbonization of Bilbao. A "diagnosis" workshop was organised in six working groups: Governance and society, energy, mobility, adaptation to climate change, built environment and digitization. Each group gathered local expertise in diverse sectors and promoted their involvement in the diagnosis and co-development of the vision for Bilbao.

Taking into account considerations and conclusions from that first event, subsequent meetings were arranged as part of the existing City Vision roadmap. In these meetings, a preliminary Vision 2050 as well as strategies that will be used as an input for the upcoming SECAP of the city for 2030 were discussed.

The H/C Plan forms an important aspect within this City Vision. The Decarb City Pipes 2050 project has enabled the preparation of a detailed analysis, including a geospatial evaluation of the building stock. As part of the HC Plan, Bilbao is undertaking an analysis of local energy scenarios and possibilities for implementing spatial solutions at a disaggregated scale. The evaluation of all the data mapping (heating equipment, district heating demand, use of buildings etc.) which is described in more detail in the **Analysing Data Section,** has led to the identification of areas most suitable for the application of district heating and, in turn, for individual solutions.

This mapping also includes an analysis of potential sources for heat exchanges (on terrain, the river etc.), to determine areas for installing heat pumps or to connect to district heating. Furthermore, the ownership strucutres of buildings (municipal or private), areas that are to be rehabilitated in the next years, as well as the level of protection of buildings have been analysed. This compilation of information is relevant for the identification of areas that are particularly suitable for specific solutions.

Framework and principles

Main principle of Bilbao's decarbonisation strategy is to phase out direct use of fossil fuel in its building stock by 2050. This entails that the use of natural gas for heating will need to be completely displaced by 2050. Complementary decarbonisation measures include increased refurbishment of building with high energy efficiency requirements: 50% of the building stock is expected to be nearly-zero by 2050, thereby reducing energy supply needs. In this first heating and cooling plan, electrification is considered as being the most suitable option for both, individual and centralised heating and cooling systems. The heating and cooling strategies proposed are based on the installation of heat pumps based on air, water, and geothermal. One of the biggest opportunities is seen in the possibility of using hydrothermal or geothermal heat sources for heat pumps and thus achieving a high coefficient of performance (COP). The foreseen scenario considers several renewable energy sources combinations to supply heat pumps, particularly photovoltaic energy. The potential additional benefits of heat pumps to improve energy flexibility of the city's energy system were also considered.

The following barriers have been considered for the implementation of the electrification scenario: Heat pump technology, while already very mature, it is still rather unknown to the public. Even though Life Cycle Costs or Total Cost of Ownership of the systems paint a better picture for heat pumps than for gas or oil boilers, the high initial investment is often seen a main barrier for heat pumps. In apartment buildings, agreement must be reached among building owners if a central building solution is to be installed, which can also be a difficult task. Moreover, the large space required for the equipment and storage and its potential visual and acoustic impact are some of the challenges the development team will have to cope with. On the other hand, there is a perceived uncertainty about operating costs and the factors that may affect them (actual seasonal COP, changes of electricity price etc.). In general, heat pump technology is still a rather new concept for most citizens. Municipal regulations (i.e. General Urban Development Plan, Special Rehabilitation Plan, or restrictions on outdoors units) are also additional factors which influence the implementation of the electrification scenario.

Bilbao currently analyses the potential for leap-frogging from natural gas by changing current oil boilers to heat pumps. Recent urban experiments have confirmed some of the above-mentioned barriers for implementing heat pumps at building or apartment level. Since district heating systems do not face the same barriers as heat pumps, they also need to be examined in more detail. This solution could fit the city's energy supply requirements, particularly in some areas such as the old town or Zorrozaurre island. There, the river can be used as a means for heat exchange to efficiently operate heat pumps.
In the case of a district heating solution, the heat distribution system and the required temperature at which the system should operate are issues that need to be investigated in more detail. For the city of Bilbao, the use of H_2 or biogas for heating and cooling of buildings is unlikely.

Another principle that Bilbao is basing its studies on is the goal of creating a local network of renewable energy generation in a large part of its building stock. Shared self-consumption, the creation of local energy communities, a flexible system and an efficient energy demand management strategy will be the pillars for Bilbao's decarbonisation by 2050.

Analyses data and aggregation

Building stock energy model

The building stock energy model of the city of Bilbao has been developed by using the Enerkad® tool. The model can be used to test different scenarios for urban energy transition. For this H/C plan, the model has been used to assess the viability of district heating systems and other systems that can decarbonise the heating and cooling supply in Bilbao.

This model uses basic information from the cadastre as input data, from which building characteristics and heating and cooling schemes are inferred. The Enerkad tool calculates the hourly energy demand for each of the end uses of the building: heating, cooling, DHW, lighting and equipment. Using data from energy certificates regarding the installation type and fuel (see Appendix), fuel consumption and its associated costs and emissions can also be calculated.

The building stock model has been adjusted using real data regarding total energy consumption of the city, provided by the energy distribution companies. This is a crucial step in order to quantify energy consumption correctly and not to overestimate the reduction potential of the interventions planned.

The results are obtained in different formats, including several GIS-based ones, which allow for easy visualisation and linkage of results with other geo-referenced information.

The main GIS layers extracted from the building stock energy model are as follows:

1. **Configuration of heating distribution within the buildings.**
   Buildings with central heating systems, for example with a boiler room in a residential building (from which heating and domestic hot water is distributed to individual apartments), are easier and cheaper to connect to district heating networks.

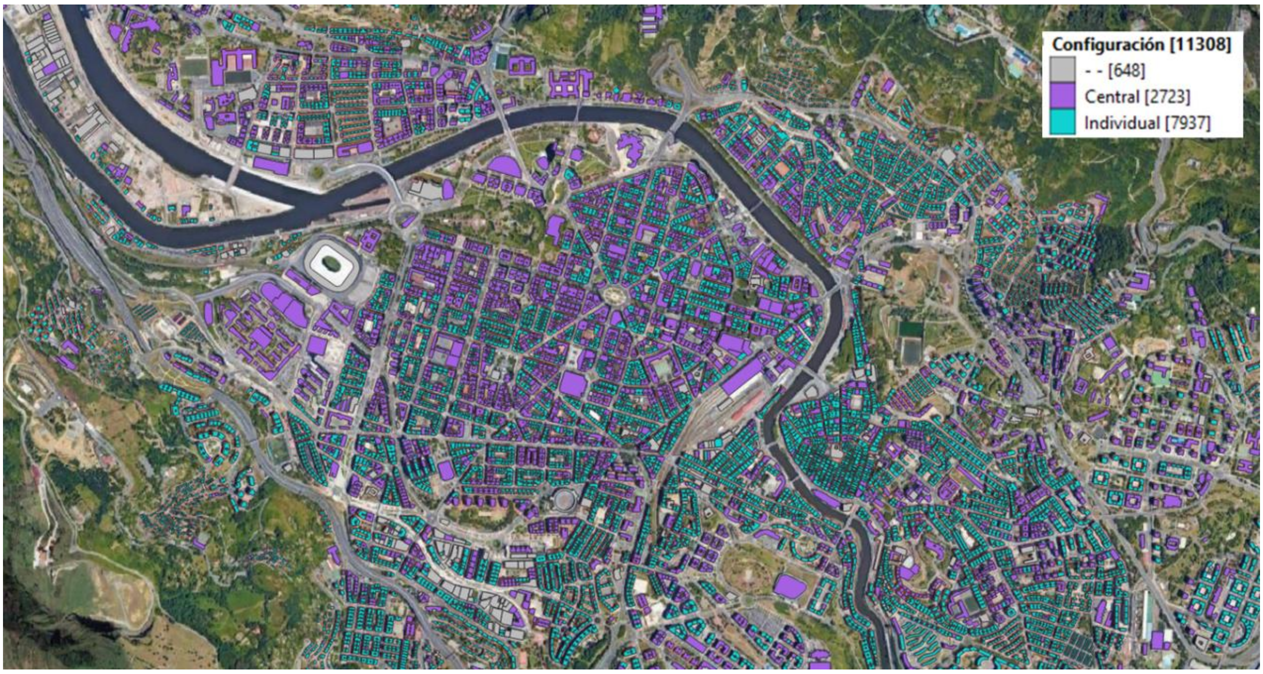


FIGURE 6 CONFIGURATION OF HEATING DISTRIBUTION

2. **Energy source**
   Buildings with polluting (and more expensive) energy sources (e. g. Oil, LPG, Joule Effect electric heating) will show large environmental and economic benefits when being transformed.

FIGURE 7 ENERGY SOURCE

3. **Heating and cooling demand per square meter (usable floor area)**
   Buildings with high heating demand are more likely to require a refurbishment or a transformation to a more efficient system, not least to reduce energy bills.

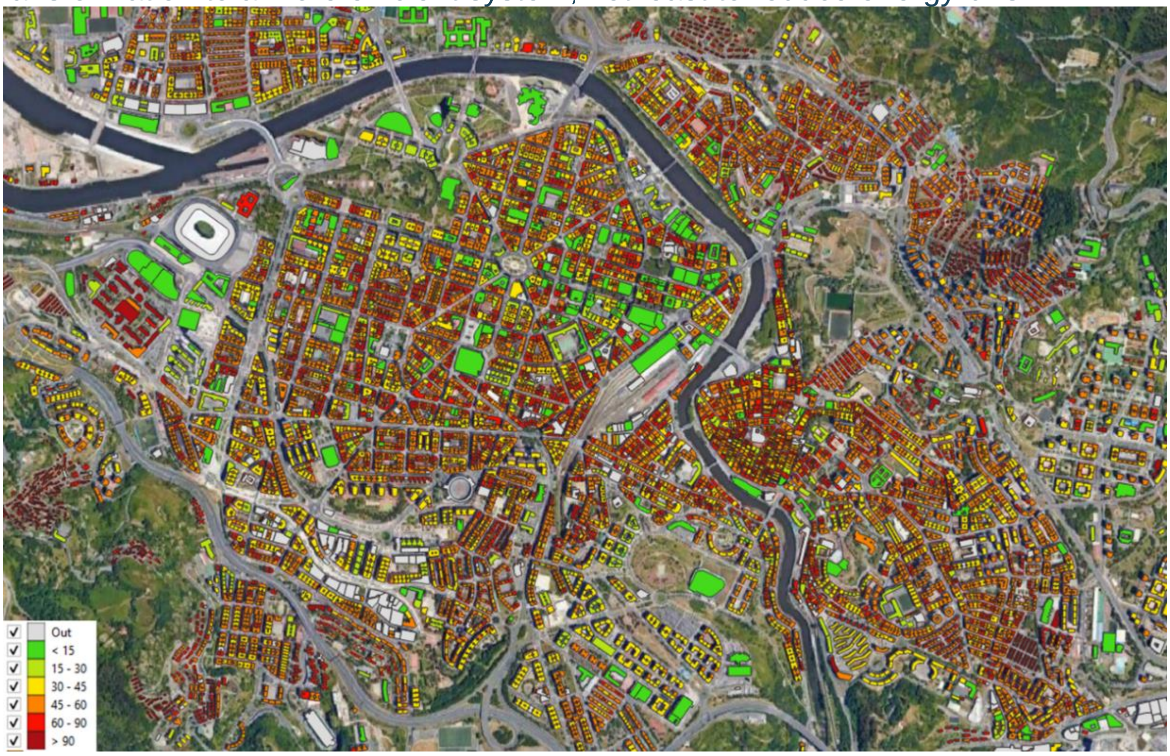


FIGURE 8 HEATING DEMAND [KWH/M^2] FOR THE CITY OF BILBAO

4. **Heat Density**

Heat density is the total thermal energy demand of the building per m^2 of building floor area, calculated using the results of the energy model. Areas with high heat density strongly support the economic viability of a district heating network. This value can be converted to the MWh/hectare indicator, which is commonly used for the viability assessment of DH systems.

FIGURE 9 HEATING DENSITY [MJ/M2]

5. **Heating/cooling density ratio**

Means the ratio between heating and cooling density, which supports a highly efficient use of heat pumps.

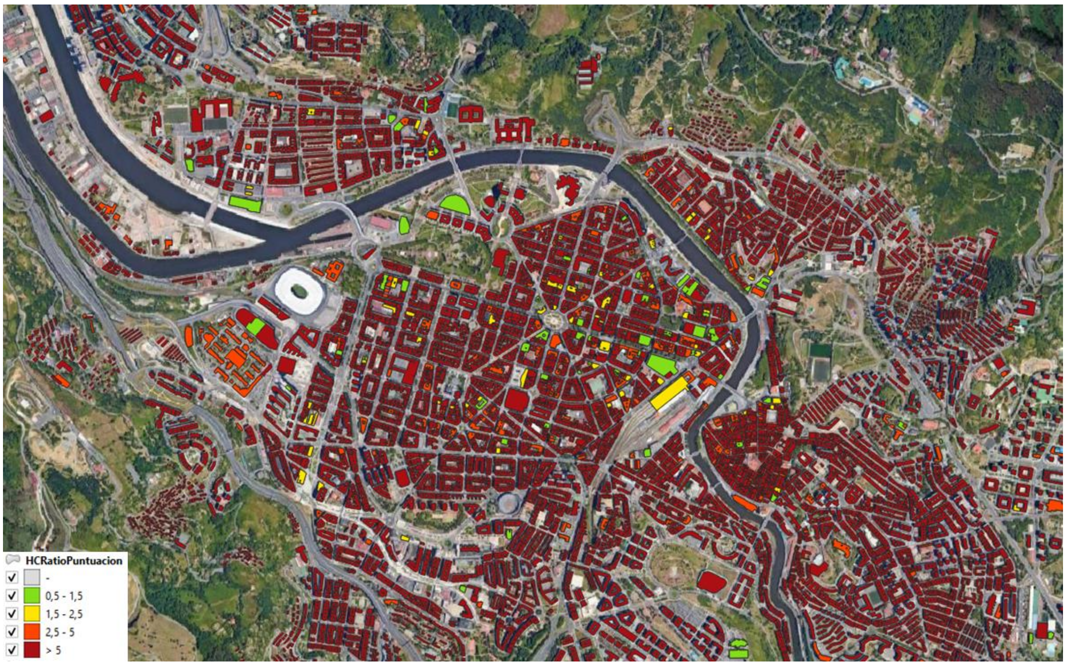


FIGURE 10 HEATING/COOLING RATIO

Aggregation of additional information layers

The following additional geo-referenced layers were identified as highly relevant to the analysis of heating and cooling characteristics of the building stock.

1. **Potential heating/cooling energy sources:** Refers to the proximity to available heating or cooling sources for heat exchange heat with a district heating network. Availability of waste heat, geothermal or hydrothermal sources can improve the economic viability of district heating or cooling networks.
2. **Available public space**: Availability of public space for the construction of necessary infrastructure.

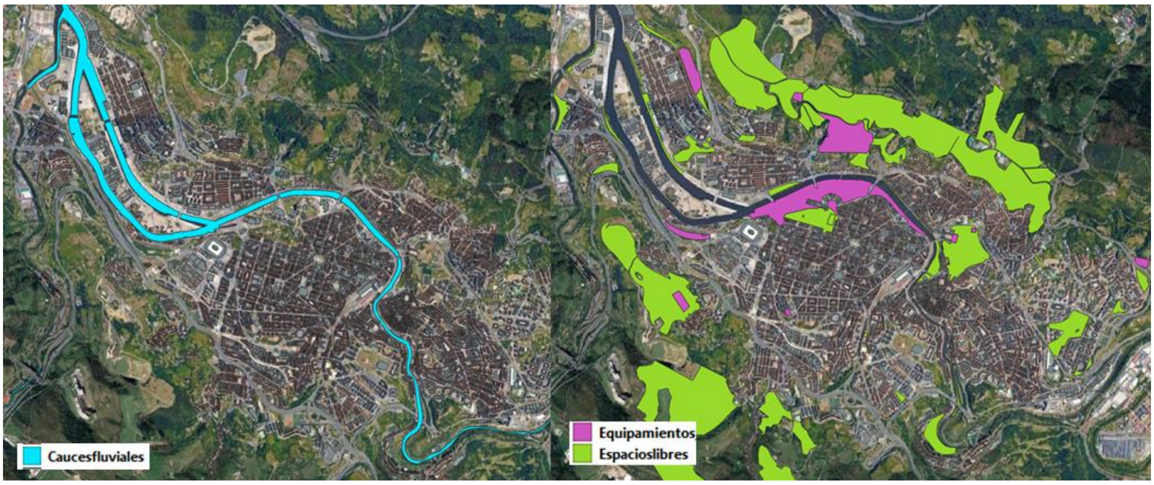


FIGURE 11 POTENTIAL ENERGY SOURCES AND AVAILABLE PUBLIC SPACE IN BILBAO

3. **Protected buildings**: Historic buildings or protected parts of the envelope that do not allow retrofitting or rooftop installation of elements such as photovoltaic panels or external units for heat pumps.

FIGURE 12 PROTECTED BUILDINGS IN BILBAO

4. **Public buildings**: Buildings owned by public bodies such as the municipality or the Basque government. These are buildings which have a specific requirement for

decarbonization under the Basque Energy Sustainability Law 4/2019, and for which the implementation of low carbon strategies has become a priority.

FIGURE 13 PUBLIC BUILDINGS IN BILBAO

5. **City plans (future and incorporated):** Plans for urban developments or renewal currently included in urban planning or defined future plans.

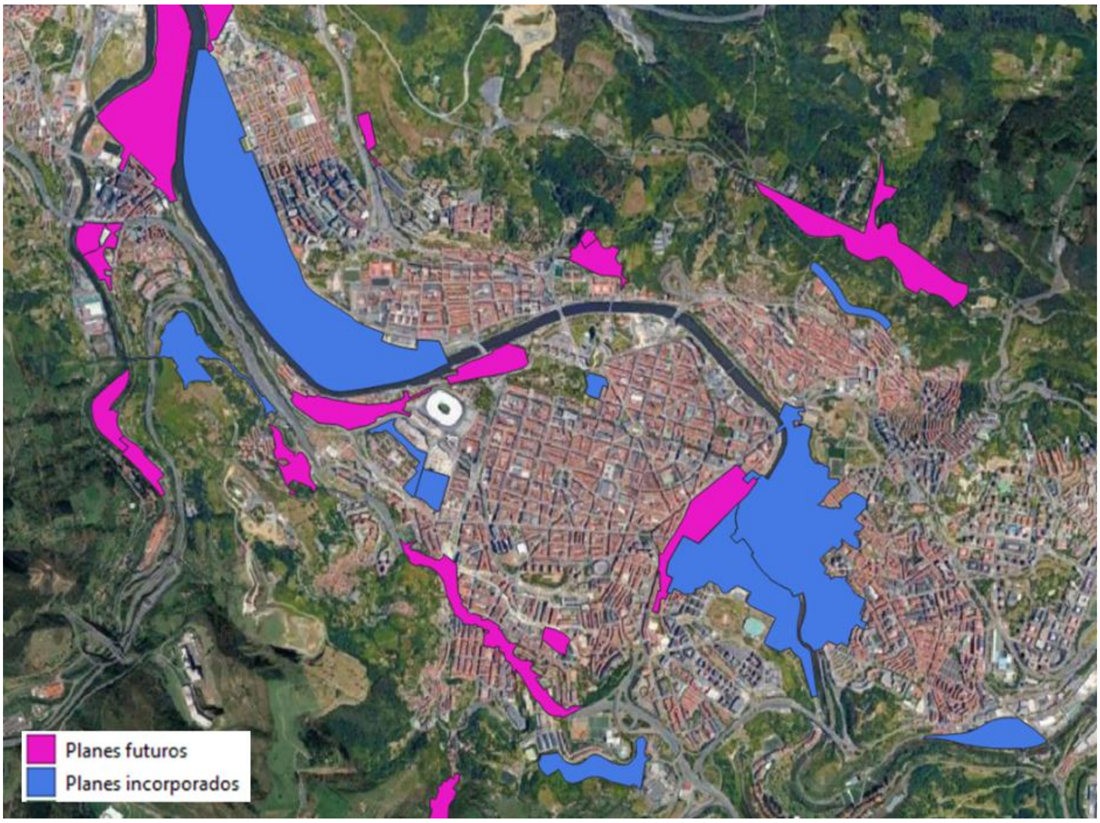


FIGURE 14 MUNICIPAL PLANS IN BILBAO

6. **Spatial delimitation of degraded areas**: These areas have access to subsidies for implementing energy efficiency and refurbishment strategies. Therefore, it is more likely that holistic renovation projects will be developed.

FIGURE 15 DEGRADED AREAS IN BILBAO

H/C planning

All identified sources of information and the building stock energy model are used to assess the feasibility of the proposed decarbonization strategies and thus define the H/C plan.

The strategies for decarbonizing the building stock, evaluated in accordance with the H/C Outlook developed by the City, consist of:

- Strategy 1 - Deep renovation of building blocks
- Strategy 2 - Individual heat pumps
- Strategy 3 - District heating and cooling networks

To get an overview of which areas have the most favourable conditions for implementing decarbonisation strategies, a weighted aggregation of the georeferenced datasets was performed (Figure 16). For this purpose, each of the categories of each layer is scored from 1 to 10, with 10 being the most favourable score for the implementation of a specific strategy. The scores may vary from one strategy to another depending on its characteristics.

A weighted overlay is performed using a GIS tool, in which the layers are weighted differently depending on how relevant they are for the proposed strategy. As a result, a final layer is obtained with the corresponding score in each pixel, with 10 being the maximum score and 1 the minimum. This final layer forms the basis for potential zoning and more detailed evaluation of the strategies in selected districts.

In addition to the raster layers, the ArcGIS Hot Spot analysis tool was used to facilitate visualisation and understanding of the results. This tool identifies statistically significant spatial clusters of hot spots and cold spots.

The +/-3 values obtained reflect statistical significance at a 99% confidence level; the +/-2 values reflect statistical significance at the 95% confidence level; +/-1 values reflect statistical significance at the 90% confidence level; the value 0 is not statistically significant.

This data, along with the generated grid, is displayed in a point layer with information for each of the buildings in the chapter “Strategy analysis”.

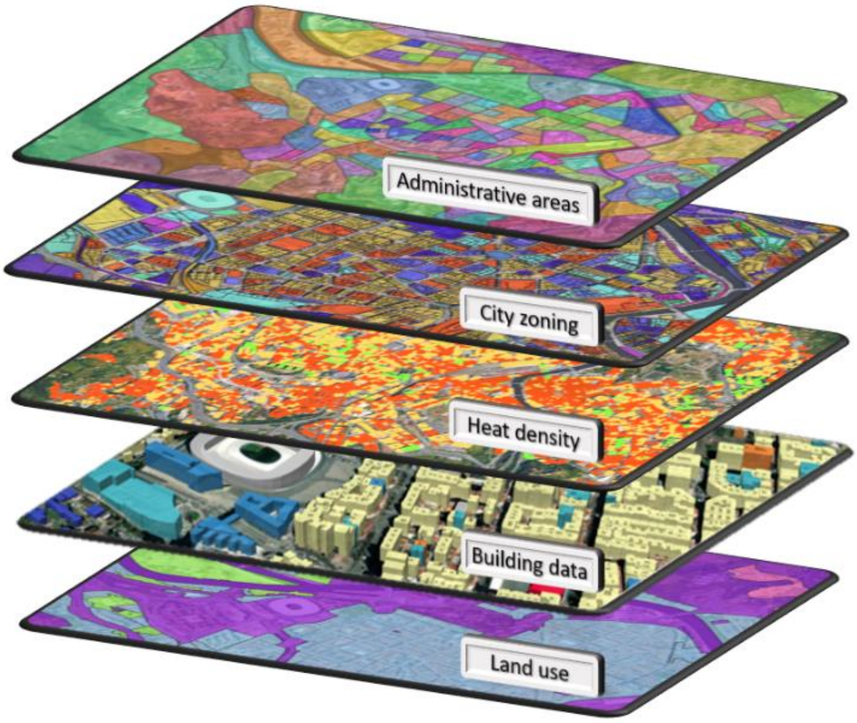


FIGURE 16 LAYER OVERLAY METHODOLOGY EXAMPLE

Layer prioritization

The AHP (analytic hierarchy process) methodology, a structured technique for dealing with complex multi-criteria decisions, was used to objectively assign weights to the layers .

This method provides numerical values or priorities from subjective assessments by making a series of judgements based on pairwise comparisons of elements. This is particularly useful for decisions involving human perceptions and judgements, or for cases where a large number of parameters need to be compared or prioritised.
The advantage of the AHP lies in the inclusion of qualitative aspects that are often not included in the analysis due to the complexity to be measured, but may be relevant in some cases. The result of the AHP is a ranking or prioritisation of the alternatives that show the overall preference for each of them.

Based on the nature of the layers used in the analysis, these were divided into four categories or dimensions. A pairwise comparison was then done on two levels: first by comparing the categories and then the layers included in each of them.

TABLE 11 GROUPING OF LAYERS BY DIMENSIONS

DIMENSIONS	LAYERS
Resources - heat exchange potential and available space	Distance to green areas and available spaces
	Distance to water bodies
Building characteristics	Protected buildings
	Public buildings
	Fuel for heating purposes
	Configuration of building energy systems
Urban planning	Degraded areas
	Current and future urban development plans - PGOU
Energy use	Heating demand (kWh/m^2)
	Heating density
	Heating/cooling ratio

In this way, a weighting is obtained for each of the dimensions and a relative importance for each layer, and finally the final weighting of each layer. This process is performed independently for each strategy, since the relative importance of the dimensions and layers varies depending on the strategy to be applied. After a pairwise comparison, the relative weight of each layer in the three strategies is obtained.

A workshop with personnel from different departments at Bilbao City Council was held to perform the AHP, and to obtain weighting results for the different layers considered in the analysis. The results are shown in Table 12.

TABLE 12 FINAL WEIGHT OF THE LAYERS FOR THE 3 PROPOSED STRATEGIES

Dimensions	Layers	Sc1	Sc2	Sc3
Resources	Distance to green areas and available spaces	1,8%	1,7%	25,5%
	Distance to water bodies	1,8%	1,7%	25,5%
Building characteristics	Protected buildings	27,3%	25,2%	1,7%
	Public buildings	24,4%	23,0%	1,7%
	Fuel for heating purposes	6,8%	3,6%	0,6%
	BES configuration	3,8%	6,3%	4,6%
Urban planning	Degraded areas	12,9%	6,0%	3,1%
	Current and future urban development plans -	3,2%	18,1%	28,2%
Energy use	Heating demand (kWh/m^2)	13,0%	9,1%	1,0%
	Heating density	3,9%	3,7%	7,2%
	Heating/cooling ratio	1,1%	1,5%	0,9%

Depending on the type of decarbonization strategy considered, some of the layers do not apply or are of minor importance.

The results of strategies 1 and 2 are very similar in terms of the weights assigned to each layer, since the urban planning dimensions and characteristics of the building have been prioritised in both cases. Both strategies are strongly conditioned by the protection of the buildings. This forms a harsh constraint for making modifications to the exterior of the building, either for refurbishment or aerothermal systems that affect the façade or the roof. Of the 11,308 buildings included in the Bilbao model, 4,426 have some form of protection, representing almost 40% of the total building stock. These buildings are mostly located in the city centre; Casco Viejo, Abando, Indautxu or San Ignacio. The rest is scattered throughout all other areas of the city.

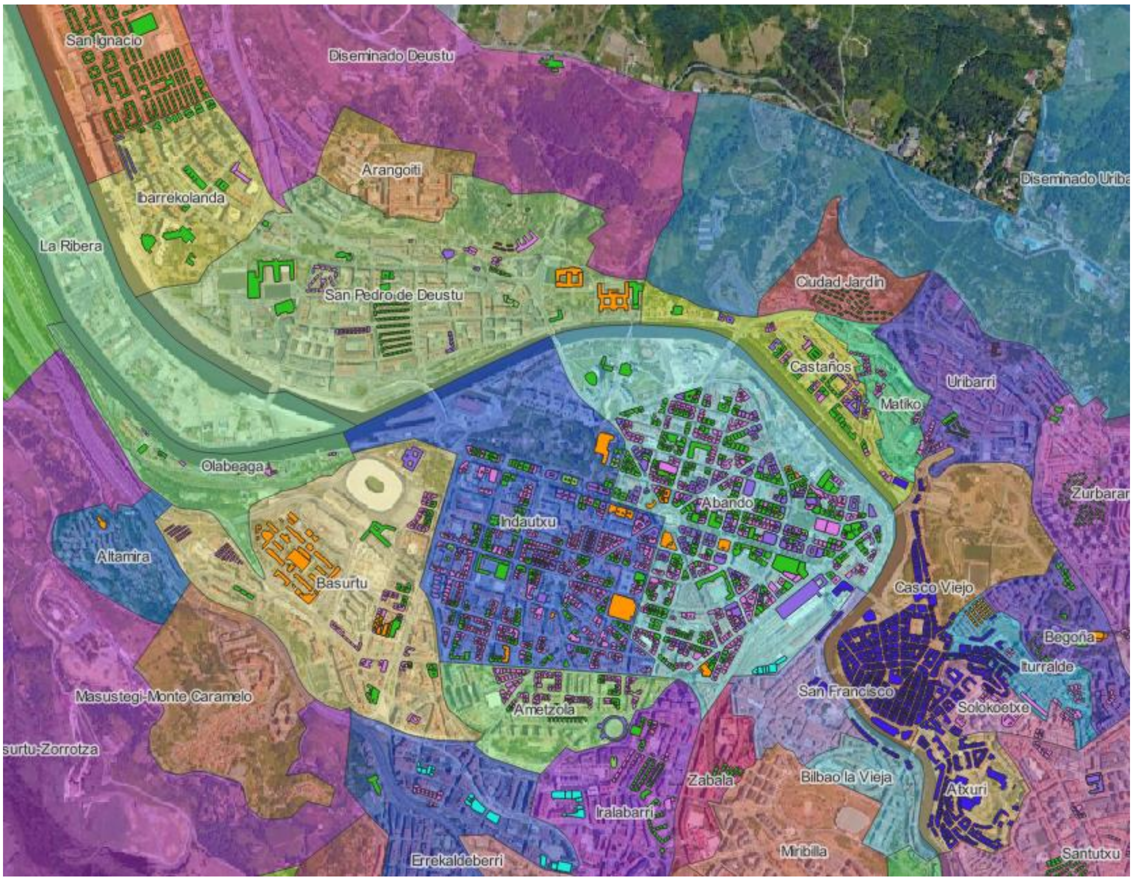


FIGURE 17 LOCATION OF PROTECTED BUILDINGS IN THE CITY'S NEIGHBOURHOODS

In the case of the strategy focused on refurbishment, more weight has been given to degraded areas, since they have greater access to subsidies or financial incentives for the implementation of this type of intervention. Taking into account more technical aspects, a moderate weight has been put in relation to thermal energy demand, since retrofitting buildings with low energy performance can have a major impact on whether or not the city's 2050 decarbonisation targets are met.

For implementing aerothermal systems on the other hand, more weight has been put on urban plans, since implementing such systems is much simpler in new construction areas or in areas with already planned interventions. These new areas also have the advantage of not being part of the historical heritage, which, as mentioned above, is one of the major limitations of interventions that change the aesthetics of the façade and/or the roof.

For the strategy based on the implementation of district networks, greater weight is given to the availability of resources or adequate space for the construction of infrastructure required. The most important aspect in this case concerns the urban development plans, especially future ones, which would enable the inclusion of these systems already in the project phase, facilitating their implementation at a lower cost.

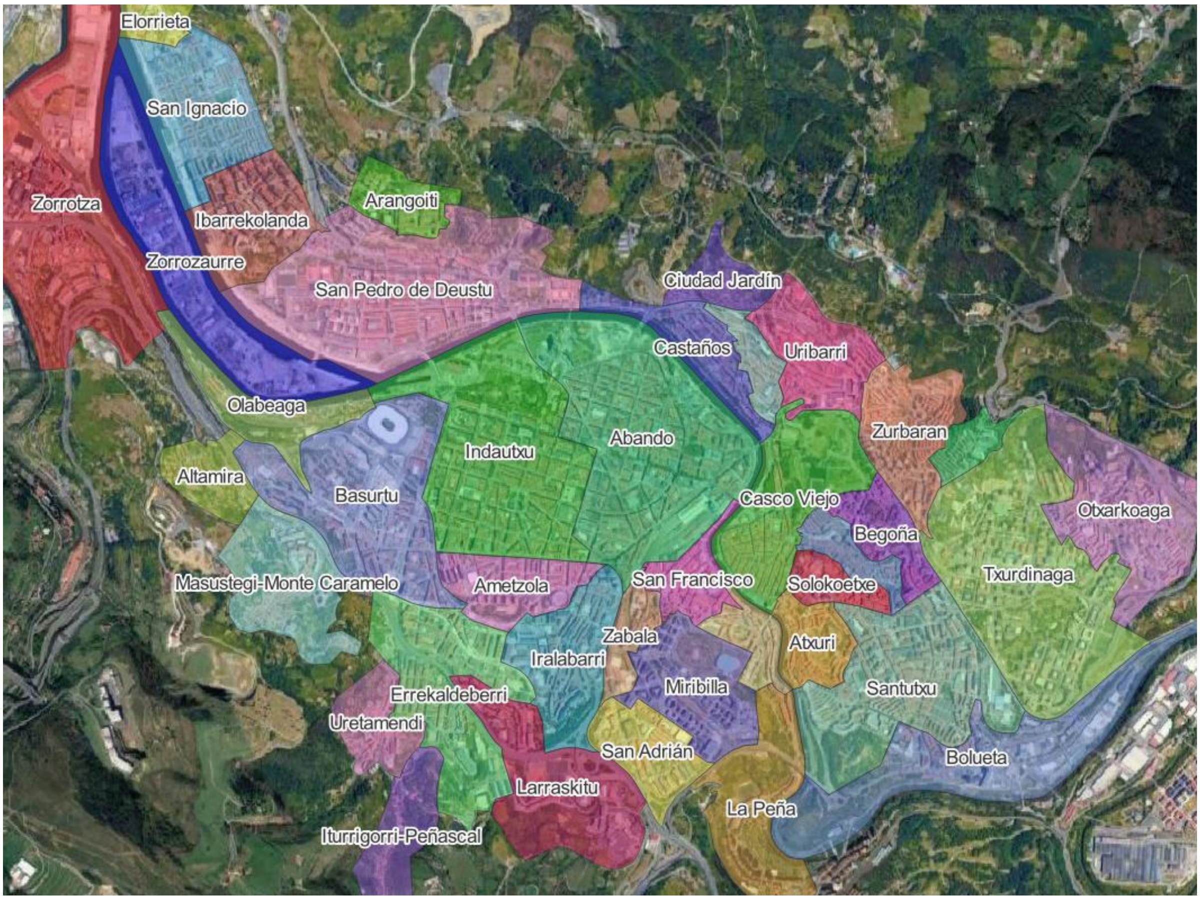


FIGURE 18 ZONING OF BILBAO BY NEIGHBOURHOODS

Strategy analysis

In this section the results are shown using two types of maps. Firstly, for each of the strategies, a raster layer is shown with a score for each of the buildings. This score is obtained by applying the scores shown in Table 2. These scores range from 1 to 10, with 1 being the minimum score and 10 the maximum.

A low score indicates an impossibility or great difficulty of implementation, a high score, in turn, indicates a great potential or an easy implementation of the selected strategies in each case.

Secondly, an analysis of hotspots is depicted. The ArcGIS Hot Spot analysis shows statistically significant spatial clusters of hot spots (high values) and cold spots (low values) taking into account a distance band or threshold distance.The +/-3 values obtained reflect statistical significance at the 99% confidence level; the +/-2 values reflect statistical significance at the 95% confidence level; the +/-1 values reflect statistical significance at the 90% confidence level; the value 0 is not statistically significant.

Strategy 1: Deep renovation of building blocks

There is no area with a high refurbishment potential. Due to the great weight of building characteristics, especially in relation to the level of protection, large areas have a very low score. As noted above, nearly 40% of the buildings in the city are currently protected.

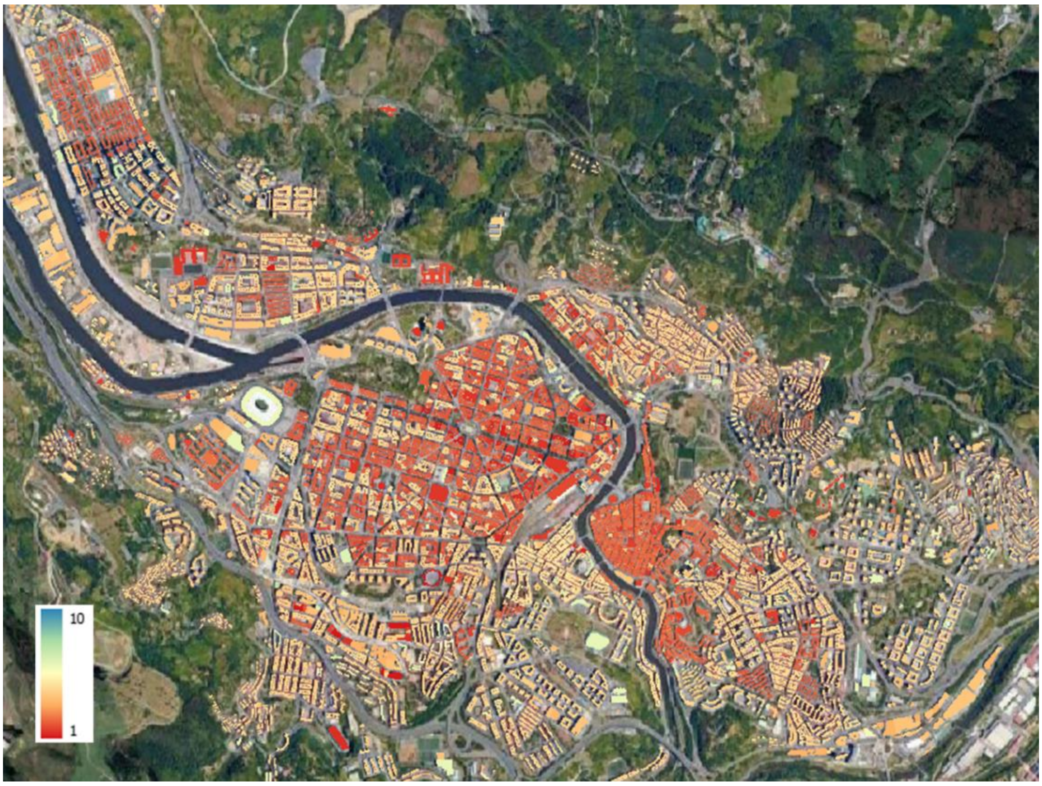


FIGURE 19 BUILDING SCORE RASTER FOR STRATEGY 1

In the image of the hotspot analysis, large areas are shown in red. Even though areas are grouped with higher scores, this does not necessarily mean that they are favorable for retrofit. As can be seen in Figure 19, 97% of the buildings scored less than 5 for this strategy.

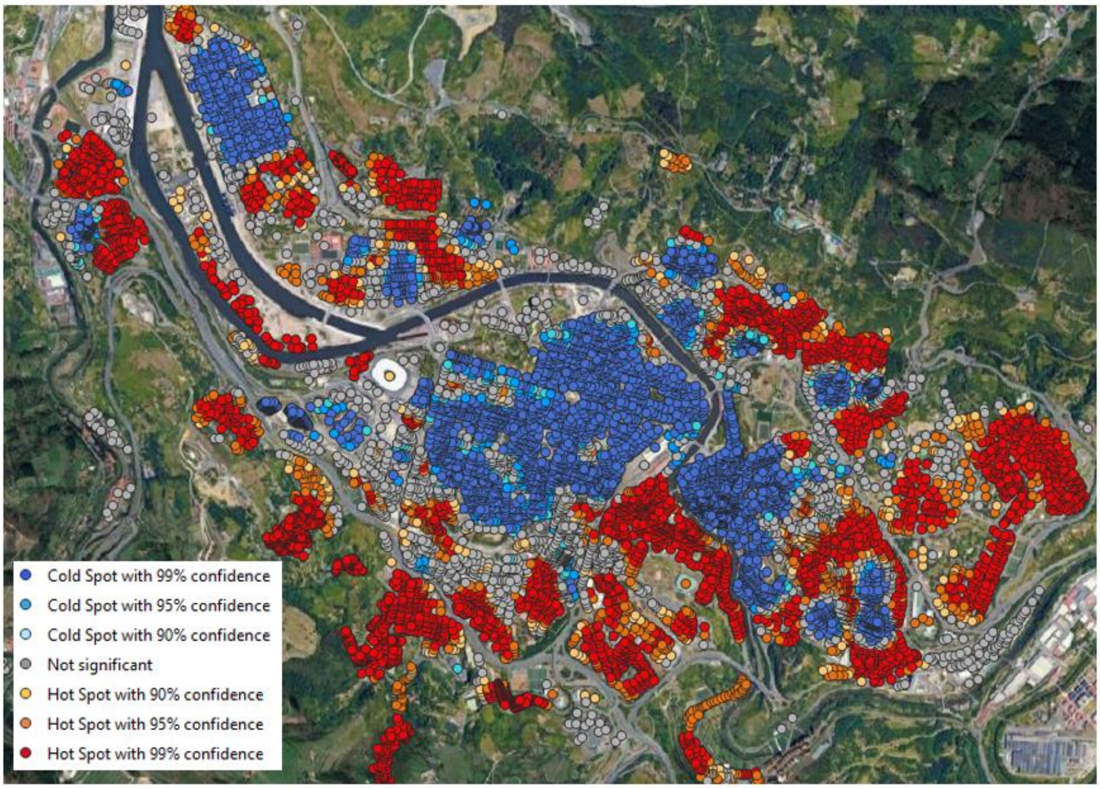


FIGURE 20 HOTSPOT ANALYSIS FOR STRATEGY 1

Strategy 2: Individual heat pumps

Although there are no areas with a particularly high score for the use of aerothermal systems two areas particularly stand out: Zorrozaurre, since it is a newly developed area that is not part of the protected historical heritage, and the area that includes the neighbourhoods of San Francisco and Bilbao la Vieja, since it is located in an area with development plans and without any type of protection.

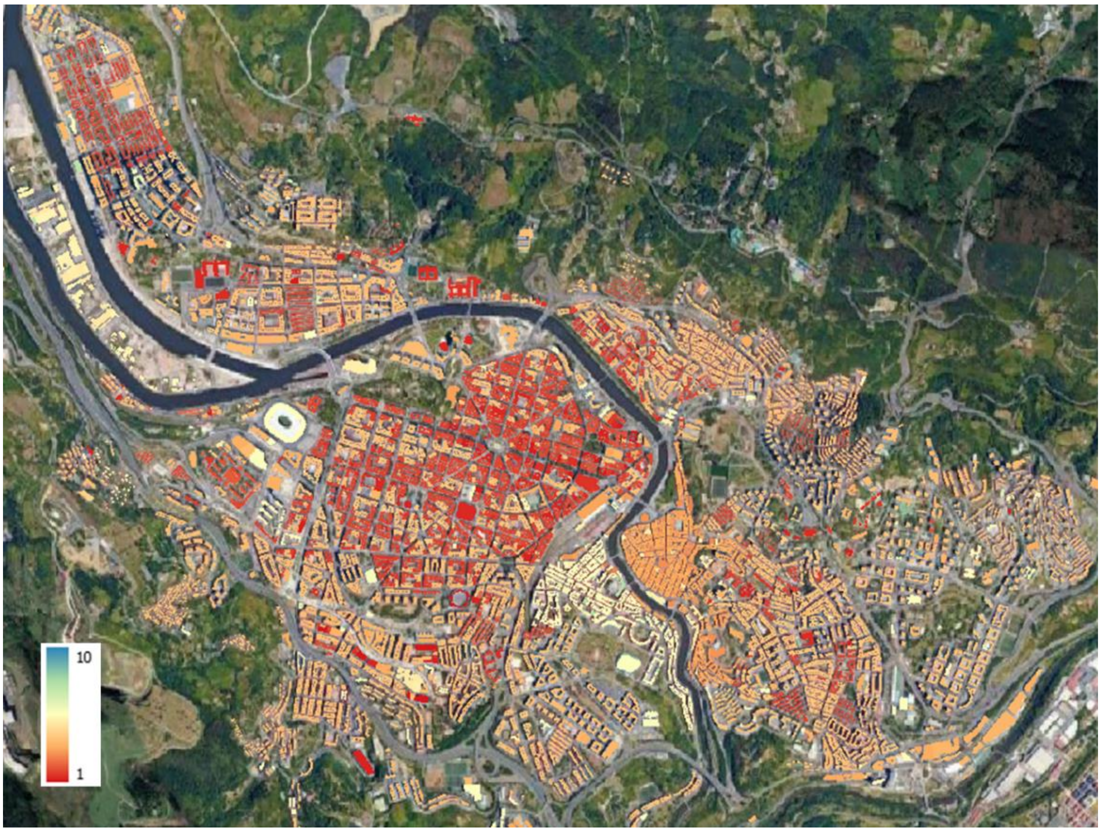


FIGURE 21 BUILDING SCORE RASTER FOR STRATEGY 2

A detailed analysis of the hotspot maps, shows that other smaller areas, such as Peñascal and Altamira, also have clusters of buildings with above-average scores.

FIGURE 22 ZOOM IN PEÑASCAL AND ALTAMIRA NEIGHBOURHOODS

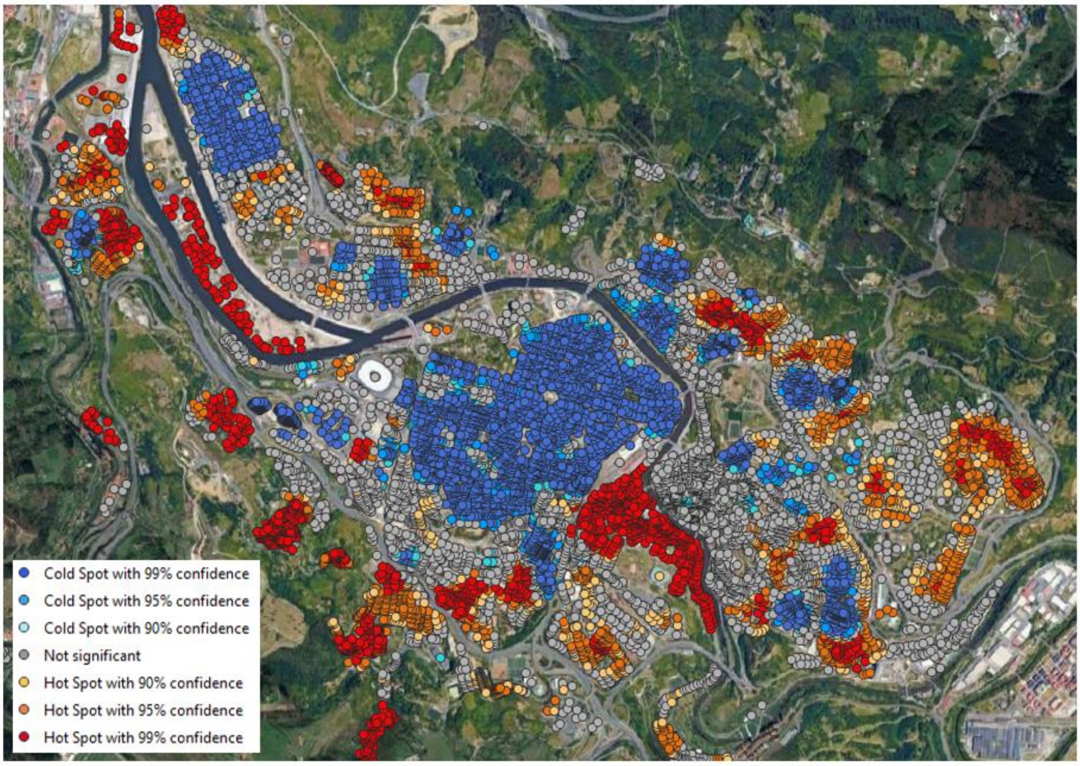


FIGURE 23 HOTSPOT ANALYSIS FOR STRATEGY 2

Strategy 3: District heating and cooling networks

Under this strategy, the protection of buildings was not considered a constraint, as connection to DH networks should be feasible in most cases. Greater importance was placed on the availability of the resource and the distance to it, as well as the space available to build infrastructure if necessary.

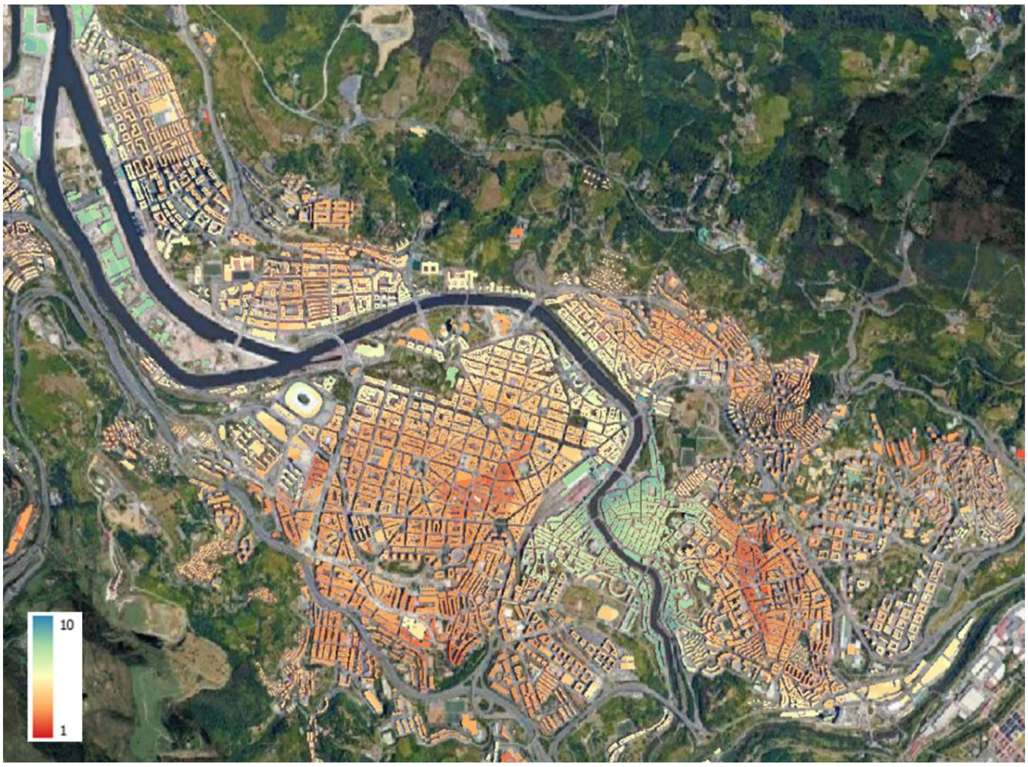


FIGURE 24 BUILDING SCORE RASTER FOR STRATEGY 3

In this third strategy, while all areas close to the river performed relatively well, there are some that stand out on the map: Casco Viejo, Bilbao la Vieja andSan Francisco, three neighbourhoods located in what are classified as Integral Rehabilitation Areas (ARIs). This is an area with very old buildings in which few, if any, improvements have been made in terms of thermal efficiency. Thus, their consumption is likely to be relatively high. In the case of the old town, the installation of a district heating network is an option that should be seriously considered, as the analysis classifies this area as favourable, while it is unfavourable for the other strategies, mainly due to its protected status.

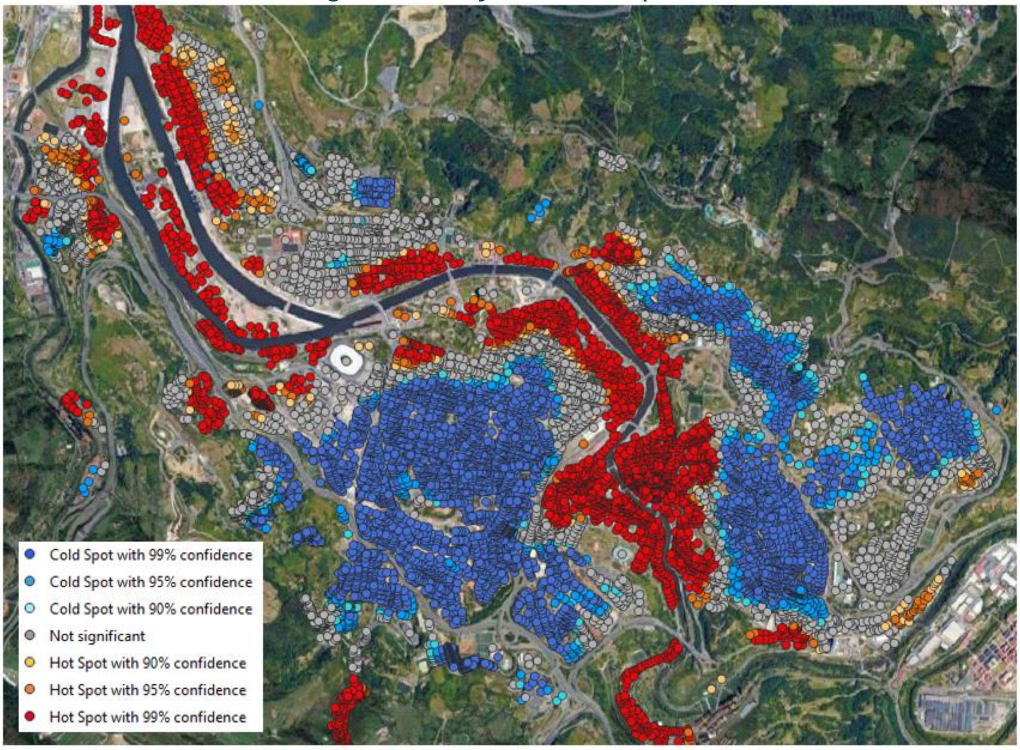


FIGURE 25 HOTSPOT ANALYSIS FOR STRATEGY 3

FIGURE 26 ZOOM ON CASCO VIEJO, BILBAO LA VIEJA AND SAN FRANCISCO

Zorrozaurre is an area currently under development in which a district network is already planned. Both, residential and tertiary buildings are expected to be connected to this network in the near future.

FIGURE 27 ZOOM IN ZORROZAURRE

Bolueta: this is also an area currently under development where three large residential buildings have been constructed and three more will be built in the coming years. Although the energy demand of the new buildings is relatively low, they are high rise. Thus, the energy density is likely to be sufficiently high for a district heating network. Since the buildings have centralized gas boilers, it would make their connection to a decarbonised heating network relatively easy. Furthermore, the area is close to the river and with enough open space, which in theory would be sufficient to install necessary infrastructure for district heating.

The fact that both Bolueta and Zorrozaurre are still areas under development for the coming years, makes it much easier to implement such systems. If these considerations are incorporated into urban development plans early on, costs may also be lower.

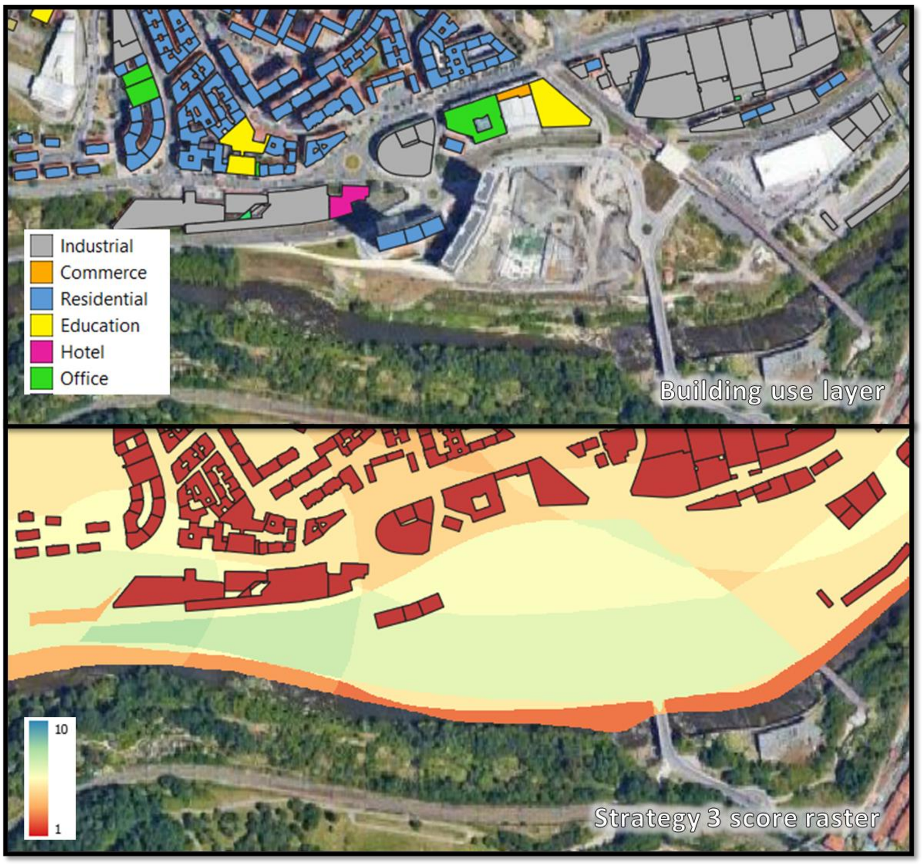


FIGURE 28 DETAIL OF THE AREA UNDER DEVELOPMENT IN BOLUETA (BUILDING LAYER AT THE TOP OF THE PICTURE AND ZOOM IN THE SCORE RASTER FOR STRATEGY 3 AT THE BOTTOM)

Summary/conclusions

When analysing energy transition scenarios in the building stock, technical criteria such as actual energy use, heat density or other technical characteristics are generally used as main factors influencing feasibility of interventions. However, for planning heating and cooling strategies within a city, the technical analysis needs to be complemented with other aspects that can be crucial for implementation, such as current legislation or urban planning limitations.

The analysis of three strategies for decarbonising Bilbao city's heating and cooling clearly show that urban planning limitations have a great weight on defining areas suitable for certain solutions.

The GIS and hotspots maps for each strategy, give an overview of areas in the city, which are more favourable for district heating or the installation of heat pumps. These results give as a first indication of their potential within the city, and serve as a basis for deciding on a future heating and cooling system composition, suitable to achieve the city´s climate and energy goals by 2050.

Appendix: Data used

Data for the building stock energy model

The minimum data required for the generation of the building model are publicly available and accessible, as they are data from the cadastre. Other information included in the model has been provided by the municipality, obtained both, from its own databases and by requesting it from other external organisations. Among these data sets, most important sources include the register of centralised boilers of the city and the energy certificate database provided by the regional basque government. These sources, however, do not provide 100% of the data on the energy systems of buildings, but roughly 80%. Despite being a very high percentage, this, nonetheless, generates some uncertainty.

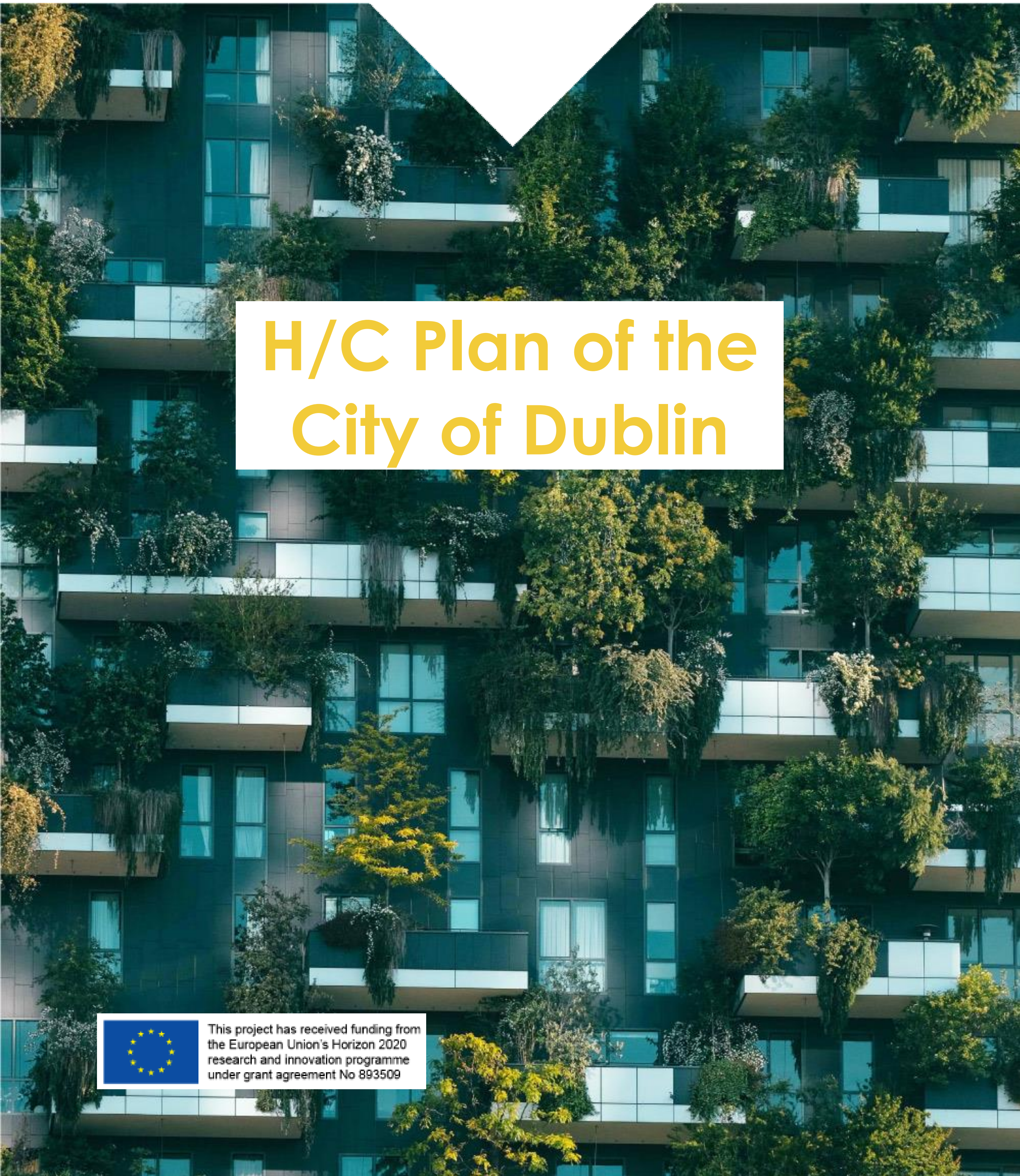
Furthermore, as far as the information obtained from energy certificates is concerned, in most cases a certificate is only available for a single dwelling, which then is extrapolated to the rest of the building. In some cases, this assumption can lead to misassignment of individual heating and cooling systems.

Other data used for the H/C plan

The rest of the information on the built environment, such as available space, new developments or protected areas, is complete and mostly publicly accessible.

It would have been good to have information available on the ownership of the buildings, apart from whether they are fully public or private buildings. Knowing whether buildings have a single owner or several owners can be a determining factor when carrying out the proposed interventions.

Overall, the quality of the data is good and for the most part publicly accessible. If it was not public, it was readily available upon request to the municipality.



H/C Plan of the City of Dublin

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 893509

H/C Plan of the City of Dublin

Introduction

Heating is a hugely important sector in Ireland when it comes to decarbonisation, as it represents approximately 40% of energy demand (twice the demand of electricity) and is the worst performing sector in terms of renewable proportion (currently at 6.3% of total heat production) behind both, electricity and transport.

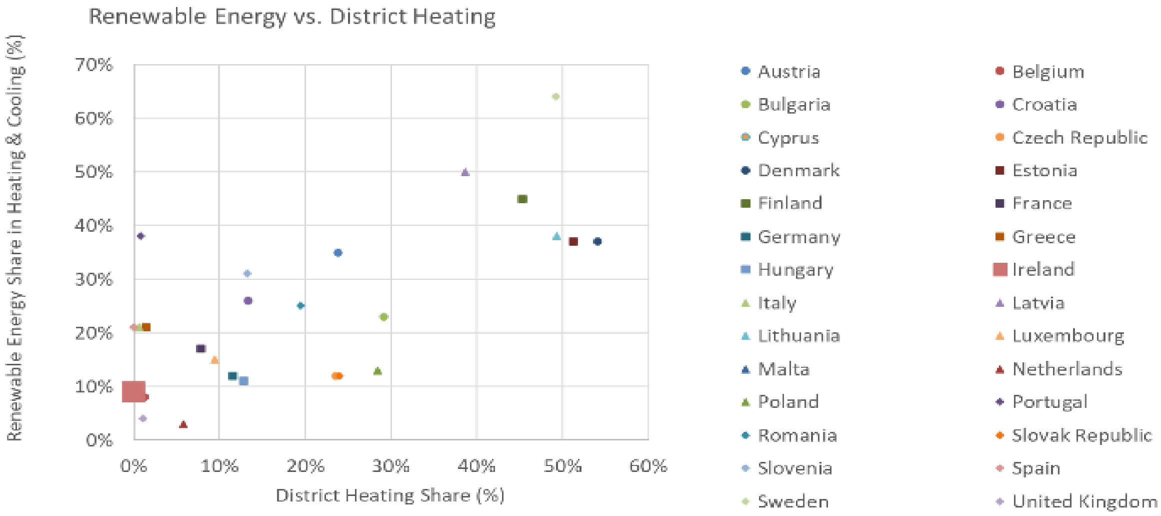


FIGURE 29: RENEWABLE ENERGY VS. DISTRICT HEATING

District heating networks potential to enable greater uptake of renewable and waste heat sources is shown in the figure above. In general, there is a strong correlation between DH and renewable heat proportions.

The majority of buildings in Dublin use gas fired heating. The gas grid covers practically the whole city, developed at national level by semi-state-owned companies without considering where DHC grids may be a better option.

The heating sector currently has a very low penetration of renewable energy. Ireland is the worst performing country in the EU with a renewable heat proportion of just 6.3%.Gas is still the dominant heat fuel followed by direct electric (not heat pumps).

District heating is new technology in Ireland, currently representing less than 1% of the heat market but with potential for this to be between 50% and 60% based on a 2019 study performed by the Heat Roadmap Europe researchers and results from SEAI's National Heat Study. The potential for DH has been recognised in the national Climate Action Plan 2021 where a target of 2.7 TWh

of heat is to be supplied via DH by 2030. This target represents 10% the all residential and commercial heating in the country.
To support this roll out of DH, the Climate Action Plan includes measures that the government will take, namely (to):

- Support through the Climate Action Fund.
- Establish a system of governance for the development of district heating policy.
- Perform research to support the rollout of district heating in Ireland.
- Develop a regulatory framework to protect customers & suppliers.
  Ensure a planning framework that encourages and facilitates the development of DH – zoning of areas for DH.
- Identify appropriate financing mechanism to support delivery of DH including financial incentives similar to retrofit grant programs.
- Update relevant regulatory & legislative tools to enable roll out of DH infrastructure.

There is an agreement today that more bottom-up effort is required, but municipalities have a very low level of autonomy trying to find paths through their limited remit to influence the use of energy and emissions in their regions.
Dublin has become a pioneer in Ireland for local level energy planning and DHC implementation, both of which are completely new practices in Ireland. Codema, as the energy agency for Dublin, has been building these skills and practices with the Dublin municipalities through numerous EU & national level projects. The municipality has now committed to developing a citywide DH scheme, outlined in the "Dublin City Climate Change Action Plan 2019-2024".

Importantly, Dublin intends to use its local working group to create effective leadership, policy and buy-in to the low-carbon heating/cooling transition needed to overcome barriers to the roll-out of other alternatives to gas grids.

The Dublin Local Working Group is made up of local, regional & national level stakeholders who are fundamental to a successful roll-out of low carbon grids in the city. This is a new group established specifically for this project.

Dublin has made significant progress in DH in the last few years. The first large-scale DH network in the county is currently being constructed and will be operational by July 2022. This DH network is the first not-for-profit public utility in the country and the first to use data centre waste heat as its heat source.

The development of a much larger DH network in the Poolbeg area of the city is also progressing. A preliminary business case report has been produced for this project as well as extensive engagement with customers and ESCo's, who may be responsible for the construction and operation of the proposed network. There has also been significant progress made in planning policy in the city to support DH with requirements for buildings to futureproof for connection in certain areas of the city.
€20 million in funding has also been secured for this project's development.

Further potential projects are also being explored by Codema looking at geothermal heat, sector integration to utilise otherwise curtailed renewable electricity for heating, further data centre projects, etc.

Facts & figures

Population and Population Growth

The most recent census has the population of Dublin County at 1.34 million inhabitants. Increases in the building sector energy demand to 2030 can be attributed to a number of variables. The main impact on future predicted energy demand can be linked to population growth,which is coupled with an increase in both residential and non-residential buildings, which is driven by planning developments. The Economic and Social Research Institute (ESRI) has published population projections and annual average population growth rates for Ireland, this is further broken down by region (see Table below). For Dublin it has been estimated that the population from 2016 to 2040 would increase annually by an average of 0.9%.

TABLE 13: ESRI POPULATION GROWTH RATES BY REGION[9]

	Population ('000s)			Annual Average Growth		Population Share	
	2011	2016	2040	2011-2016 %	2016-2040 %	2016	2040
Border	514.9	523.2	589.0	0.3	0.5	11.0	10.5
Midland	282.4	292.3	330.5	0.7	0.5	6.1	5.9
West	445.4	453.1	534.1	0.3	0.7	9.5	9.5
Dublin	1,273.1	1,347.4	1,639.8	1.2	0.9	28.3	29.1
Mid-East	531.1	560.0	707.5	1.1	1.1	11.8	12.6
Mid-West	379.3	385.0	449.4	0.3	0.7	8.1	8.0
South-East	497.6	510.3	585.4	0.5	0.6	10.7	10.4
South-West	664.5	690.6	799.2	0.8	0.7	14.5	14.2
State	4,588.3	4,761.9	5,634.8	0.8	0.8	100.0	100.0
Northern and Western	837.4	847.4	961.6	0.2	0.6	17.8	17.1
Eastern	2,209.5	2,328.5	2,839.2	1.1	0.9	48.9	50.4
Southern	1,541.4	1,585.9	1,833.9	0.6	0.7	33.3	32.5

The National Planning Framework[10] (NPF) for Ireland is projecting a need for 550,000 more homes by 2040, of which 25% of these (137,500 homes) have been planned for Dublin. The NPF has also identified that over recent years there has been an 'ongoing shift in population and jobs towards the east counties'.

The figure below shows the current average occupancy per dwelling by small area, which has been sourced from the 2016 census. Mean dwelling occupancy was calculated by dividing the total number of occupants per household ("T6_3_TP" or "Total Persons") by the total number of dwellings ("T6_3_TH" or "Total") in each small area. The legend represents the mean number of occupants per dwelling in each small area, where red and green indicate a higher and lower number of occupants respectively. In Ireland the average

[9] https://www.esri.ie/system/files/publications/RS70.pdf

[10] https://npf.ie/project-ireland-2040-national-planning-framework/

household size was 2.75 people per dwelling[11]; in the Dublin region this is approximately 2.72 people per household.

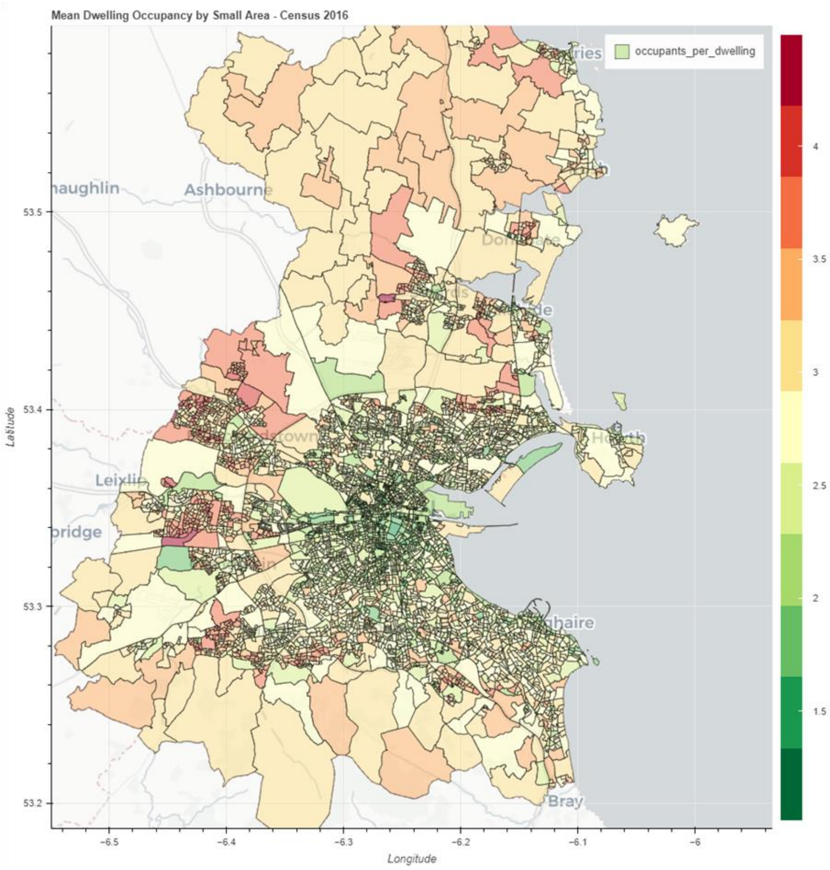


FIGURE 30: AVERAGE DWELLING OCCUPANCY BY SMALL AREA IN 2016 (SOURCE: CENSUS 2016)

It should be noted that even though the number of buildings (both domestic and non-domestic) are set to increase, building regulations, particularly for new builds, have set out strict guidance on energy performance in buildings.
All new buildings are to be built to nearly zero-energy building (nZEB) standards, which is defined as a building that has a very high energy performance, as determined in accordance with Annex I of the Energy Performance in Buildings Directive, i.e. the Dwelling Energy Assessment Procedure (DEAP) and Non-domestic Energy Assessment Procedure (NEAP). Codema has used typical heat demand figures for these nZEB buildings and assumed a similar floor area per capita requirement for housing and commercial buildings to calculate the additional heat load for this population increase.

Dwelling Ownership

Home and business tenure is an important consideration for building energy upgrades. People living or having a business in rented accommodations are less likely to take on any upgrades to their property, whereas owner occupied buildings are more likely to be retrofitted as the owner occupier will be seeing upgrade benefits in the reduction of consumed energy costs. This often means that for rented accommodation and business properties, building owners would have very little incentive to invest in costly measures to improve energy efficiency as they do not directly benefit from them. Introducing minimum energy performance standards for rented buildings might be a way to increase the rate of retrofits in these buildings.

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[11] https://www.cso.ie/en/releasesandpublications/ep/p-cp1hii/cp1hii/od/#:~:text=In%202011%20there%20were%20on,increased%20from%202.40%20to%202.48.

This map of Housing Percentage Ownership was created using the open-access Small-Area Population Statistics (SAPS) 2016 data provided by the CSO. Ownership was calculated by dividing the total number of dwellings owned with a mortgage (T6_3_OMLH":"Owned with mortgage or loan"), together with the dwellings owned outright (T6_3_OOH":"Owned Outright") by the total number of dwellings ("T6_3_TH":"Total"). The colour ramp represents percentage ownership of the housing stock where red and green indicate a higher and lower ownership, respectively.

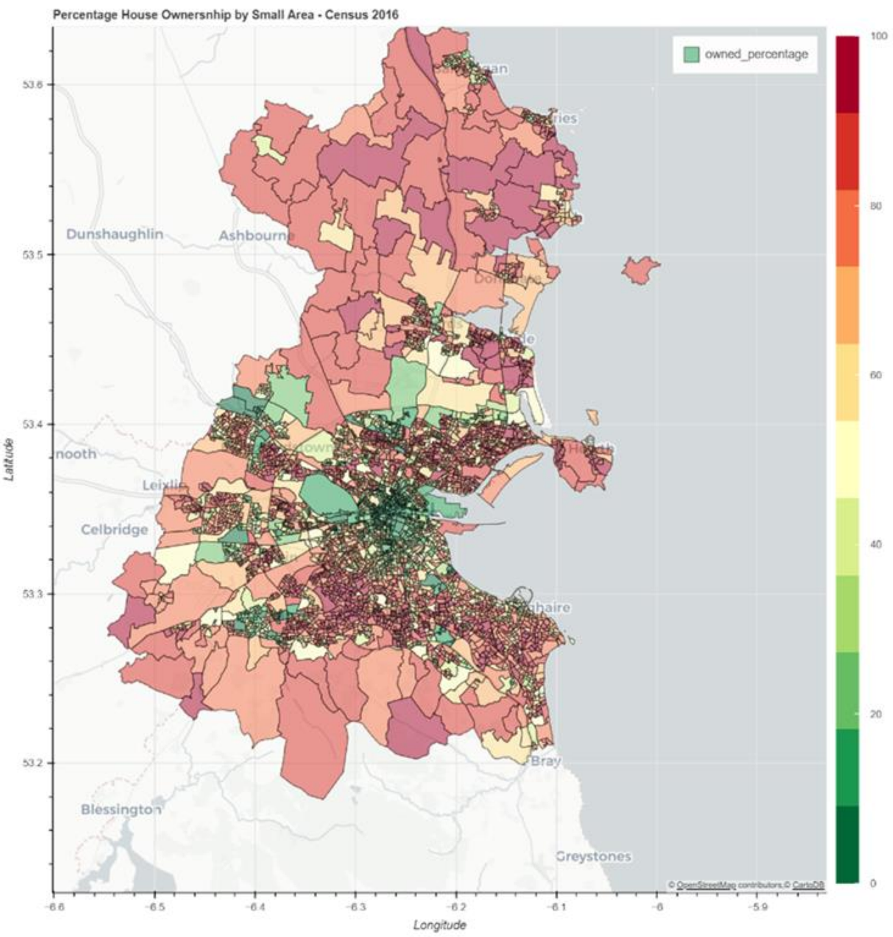

FIGURE 31: HOME OWNERSHIP PERCENTAGES IN DUBLIN BY SMALL AREA (SOURCE: CENSUS 2016)

The figure above shows the home ownership percentages in the Dublin Region. The lowest home ownership can be found in the inner city area and these areas overlap with areas that have a high number of apartments. For example, 52% of all residential buildings in Dublin 1, 2, 7 and 8 are apartments; these same areas also have poor BERs, with 68% of the residential stock with a D1 BER or worse. Therefore, these buildings (inner city apartments) will be some of the hardest to retrofit.

Analysis of the rebound effect in residential dwellings, Aydin et al12 compared theoretical consumption (based on that expected from the Energy Performance Certificate/Building Energy Rating) to actual consumption (based on metered gas consumption) for 710,000 buildings in the Netherlands. It was found that as energy efficiency gains change, the perceived cost of energy services generates shifts in consumption patterns in what is referred to as the Rebound Effect. In simple terms, the Rebound Effect is the percentage of the theoretical savings that are not realised in reality. The results of this study show a

[12] Aydin, E., Brounen, D. and Kok, N., 2013. The Rebound Effect in Residential Heating. https://www.tilburguniversity.edu/sites/tiu/files/download/The%20Rebound%20Effect_EA300813.pdf

rebound effect of 26.7 % among homeowners, and 41.3 % among tenants. These figure were used to derive more accurate future heat demands for dwellings whose fabric will be upgraded.

Current Situation - Heating Technologies

The majority of buildings in Dublin use gas fired heating. The gas grid covers practically the whole city, developed at national level by semi-state owned companies without considering where DHC grids may be a better option. The figure below shows the breakdown of type of heating technologies currently installed in Dublin. This shows that gas is the dominant heat fuel followed by direct electric (not heat pumps), particularly in the inner city where many apartments are heated in this way. the current distribution of fuel sources in residential dwellings reads:

- Gas 74% (mainly individual),
- Electric 18% (mainly direct),
- Oil 7%, and
- Coal/Biomass 1%

(percentages relating to the share of dwellings supplied by each respective fuel source).

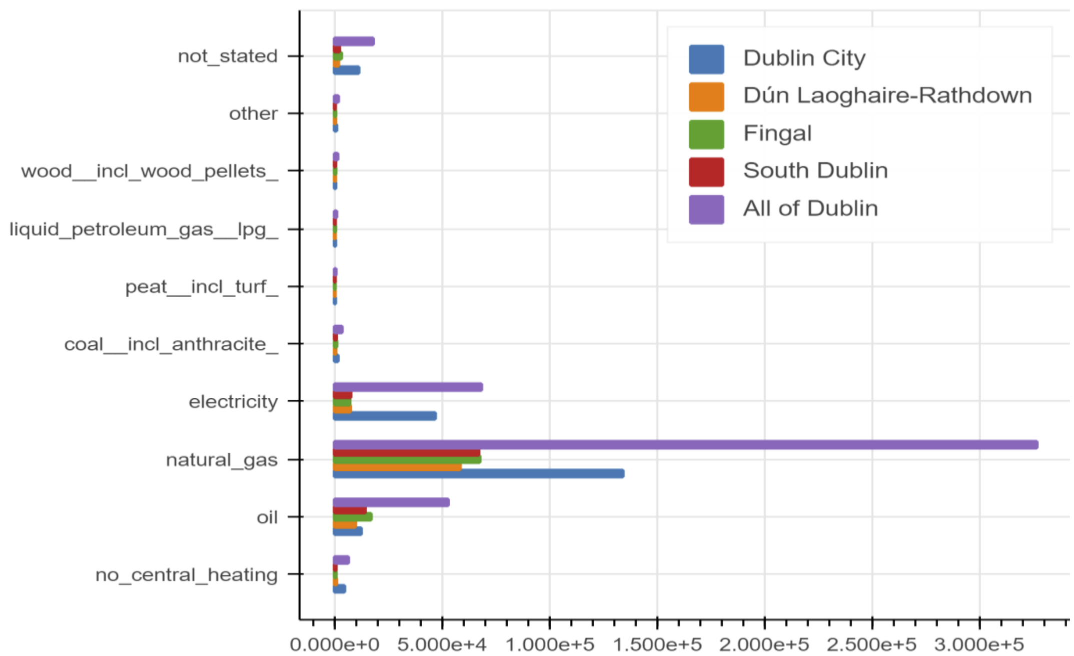

FIGURE 32: HEATING TECHNOLOGIES USED IN IRELAND

Current Energy Infrastructure

The main piece of heating infrastructure in Dublin is the gas network. The current gas network in Dublin is approximately 5,700km in length. A breakdown of the gas network by pressure and pipe construction material can be seen in the table below.

TABLE 14: DUBLIN GAS NETWORK PIPELINE LENGTHS

	HP (metres)	MP (metres)	LP (metres)	Total Length (m)
Polyethelene	0	2,015,406	3,367,718	5,383,124
Steel	255,795	48,680	4,278	308,753
Cast Iron	0	0	71	71
Ductile Iron	0	0	1	1
Total length by Pressure	255,795	2,064,085	3,372,067	

The other piece of infrastructure used for heating is the electrical grid. This infrastructure and its constraints have also been mapped for Dublin. The constraints based on available substation capacity can be seen in the figure below. These constraints were used to calculate the cost of grid upgrades associated with heat pump adoption by adjusting the average upgrade cost based on the portion of capacity available on the grid within a given area.

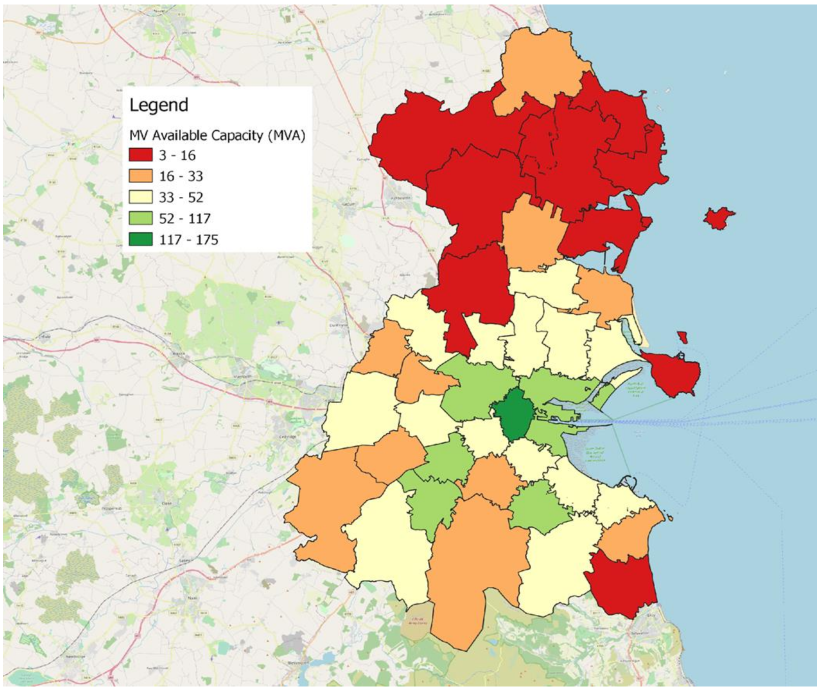

FIGURE 33: ELECTRICAL SUBSTATION REMAINING CAPACITY (MVA) MAP

Process

This section provides an overview of the process used in developing the H/C Plan. The main steps in the H/C plan process were as follows:

1. Data gathering: Stakeholder engagement with CSO, SEAI, Valuations Office, Utilities (ESB on the electricity side and GNI on the gas side), Local Authorities, Academic Institutions to gather and understand available data.
2. Mapping of data in GIS (Geographical Information System)
3. Generating calculations based on data to provide insight on decarbinisation pathway to find what is the most cost-effective way to decarbonise heat for each area of Dublin using €/tCO_2 saved as the primary metric which is discussed in greater detail in the Analyses and data aggregation section.
4. Draft plan discussed with the local working group.
5. Finalised cost-effective spatially mapped pathway (see 2030 map below)

The scope of the H/C Plan focused on the space and hot water heating in Dublin rather than high temperature industrial heat requirements although lower temperature industrial was included. The main goal was to identify the best technology pathway for heating in each of the almost 5,000 small areas in Dublin. The two main technologies investigated were district heating and air-source heat pumps. The preferred option was determined based on having the lowest cost of carbon abatement (€/tCO_2).

Framework and principles

Pathway determined by lowest cost of carbon abatement in heating sector DH vs ASHPs (including Capex, Opex, Repex and CO_2 equivalents from methane and refrigerant leaks) for the period up to 2030 and 2050 (i.e. not just in that year). The key metric used was the €/tCO_2 saved. Decarbonisation of the gas grid limited by capacity to produce biomethane and the current technical restriction on using hydrogen in existing gas infrastructure (see emissions factor below)

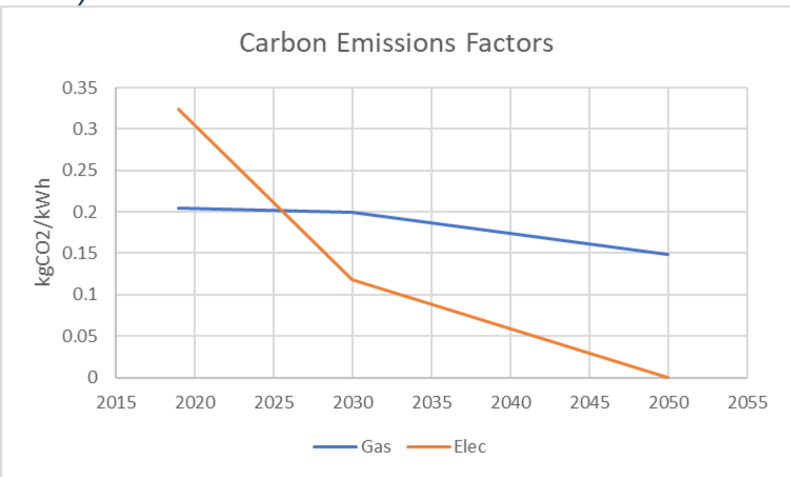

FIGURE 34: CARBON EMISSIONS FACTORS

Green hydrogen is not considered suitable for low-exergy applications such as space heating and hot water preparation due to inherent inefficiency when compared with alternatives.
Assumed that all future buildings will be nZEB and various fabric upgrade options were considered for existing buildings.

Heat Sources in Dublin

The graph below should range of 18 heat sources investigated by Codema for heat planning purposes and also includes typical temperature ranges for each heat source and highlights how that matches up against potential end use temperature requirements.

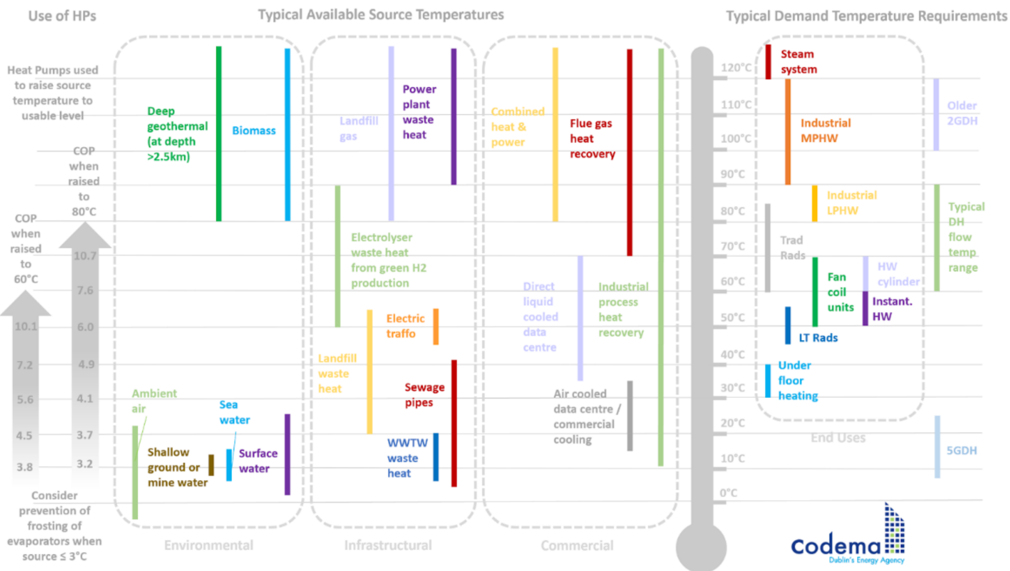

FIGURE 35: HEAT SOURCE AND END-USE TEMPERATURES

The graph below shows the breakdown of heat sources available in Dublin for the current and future scenario. It can be seen from this graph that the main changes over this period is the significant reduction in heat available from power plants as renewable electricity generation increases. This reduction is offset by increased heating potential from data centres and from renewable electricity generation which would otherwise be curtailed.

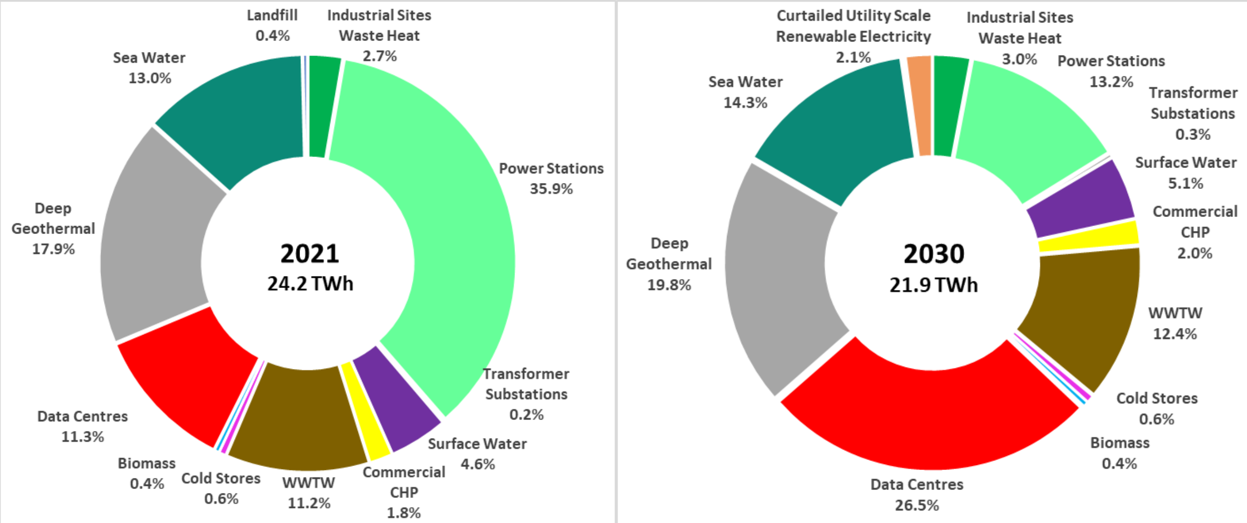

FIGURE 36: HEAT SOURCE BREAKDOWN FOR 2021 AND 2030

It should also be noted that the capacity figure for the surface water heat loads shown in the figure above is a conservative one, as it is based on the Q95 flow (i.e. dry weather flow). This flow rate was chosen based on the assumption that the source waterways are fisheries and as such, have limits on the degree to which their original temperature can be altered without adverse impacts on the fishery. This also assumes a constant heat extraction rate. It may be possible to have variable extraction controlled by the source temperature to prevent excessive cooling of the source. Under these conditions, the mean flow could be used; this would increase the potential heat capacity from surface water. If it was assumed that there is no impact on fisheries and therefore that the reduction in river temperature is only limited by technical constraints, then this capacity could increase further compared to what is shown in the graph.

These sources have been broken down based on their average supply temperatures in the graphs below. This provides an indication of the quantity of higher temperature heat that could be utilised for direct use in DH networks (>60°C) without requiring heat pumps. The medium temperature sources which can supply heat between 20°C and 60°C would likely require a heat pump to bring them up to a usable temperature for typical DH networks but these could achieve very high COPs, likely to be above 3.5 and perhaps up to 12 (i.e. 12 units of heat for every 1 unit of electricity). The low temperature range (<20°C) would require heat pumps to raise their temperature to a usable level. Even when using the same sources as individual building heat pumps, these large-scale heat pumps generally provide better COP than the smaller alternatives. This is due to a number of reasons; these large-scale HPs are continually monitored to ensure their performance is optimised, they have continual maintenance to ensure efficient operations and the economies of scale allow for use of two-stage compression, which improves efficiency when using lower temperature sources.

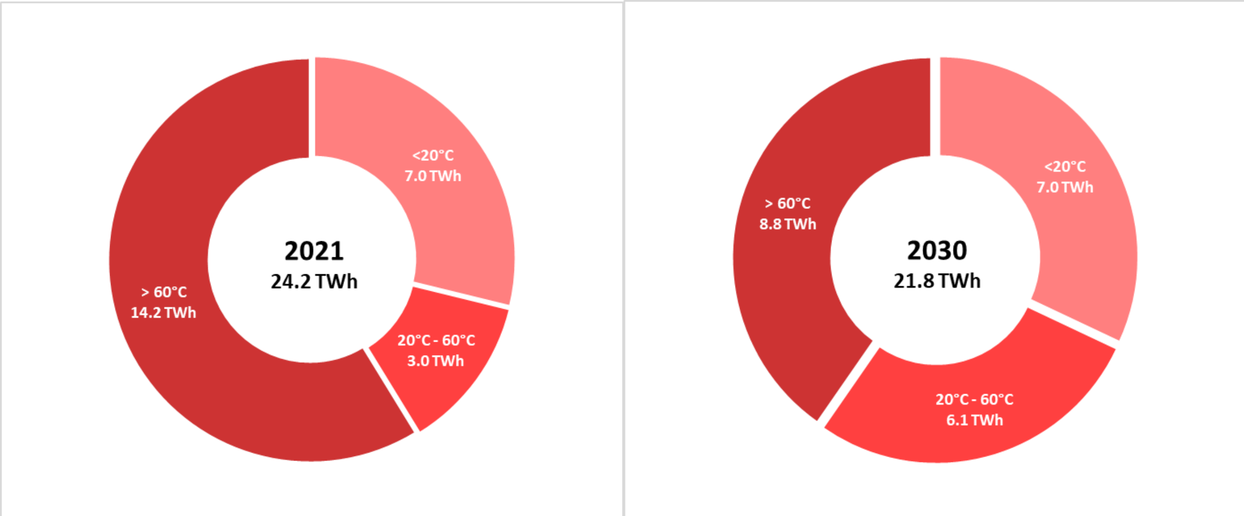

FIGURE 37: HEAT SOURCE BREAKDOWN BY TEMPERATURE FOR 2021 AND 2030

Analyses of data and aggregation

The analysis outlined in this section is based on analysis performed by Codema as part of the Dublin Region Energy Masterplan.

Initial Assessment of Heat Demand

The heat demand was calculated using domestic building energy rating (BER) information for the dwellings for which this was available and these demand demands were then extrapolated to the full buildings stock based on the age and location of the dwellings for which the BER was not available. Codema created a synthetic building stock model to facilitate this and to allow future fabric upgrades to be analysed. This building stock model allows for the u-value of various elements of a dwellings envelope (walls, windows, etc.) to be adjusted and for a new heat demand to be generated based on these changes. Commercial building heat demands were calculated using the building floor areas and CIBSE benchmarks. Public sector heat demands were based on metered consumption.

The maps on the next page show the heat demand density in TJ/km² for each CSO small area in the county. This metric is one of the key indicators for DH suitability. An interactive version of these maps is available on the Codema-dev GitHub page. The breakdown of demand categorised as very feasible, feasible, not feasible, etc. can also be found on this webpage. The table below provides indicative figures for DH suitability based on this heat demand density metric alone. The DH vs HP assessment in the next section of this report builds on this analysis and directly compares the two low-carbon heating options based on the cost of carbon abatement. Interestingly the carbon abatement cost analysis shows district heating as a better option for even more of Dublin than the analysis based on demand density alone.

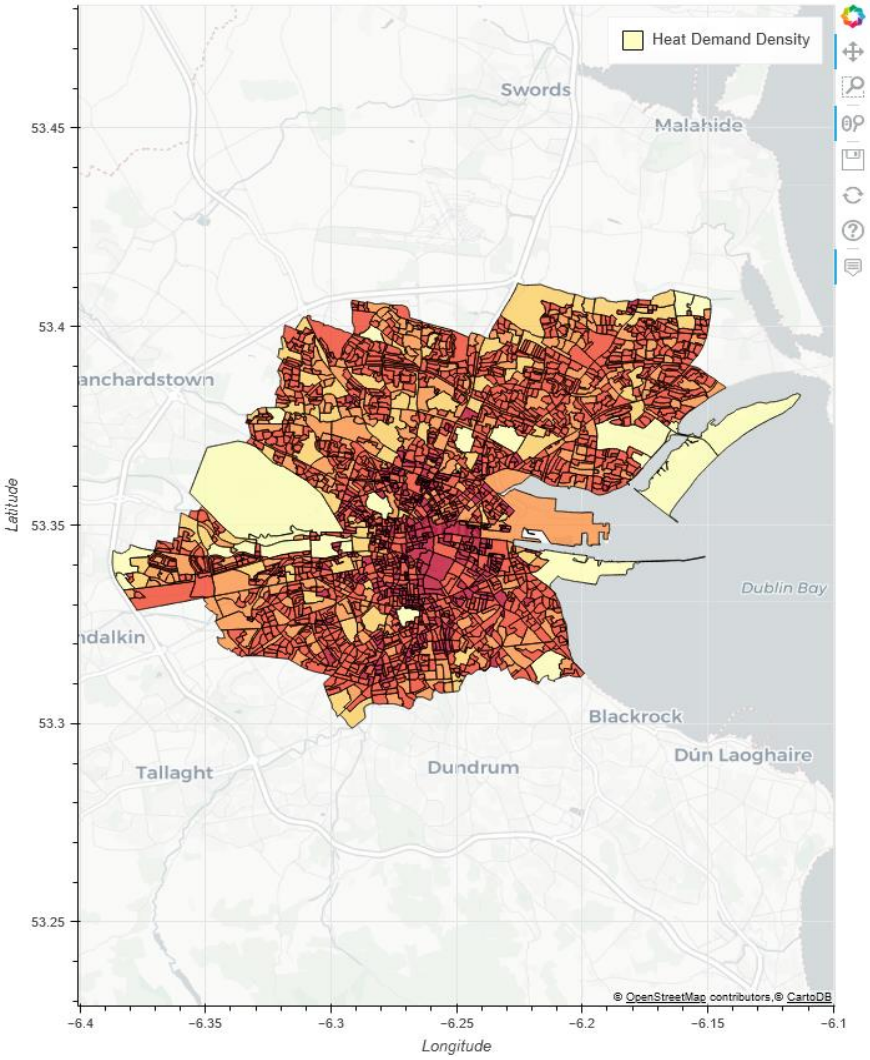

FIGURE 38: EXAMPLE OF HEAT DEMAND DENSITY MAPS PRODUCED

The table shows that 83.5% of heat demand in Dublin city is suitable for DH (above 120TJ/km^2) and that this could increase to 96.6% with supporting regulations in place.

TABLE 15: BREAKDOWN OF SUITABILITY FOR DUBLIN CITY

Feasibility	Residential [MWh/year]	Non-Residential [MWh/year]	Total [MWh/year]	Band [TJ/km²year]	% Share [MWh/year]
Not Feasible	23733	7803	31535	<20	0.7
Future Potential	89688	34996	124683	20-50	2.7
Feasible with Supporting Regulation	430562	172766	603327	50-120	13.1
Feasible	2229477	431259	2660736	120-300	57.7
Very Feasible	627162	561711	1188872	>300	25.8

Final Assessment of DH vs Heat Pumps

Two main heat decarbonisation strategies were assessed; one based on the adoption of district heating networks and the other looking at the widespread adoption of air source heat pumps. This analysis was performed for every CSO small area. The total number of CSO small areas in Dublin is 4,884. The determining factor in choosing one technology over the other was the cost of carbon abatement. The technology with the lowest carbon abatement cost (€/tCO_2 abated) was chosen as the preferred decarbonisation pathway. The cost and carbon abatement figure was calculated based on local conditions within each small area as discussed below.

District Heating Costs

The network length within each small area was determined through the use of random sampling. In this sampling exercise, indicative networks were drawn on multiple areas of a certain urban fabric. An example of the network routes drawn can be seen in the map below in red. The network length was then compared to the road centre line lengths from open street map (OSM). This relationship was then used to estimate the network length required within each small area.

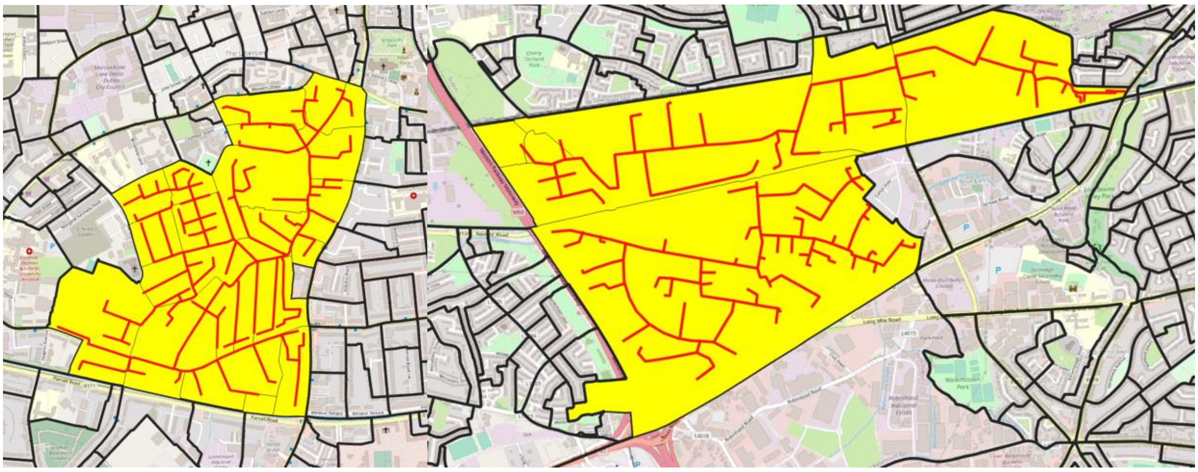

FIGURE 39: EXAMPLE OF NETWORK LENGTH ANALYSIS PERFORMED

The average DH pipe diameter rounded to the nearest standard pipe size was estimated for each small area based on the linear heat density using the following relationship[13]:

$$\text{Average DH Pipe Diameter (mm)} = (0.048 * \ln(\text{Linear Heat Density in MWh per metre}) + 0.063) * 1000$$

The capital cost of the heat production equipment was estimated based on a representative €/kW figure, which includes the capital cost of the main heating plant, backup heating plant, and auxiliary and automation equipment. The kW used to determine the cost was based on an average diversified peak heat demand for each domestic dwelling plus the diversified peak commercial demand based on the calculated annual heat demand and a typical equivalent run hours for commercial buildings.

The cost of heat interface units and heat substations were also included for the DH option based on an average kW peak demand per building.

[13] https://hre.aau.dk/wp-content/uploads/2018/09/STRATEGO-WP2-Background-Report-6-Mapping-Potenital-for-DHC.pdf

Heat Pump Costs

The capital cost of the heat pump option was calculated using a figure of €1,200/kW thermal output. This figure assumed air source heat pumps (air to water) were fully installed including fittings, buffer tank, new cylinder (existing cylinders are not deemed compatible with efficient heat pump operation due to the relatively small surface area of their coils) and controls, but excluding the heat distribution system. Excluding the distribution system may mean the cost estimate for an efficiently-operating ASHP system may be slightly underestimated in some cases.

It is understood that once heat pumps start to represent a significant proportion of the heat market, the cost of heat pumps will reduce as supply chains improve, installation overheads reduce and the equipment cost itself also reduces. This cost reduction is captured in this analysis through the annualised replacement expenditure (Repex) cost, which assumes a 20% reduction will occur[14] within the first lifecycle of the heat pumps, i.e. before 2036.

Whilst not included in this analysis, it is also worth noting that the floor area consumed by the required hot water cylinder also has a cost associated with it. For a build-to-rent apartment in Dublin, this cost is estimated at €2,350 per dwelling, for example. This cost benefit for DH was excluded as the majority of buildings in Dublin are existing buildings and already have hot water cylinders of a similar footprint installed and are designed in such a way that the floor area freed by removing these units is of limited value.

Electrical Grid Upgrade Costs for Heat Pumps

The installation of heat pumps in homes will also have an impact on the electricity grid which, in certain areas, upgrades will be required to serve these new loads. The cost of these upgrades has been estimated for the LV & MV grid and also for the HV grid using two different approaches for domestic and commercial buildings.

The LV & MV grid upgrade cost adopted was based on costs from ESB Statement of Charges[15]. For existing homes whose current connection (typically 12kVA) will need to be upgraded (assumed to 16kVA) to service additional load from the heat pump (but also potentially EV charging and greater use of electric cookers). This connection upgrade charge is stated as being €1,539 for a single urban connection. This includes MV network costs but excludes trenching within the boundary of the site. Assuming a power factor of 0.95 for the heat pump load, this translates to a LV & MV upgrade cost of €405/kWe. The additional trenching cost is estimated at €6/m based on typical rates. This trenching cost would apply to all new connections but considering that Dublin consists of predominantly existing buildings and the limited impact of such a low cost, this trenching cost has been excluded from the analysis.

For commercial buildings, the impact of heat pumps on the building's maximum import capacity (MIC) was assessed in order to determine if the HP installation resulted in the building breaking its existing MIC threshold and thus incurring additional cost for falling within a higher MIC band. In the vast majority of cases, it was determined that the addition of a heat pump would not result in the building reaching the next MIC price band, but where it does the cost has been included.

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14 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/498962/150113_Delta-ee_Final_ASHP_report_DECC.pdf

15 https://www.esbnetworks.ie/docs/default-source/publications/esb-networks-dac-statement-of-charges.pdf

Emissions from DH, Heat Pumps and Gas

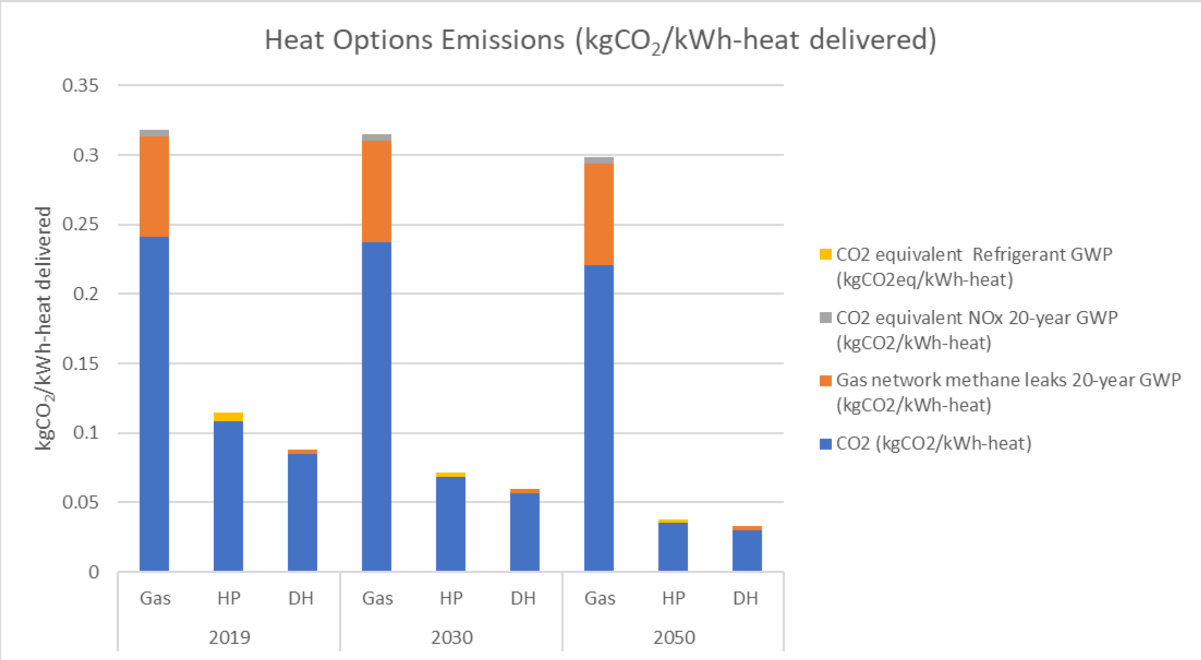


FIGURE 40: EMISSIONS (INCLUDING EQUIVALENTS) PER HEAT DELIVERED BY TECHNOLOGY

H/C planning

Based on the analysis above the following provides a summary of the findings from the H/C Plan.

Current Situation: Heating Technologies

The majority of buildings in Dublin use gas fired heating. The gas grid covers practically the whole city, developed at national level by semi-state owned companies without considering where DHC grids may be a better option. Gas is still the dominant heat fuel followed by direct electric (not heat pumps), particularly in the inner city where many apartments are heated in this way.

Heat Sources Available

The graph below shows the breakdown of heat sources available in Dublin for the current and future scenario. It can be seen from this graph that the main changes over this period is the significant reduction in heat available from power plants as renewable electricity generation increases. This reduction is offset by increased heating potential from data centres and from renewable electricity generation which would otherwise be curtailed.

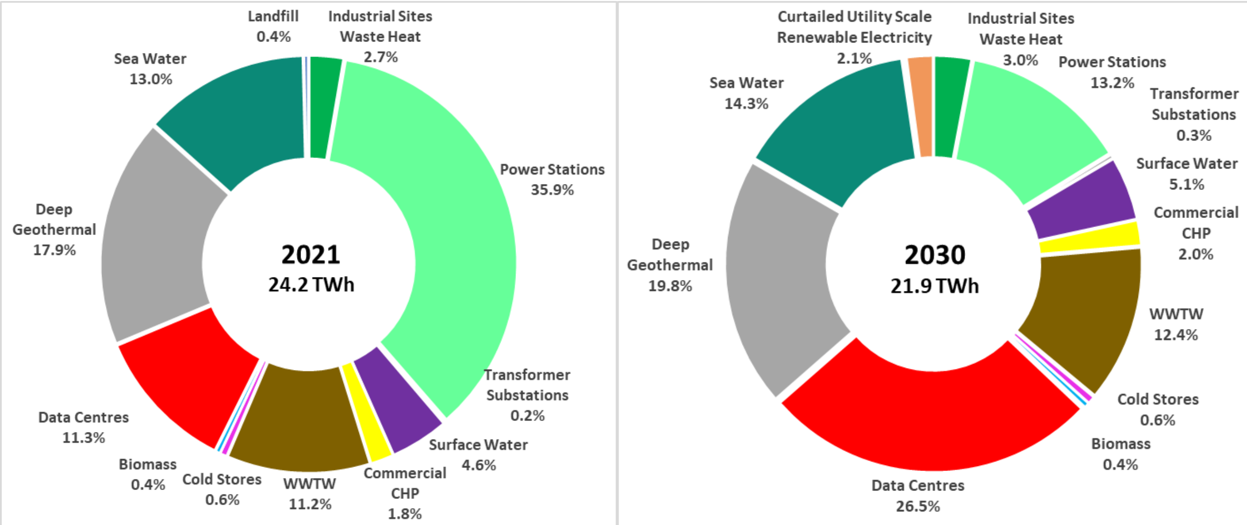


FIGURE 41: HEAT SOURCE BREAKDOWN FOR 2021 AND 2030

The location of these heat sources (totalling approximately 530 sources) is set out in the map below and can also be found online[16].

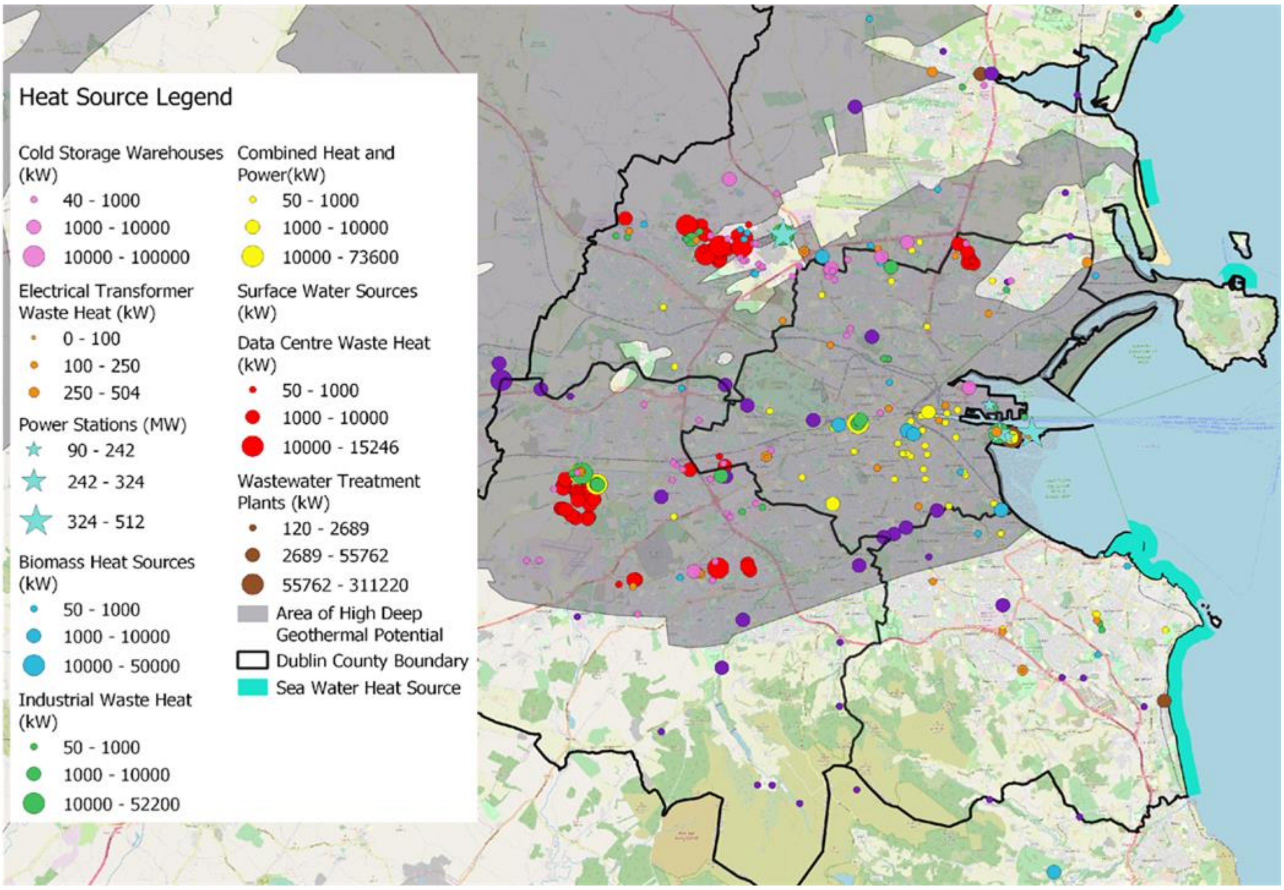


FIGURE 42: HEAT SOURCE MAP OF DUBLIN

16 https://codema-dev.github.io/map/heat-source-map/

Preferred Technology for 2030 and 2050

The figure below shows the areas most suited to each technology up to 2030. The areas coloured blue are most suited to heat pumps and the areas coloured red are most suited to district heating. The darker the colour, the more suited that area is to either technology.

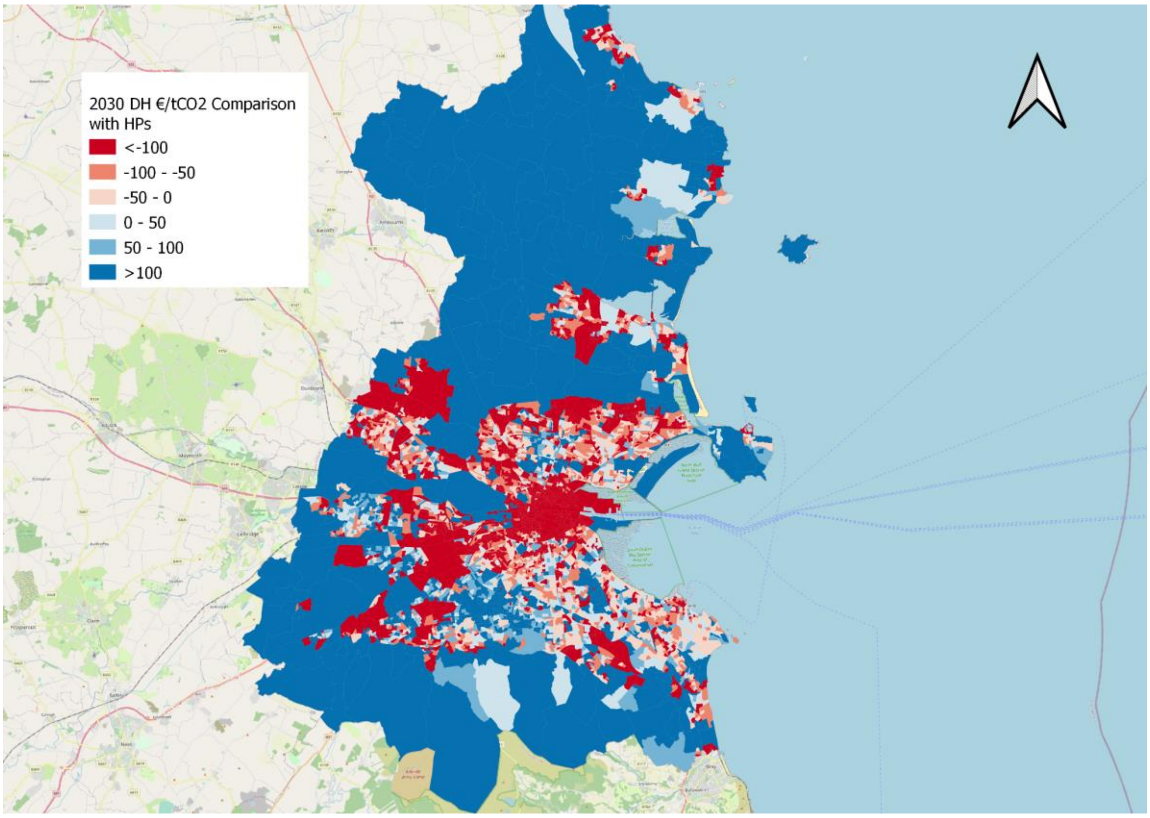


FIGURE 43: 2030 DH AND HP PRIORITY AREAS BASED ON LOWEST NON-DISCOUNTED CARBON ABATEMENT COST

District heating represents the best option for 7.43TWh of heat demand in terms of cost-effective decarbonisation, which would save 1,441.7ktCO_2 in the year 2030. However, like other technologies, the supply chain needs to be developed in order to deliver on this potential. The current national government target of 2.7TWh by 2030 reflects the supply chain growth experienced by other countries when they first began adopting DH in the 1970s. As Dublin is more advanced in the planning and development of DH systems, it is fair to assume that the majority of this target will be met by Dublin and so this was used as a reasonable interim regional target for 2030. This 2.7TWh would save 502ktCO_2 in carbon emissions and save 172.8k$TCO^2_{eq.}$ in equivalent emissions in the year 2030. The map on the next page shows the areas where DH could be first adopted (i.e. is most cost-effective) to reach this 2.7TWh target.

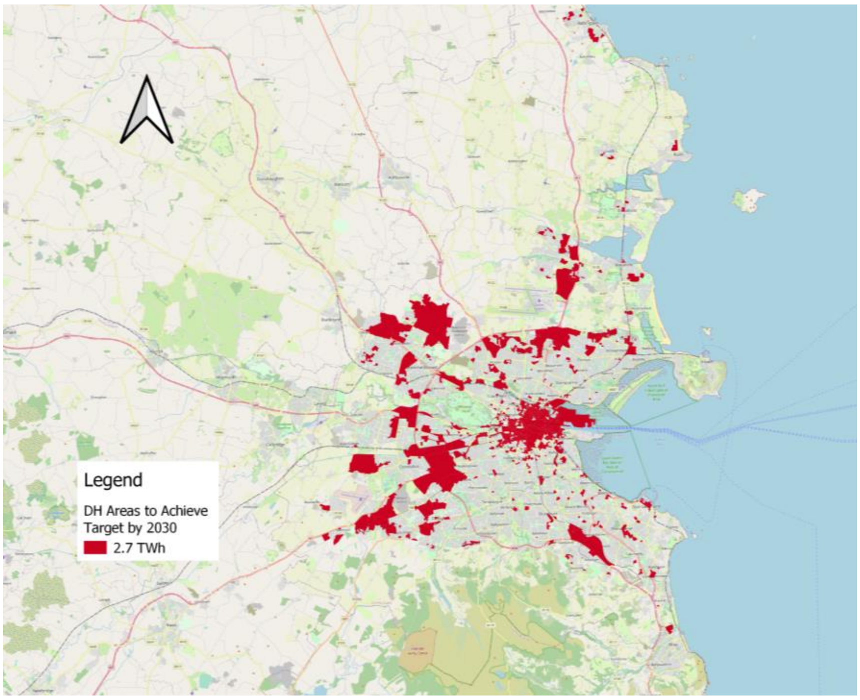


FIGURE 44: PRIORITY DH AREAS FOR ACHIEVING 2.7TWH TARGET BY 2030

The 2.7 TWh target for 2030 would require 376.3 km of distribution pipework and 774.5 km of customer connections estimated to cost €980.4 million. The total capital cost of achieving this target is estimated at €1.1 billion with the majority of this investment staying within the local economy. This would create the equivalent of 2,281 direct local jobs per year for this period to 2030.

The figure on the next page shows the areas most suited to each technology up to 2050. The areas coloured blue are most suited to heat pumps and the areas coloured red are most suited to district heating. The darker the colour the most suited that area is to either technology. It can be seen from this map that the areas suited to DH have increased over the period 2030 to 2050. The main reason for this is that the up-front capital investment in the network infrastructure is recouped over a longer period in this scenario. It is worth noting that this effect will continue beyond 2050 making DH an even better solution over time.

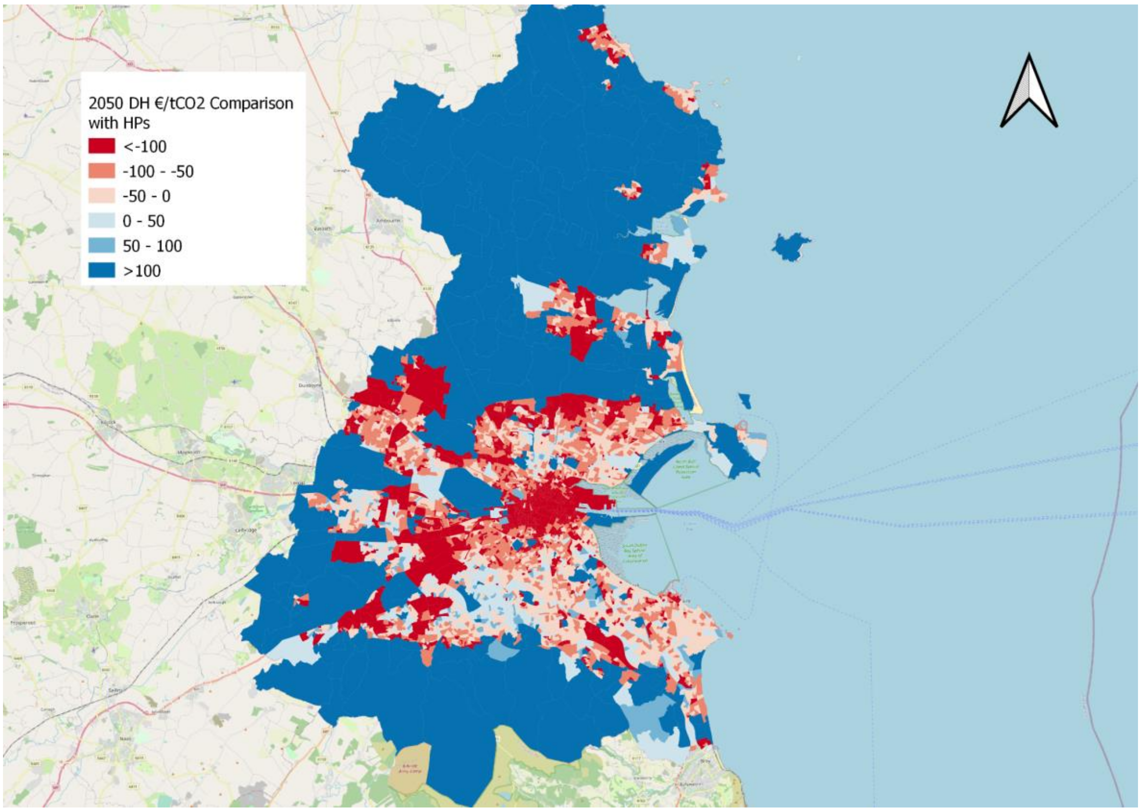


FIGURE 45: 2050 DH AND HP PRIORITY AREAS BASED ON LOWEST NON-DISCOUNTED CARBON ABATEMENT COST

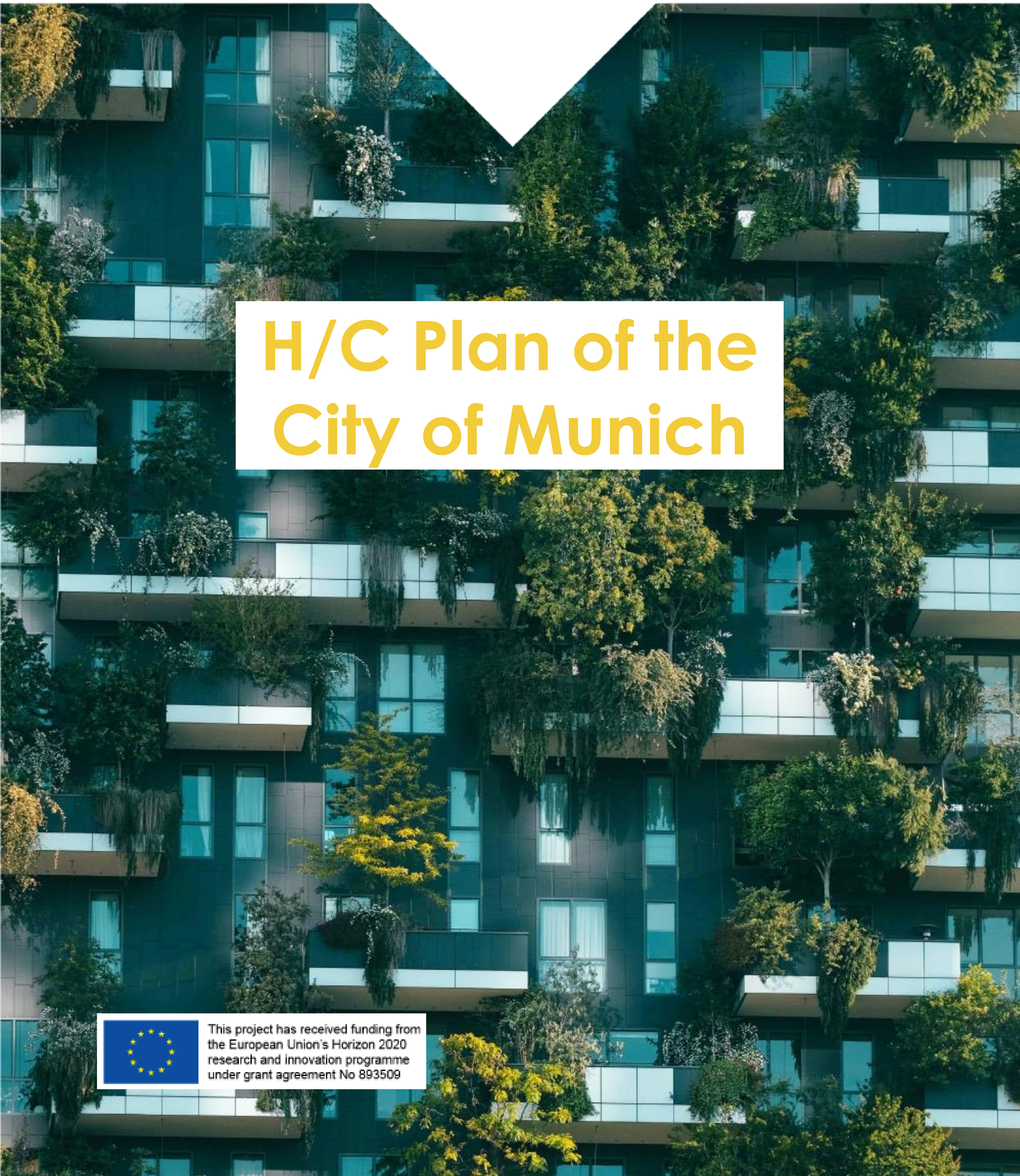
By 2050, district heating represents the best option for 9.06TWh of heat demand in terms of cost-effective decarbonisation. By 2050, it is assumed that the required supply chain is in place to deliver on the full DH potential outlined. This would save 1,550.1ktCO_2 in carbon emissions and 617.6kTCO_2eq. in equivalent emissions in the year 2050.

Appendix: Data use

The data used is described in the relevant sections of the report above. Further details on data availability and quality are provided in Deliverable 2.4.

DECARB CITY PIPES 2050

H/C Plan of the City of Munich



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H/C Plan of the City of Munich

Introduction

Sustainability means that we use only as many resources as we need to meet our current needs and the needs of future generations (Brundtland Commission, 1987).

The construction sector is one of the largest consumers of energy and resources. Around 30% of global CO_2 emissions and 40% of resource consumption are caused by the construction industry. In Germany, the construction sector is also responsible for 54% of waste generation. The provision of heating, hot water and electricity alone accounts for 40% of final energy consumption. This illustrates the huge influence of the construction sector on the consumption of resources and energy. The average lifespan of buildings between 50 and 100 years shows the social responsibility for future generations when it comes to the design of the built environment and the sustainable use of available resources.

The aim of the Energy Plan for the City of Munich is to identify potential for energy savings and for the efficient, climate-friendly provision of energy for the heating and cooling of Munich’s building stock.

On the basis of a thorough spatial analysis, paths of action have been developed, which lead to detailed measures for politicians, the administration and the public. The measures contribute significantly to the achievement of Munich's climate protection goals.

Climate protection goals of the City of Munich

In line with the German federal government's climate protection plan 2050 and the Paris climate protection agreement of 2015, the City of Munich declared to become a “climate neutral” city by 2035. The city administration and the city owned companies set the goal to reach climate neutrality in 2030, already.

With the city council resolution of 18 December 2019, Munich has declared a climate emergency. The city administration was commissioned to develop an action plan that defines a path to achieve climate neutrality for the entire city by 2035 and for the city administration by 2030.

To achieve this goal, the potential for reducing greenhouse gas emissions through energy savings in municipal properties should be exhausted. The passive house or the German so-called efficiency house 40 standard (EH 40) in combination with energy-efficient heat generation, the use of renewable energy systems such as solar energy in municipal properties and the introduction of a climate protection check in the decisions of the city administration should make a decisive contribution here.

Goals of Stadtwerke München (SWM)

Stadtwerke München (SWM) makes a significant contribution to Munich’s energy transition with its own goals and by actively supporting the goals of the city of Munich. SWM developed an ambitious District Heating Vision in the year 2012 to achieve the energy transition in the heating market. The aim is to cover Munich's entire district heating demand on a CO_2-neutral basis. Geothermal sources will account for the major share of district heating in the future. Furthermore, from 2025 onwards, SWM intends to produce as much green electricity with its own plants as the entire municipality of Munich requires.

The expansion of district cooling to replace individual air conditioning systems is a further component of SWM’s climate commitment. Energy consumption for cooling is reduced by using groundwater and city streams.

Facts & figures: the context

The City of Munich is the third largest city in Germany. Munich is the capital of Bavaria and has about 1.56 million inhabitants. The city is characterised by its ongoing growth and economic prosperity. Thus, Munich’s property market has always been under high pressure, although about thousand new buildings are built every year. In 2020, 8,300 new flats were built.

Energy standards of new buildings are quite high in Germany. However, the existing building stock is the main challenge of the heat transition. Munich has more than 300,000 buildings in total. About 172,000 heated buildings were identified based on the analysis of the Energy Plan. More than half of the buildings were built before 1978, when the first ordinance on thermal insulation came into force in Germany. The following map shows the main residential building types in Munich.

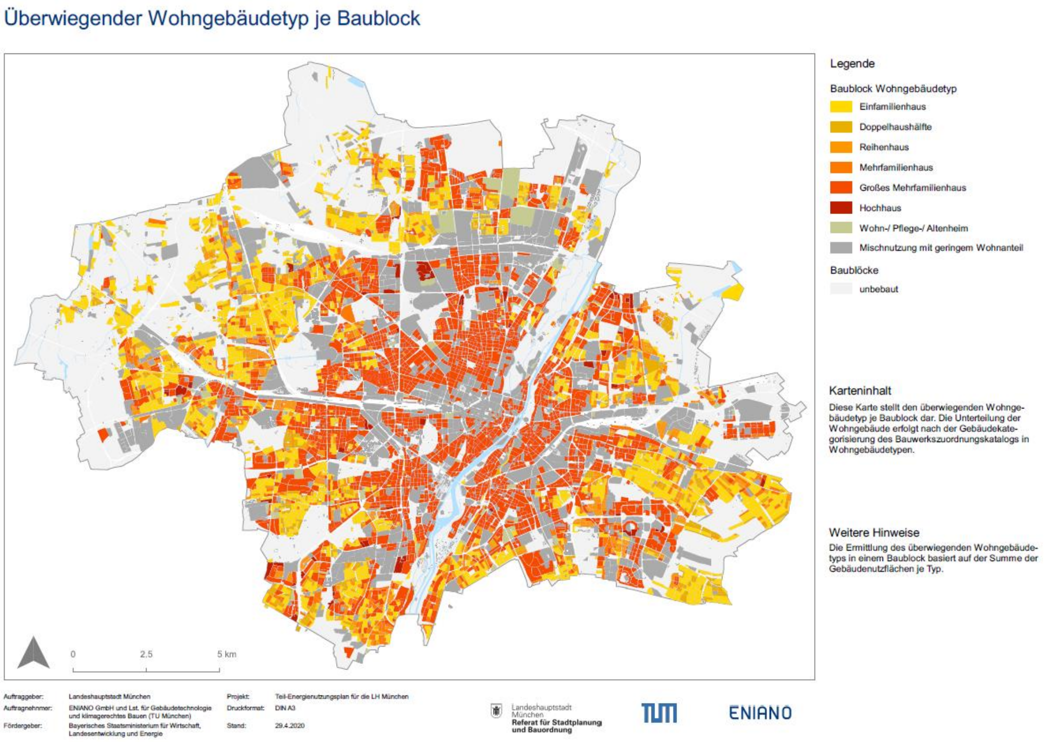


FIGURE 46: MAIN RESIDENTIAL BUILDING TYPES PER BLOCK (YELLOW: SINGLE-FAMILY HOUSES; ORANGE: SEMI-DETACHED HOUSES AND TERRACED HOUSES; RED: APARTMENT BUILDINGS, LARGE APARTMENT BUILDINGS AND HIGH-RISE BUILDINGS)

The Energy Plan (ENP) makes a significant contribution to achieving the climate protection goals of Munich and shows perspectives and recommendations for action for a sustainable and climate-neutral heat supply for the City of Munich. The development of a building-specific database forms the basis of a decarbonization strategy for the building stock. Minimizing heat-related greenhouse gas emissions through energy saving and the use of climate-friendly energy technologies is a top priority.

A key goal of the ENP is to accelerate and optimize planning processes with regard to energy management issues. The time-consuming data acquisition and editing of various data sources is no longer necessary with the ENP database.

Energy efficiency deficits within the districts are identified. Furthermore, the measures within the framework of the Energy Plan include areas of energetic refurbishment of buildings, the potential of solar thermal energy and near-surface geothermal energy as well as expansion potential for local and district heating systems. The measures define the technical scope for reducing heat demand and heat-related greenhouse gas emissions for the building stock.
Additionally, the ENP is an important source of information for the public and politicians. It also aims to make the population more aware of the issues of climate protection, sustainability, and energy efficiency.

Baseline information

The following figures were also used for generating a heating and cooling Outlook (see work package 2 of the Decarb City Pipes 2050 project).

Heat density

The following map shows the result of the heat density analysis. The highest heat density is to be found in the city centre and in the quarters north of the centre. These parts of the city are very densely populated. The city centre includes the old town of Munich with many listed buildings and the main shopping streets. The quarters north of the city centre (Maxvorstadt, Schwabing) are characterised by multi-family houses from the end of the 19th and the beginning of the 20th century.

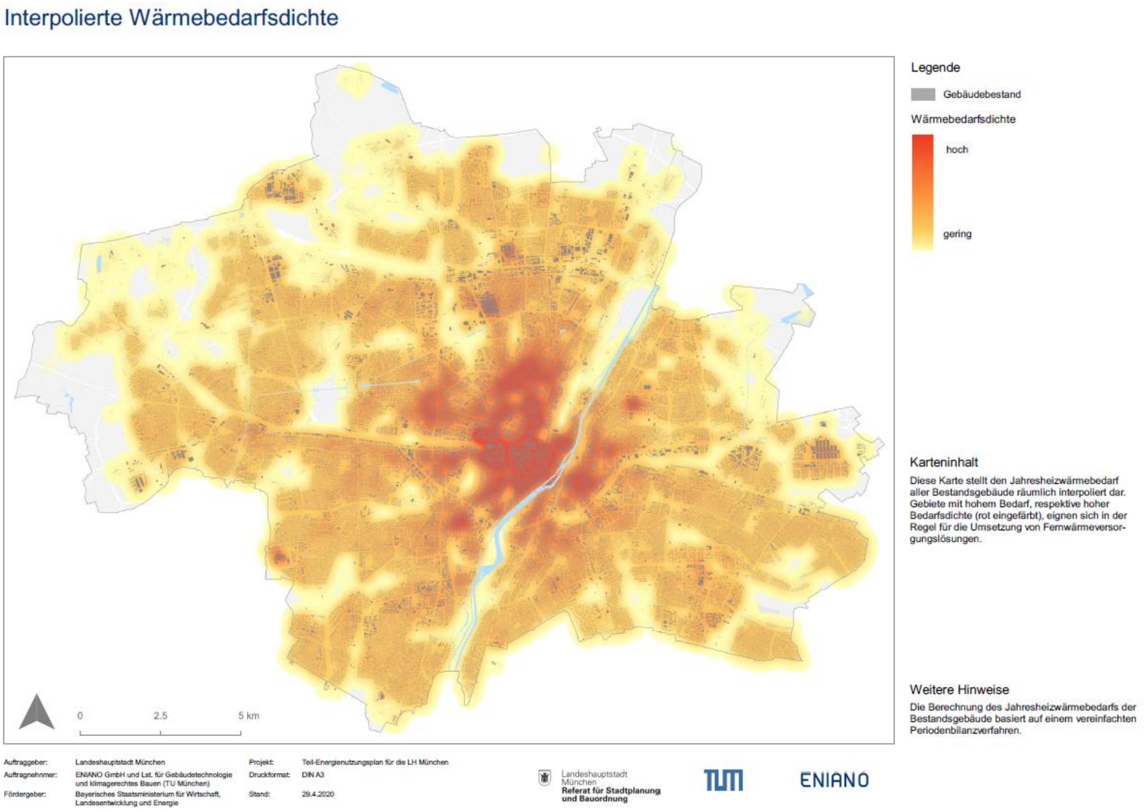


FIGURE 47: HEAT DENSITY MAP

Heat consumption

The heat consumption of residential buildings in Munich adds up to 6.3 TWh/a. Residential buildings have a share of 70 % of the total heat consumption.

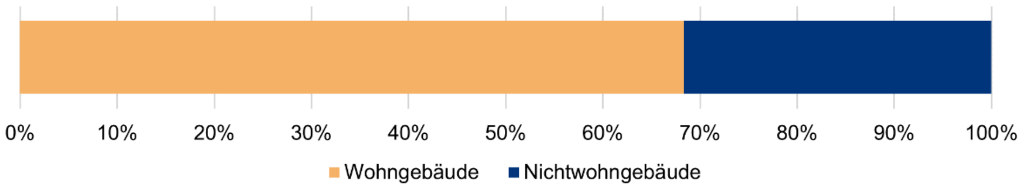


FIGURE 48: SHARE OF RESIDENTIAL (ORANGE) AND NON-RESIDENTIAL BUILDINGS (BLUE) OF THE TOTAL BUILDING STOCK

The analysis of the age and building structure shows that large apartment buildings from all age groups have the highest heat consumption. Buildings from the age group 1958 – 1968 have the highest consumption of all.

The yellow columns show the heat consumption of single-family houses. It is distinctly lower than the multi-family houses. But due to the high number of single-family houses, they have a significant heat consumption.

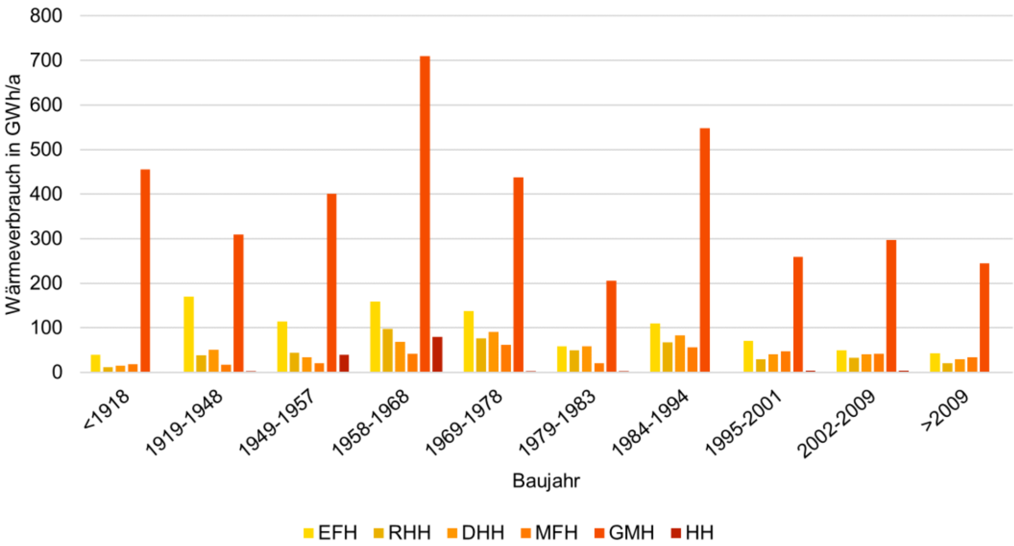


FIGURE 49 : HEAT CONSUMPTION OF THE BUILDING STOCK BY BUILDING TYPE AND AGE CLASS

Final energy consumption

The final energy consumption of all heated buildings in Munich adds up to 12.2 TWh/a. The highest share of the final energy consumption has gas, followed by district heating and oil:

- Gas: ~7,000 GWh/a (57 %)
- District Heating: ~4,200 GWh/a (34 %)
- Oil: ~1,050 GWh/a (9 %)

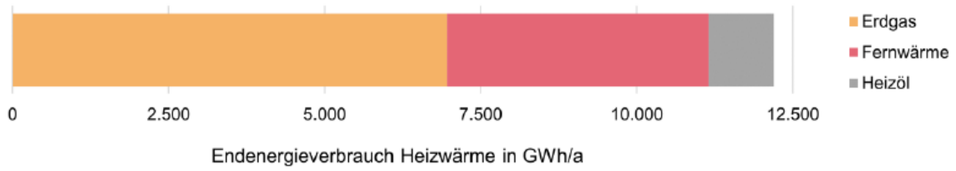


FIGURE 50: FINAL ENERGY CONSUMPTION IN GWH/A (ORANGE: GAS; RED: DISTRICT HEATING; GREY: OIL)

Heated buildings

About 172,000 heated buildings were identified and analysed in the Energy Plan.
About 129,000 buildings (75 %) are heated with gas, about 31,000 buildings (18 %) are connected to district heating, and 13,000 buildings (7 %) still have oil heating.

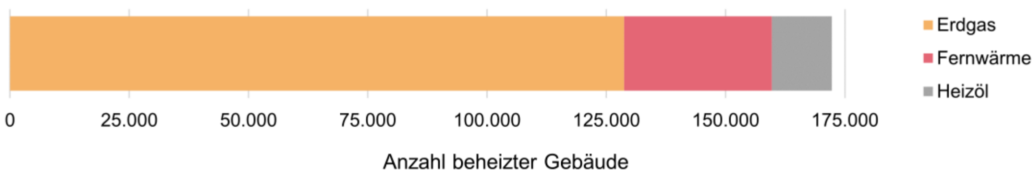


FIGURE 51: NUMBER OF HEATED BUILDINGS AND ENERGY SOURCES (ORANGE: GAS; RED: DISTRICT HEATING; GREY: OIL)

The following map shows the main energy carriers per building block. It shows the spatial distribution of the prevailing heating technologies very well. Gas is still the dominant source of heating. The map clearly shows that there are many blocks inside the district heating area that are heated with gas.

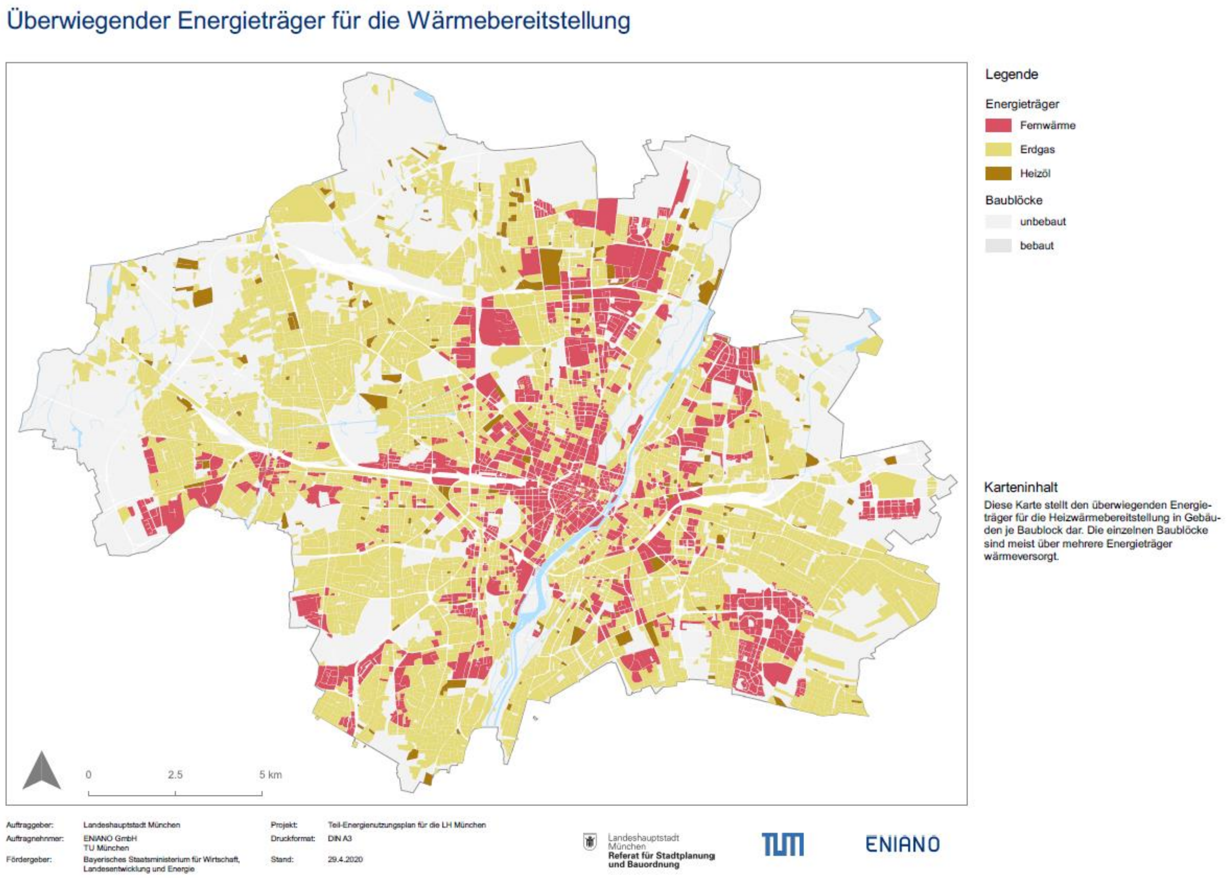


FIGURE 52: THE CURRENT PREVAILING HEAT SUPPLY ON BLOCK LEVEL (RED: DISTRICT HEATING; YELLOW: GAS; BROWN: OIL)

Process

In 2018, the project to set up an Energy Plan was commissioned to an external energy planner team (ENIANO and TU Munich). A working group with members from different departments of the City of Munich, Stadtwerke München (SWM) and other relevant stakeholders was founded to accompany the process ("Arbeitskreis Energienutzungsplan"). The Energy Plan (ENP) was set up in four phases, starting with an extensive phase of data collection and processing to create a building database. Essential steps in the first phase were, for example, the creation of a 3D building model of level of detail 2 from remote sensing data, the georeferencing of data sources or semantic transformations to harmonise data sets. The central result of this phase is a database (ENP database) that combines all relevant basic data for processing the Energy Plan from distributed data sources in a processed and documented format.

In the second phase, as part of the status-quo analysis, a digital image of Munich's building stock was created, which contains all available and energy-related information. In addition, the existing energy infrastructure of the heating sector was included in this model, which contains energy networks, heating (power) plants and renewable energy producers. These components form the basis of an energy system model that combines comprehensive results of the analysis of energy demand and energy supply as well as energy balances and greenhouse gas emissions. The result is a digital image of the heating and cooling sector and the building stock, which allows the virtual analysis and evaluation of future developments.

The third phase, the analysis of potentials, is based on the digital energy system model of Munich's current heating and cooling sector. It aims to determine the existing and future potential for energy savings and climate-friendly energy generation, and thus shows technical solutions for the implementation of the heat transition within the City of Munich. Paths of action were identified by comparing various technical options and scenarios. The paths of action form the basis of strategic consideration processes that include the given framework conditions such as climate neutrality, the available investment funds, the chronological sequence and interdependence of measures, etc.

Finally, the options for action and the coordination processes with relevant actors resulted in a comprehensive catalogue of measures with detailed instructions for implementation. The Energy Plan thus describes the medium and long-term path for the implementation of the heat transition in Munich, underpinned by projects and instructions.

In 2019, the external planners transferred the energy database to the data centre of the City of Munich. The final project report was completed in May 2021.

Framework and principles

An Energy Plan (in German: Energienutzungsplan, ENP) is an informal, strategic planning instrument that encompasses the entire area of a municipality. It formulates spatial energy efficiency objectives for energy generation, distribution, and consumption.

In Bavaria, the Ministry of Economic Affairs, Regional Development and Energy offers a funding programme to all Bavarian municipalities, which covers 70% of the cost for Energy Plans. Therefore, Munich's Energy Plan was set up according to the funding requirements. Based on the existing building stock, the Munich Energy Use Plan systematically estimated the current and future energy demands of the city. The comprehensive ENP database comprises data of about 172,000 heated buildings (e.g. age, main use, energy supply etc.) linked to a new 3D model, which was made from high-resolution aerial photographs of the entire city.

The 3D model enables planners to know the exact volume of each building, which is an important figure to estimate energy demands. Furthermore, more than 100 different data sources have been added to the model. The model will be updated regularly for example with real consumption data, information about demolition and reconstruction of buildings, and renewable energy production plants.

By spatially locating heat demands and renewable energy supply options, energy saving potentials have been identified within the city. The results of the Energy Plan are stored in the energy database, illustrated on detailed maps, and summarised in a catalogue of measures, which comprises targeted energy efficiency measures for the whole city.

Munich's deep geothermal district heating is an important component of the future energy supply system. Munich has an existing district heating network with a length of more than 800 kilometres. Currently, it is still mainly supplied by coal, gas, and waste incineration. The network supplies most of the city centre and central, densely populated districts with high energy demands in the north (e.g. Schwabing, Maxvorstadt, Milbertshofen), the south-eastern district of Neuperlach as well as the west of Munich including the new district of Freiham. The following figure shows the decision tree, which was developed to choose suitable measures for all buildings.

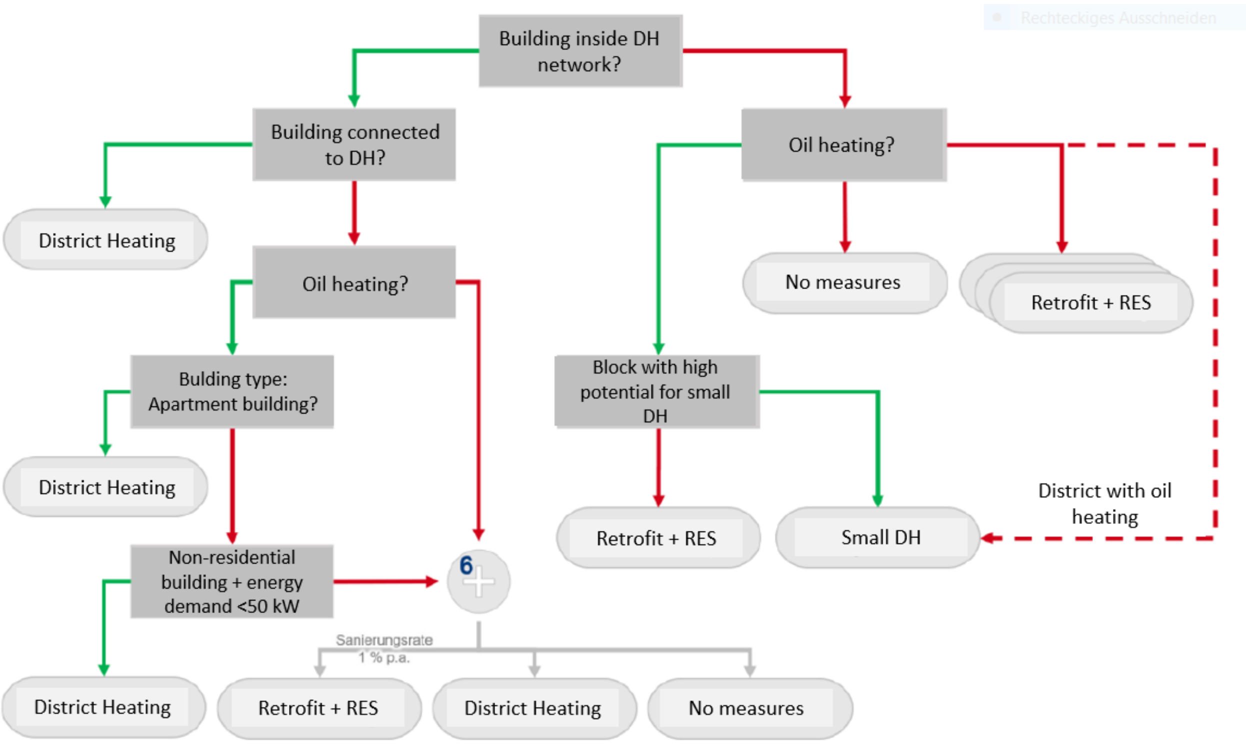


Figure 53: Decision tree for the development of measures

The geological characteristics of Munich's underground allow the use of deep geothermal energy from a depth of 2,000 metres up to more than 3,000 metres. This source of energy will account for the biggest share of district heating in the future. Therefore, a prerequisite for the scenarios of the Energy Plan was to favour district heating connections inside the district heating network and to concentrate the analysis on areas outside the district heating network.

Another framework condition was that large-scale solar parks and wind farms are not yet an option for renewable energy generation in Munich as the city area is quite small. However, Munich is situated in of the sunniest areas of Germany. There is a high potential for rooftop solar power systems, which has not been fully exploited, yet.

Small district heating networks and heat pumps were chosen to be the most suitable supply options outside the main district heating network. Analyses of hydrogeologists showed that the depth of ground water allows the use of decentralised ground water heat pumps in most areas outside the district heating network.

The Energy Plan was intended to develop a spatial heating and cooling strategy, which uses suitable renewable energy sources to phase out gas and oil heating in all parts of the city, based on the current building stock. The reduction of heat demand is as important as the transition to renewable energy sources. Thus, the most common German retrofitting standards were analysed for each building.

While the Energy Plan was developed, the city council of Munich decided to shift the climate protection goal of climate-neutrality from 2050 to 2035. This had no effect on the spatial assertions of the plan, but it means that all buildings in Munich must be retrofitted by 2035 already. At current prices, this means an investment for retrofitting (only insulation and windows) of about 13 billion to 22 billion Euros.

Munich’s Energy Plan is the basis for further planning steps, for example for integrated urban development concepts, preparatory studies, and integrated quarter concepts as well as for retrofitting managements.

Analysed data and aggregation

The Munich Energy Plan was created in four phases that correspond to the specifications of the Bavarian Ministry of Economic Affairs, Regional Development and Energy. At the beginning there was an extensive phase of data acquisition and processing to form an energy database. This included, among other things, the creation of a 3D building model from the remote sensing data of the “GeodatenService” Munich. The main result of this phase is the ENP database, which includes all relevant basic data for the building stock.

In the next phase, the status quo analysis, all available energy-related information about the building stock was determined and compiled into a digital image of the city of Munich in its current state. This included, for example, calculating the heat demand of all buildings using the 3D building model. The existing energy infrastructure of the heating sector was then integrated in the model. Comprehensive analyses of energy demand and energy supply as well as energy and emission balances were carried out using the model.

The analysis of potentials was carried out based on the current situation. It served to determine the existing and future potential for energy saving and climate-friendly energy generation, and thus shows technical solutions for the implementation of the heat transition in Munich. The range of potentials was limited to the most relevant components of the heating and cooling sector for Munich. The following potentials were examined:

- Retrofitting (for different German efficiency standards)
- Solar heat and photovoltaic
- Shallow geothermal energy
- District heating (from deep geothermal energy)
- Small / local district heating

The analysis of options and consultation with stakeholders from administration and science resulted in a comprehensive catalogue of measures with detailed instructions for implementation.

To map Munich's heating and cooling sector and its development for each building, all relevant available data was collected, documented, validated, and transferred to a uniform system. On the one hand, the data came from different departments of the City of Munich, which are usually stored there locally. On the other hand, other relevant basic and specialist data from external bodies were gathered and included in the ENP database.

The data collection included the basic geodata of the “GeodatenService” Munich, which form an essential basis of the Energy Plan and serve as a reference data set for the digital image of the building stock.

The data from the Department of Urban Planning and Building Regulations originate primarily from urban development planning, urban planning and urban redevelopment. This includes mainly information on land use, building uses, years of construction of buildings, listed (historical) buildings, conservation statutes and redevelopment areas.

The data of the (former) Department of Health and Environment contains essential information on the structure of the energy system model, on existing energy sources (fossil and renewable) and on oil tanks as well as on completed retrofitting measures. This data comes from the city's energy efficiency funding programme.

Furthermore, energy consumption data of all municipal properties from the Building Department and the Department of Communal Services (real estate management) were included in the analysis.

To investigate the potential of near-surface geothermal energy in the city, data on drinking water protection areas and a groundwater model from the Technical University of Munich were provided by the Chair of Hydrogeology with high-resolution information on the hydrogeological conditions in the City of Munich.

Since all data had different statuses, the year 2017 was defined as the reference year for the Energy Plan. For data that is not collected regularly and older data, it was a particular challenge to indicate the status of 2017 as closely as possible. If more recent data were available, these were also used.

The analysis of potentials was divided in two parts: analysis of the building stock and analysis of heat infrastructure. The building stock analysis included different retrofitting scenarios for each building. About 70 combinations of German retrofitting standards with different heat supplies for each building in Munich were simulated and integrated in the database to form a comprehensive building model. Furthermore, a solar potential analysis was carried out that not only estimated the solar potential of the roofs itself, but also how many solar cells could be installed on the roofs. The results of this analysis are visualised on an aerial view of the city. The analysis of the potential of shallow geothermal energy from groundwater resulted in site-specific and building-specific information on the use of heat pumps. The results are also shown on maps available in the Geoportal (geoportal.muenchen.de/portal/energie).

The analysis of the heat infrastructure included basic information on the number and power of Munich's heat and power plants. Furthermore, an analysis of potential extensions to the existing district heating network was carried out. For areas with sufficient heat density, an analysis of potential small district heating networks was also included in the analysis.

H/C planning

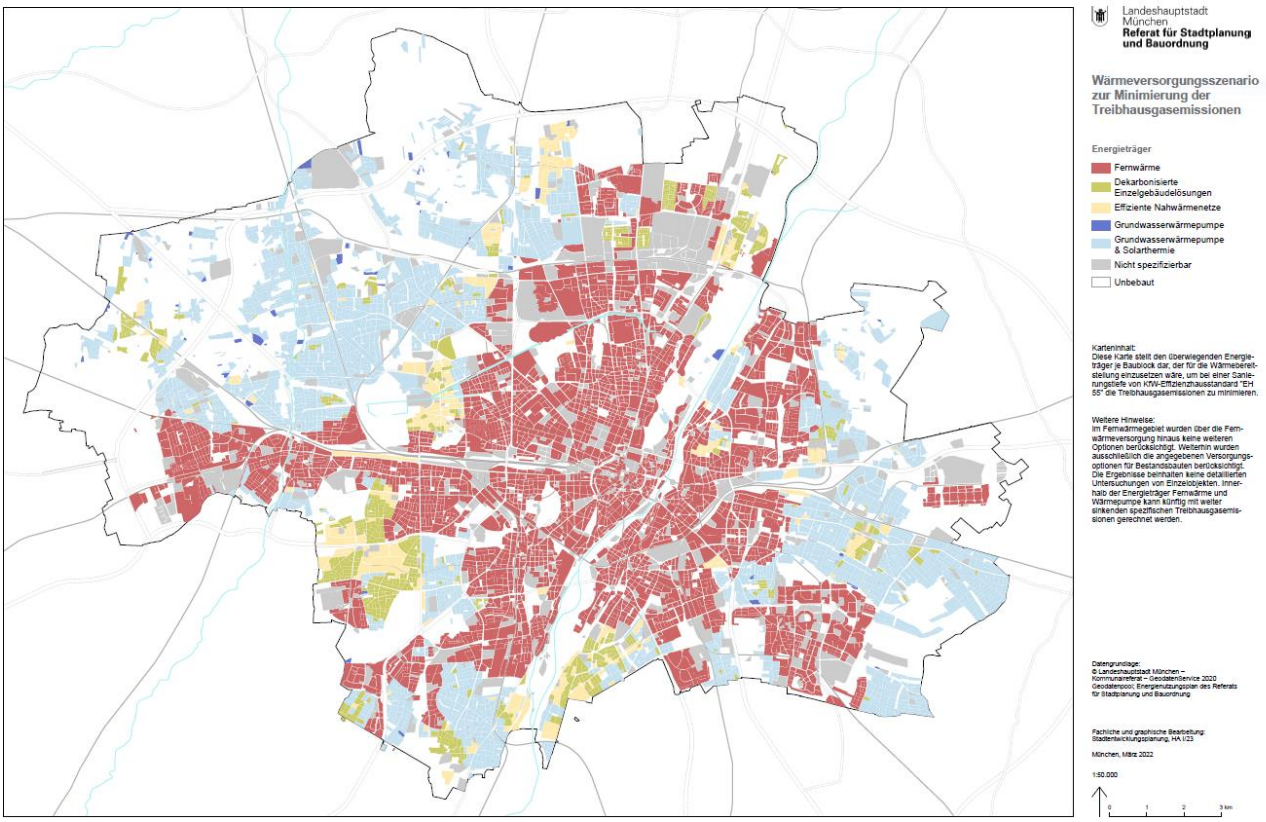


Figure 54: Heat Plan of the City of Munich

The main result of the Energy Plan is the heat supply scenario above, which is Munich's current heat plan. It shows the future heat supply of Munich that is needed to reach climate-neutrality in the building sector. The map basically says that most of the 89,200 residential buildings inside the district heating network should be connected to district heating until 2035. The district heating areas are indicated red.

For the 83,200 residential buildings outside the district heating network, there are more options. The main strategy is to make all suitable buildings ready for heat pumps. The main source of energy for the heat pumps is groundwater (dark blue areas on the map) or groundwater heat pumps in combination with solar heat (light blue areas on the maps).

Yellow areas on the map show potential areas for the development of efficient small district heating networks. The green areas indicate areas with various buildings that need decarbonised building-specific solutions in a more detailed analysis on building level.
In a second approach, it was calculated which measures would be necessary in the short-term to reach at least 33% of greenhouse gas emission reduction. Although this calculation is not in line with the goal of climate-neutrality in 2035, it still shows the huge effort which is needed in the building sector.

According to the calculations, inside the district heating network, it would be necessary to connect about 15,000 additional buildings to district heating. Furthermore, more than 5,400 buildings should be retrofitted and equipped with renewable heating systems.
Outside the district heating network, about 31,600 buildings would need retrofitting and renewable heating systems. 7,700 buildings would be suitable for small district heating solutions.

Even in this least ambitious scenario, about 60,000 buildings would need thorough measures to lower the heat demand and to replace fossil heating.

Next steps

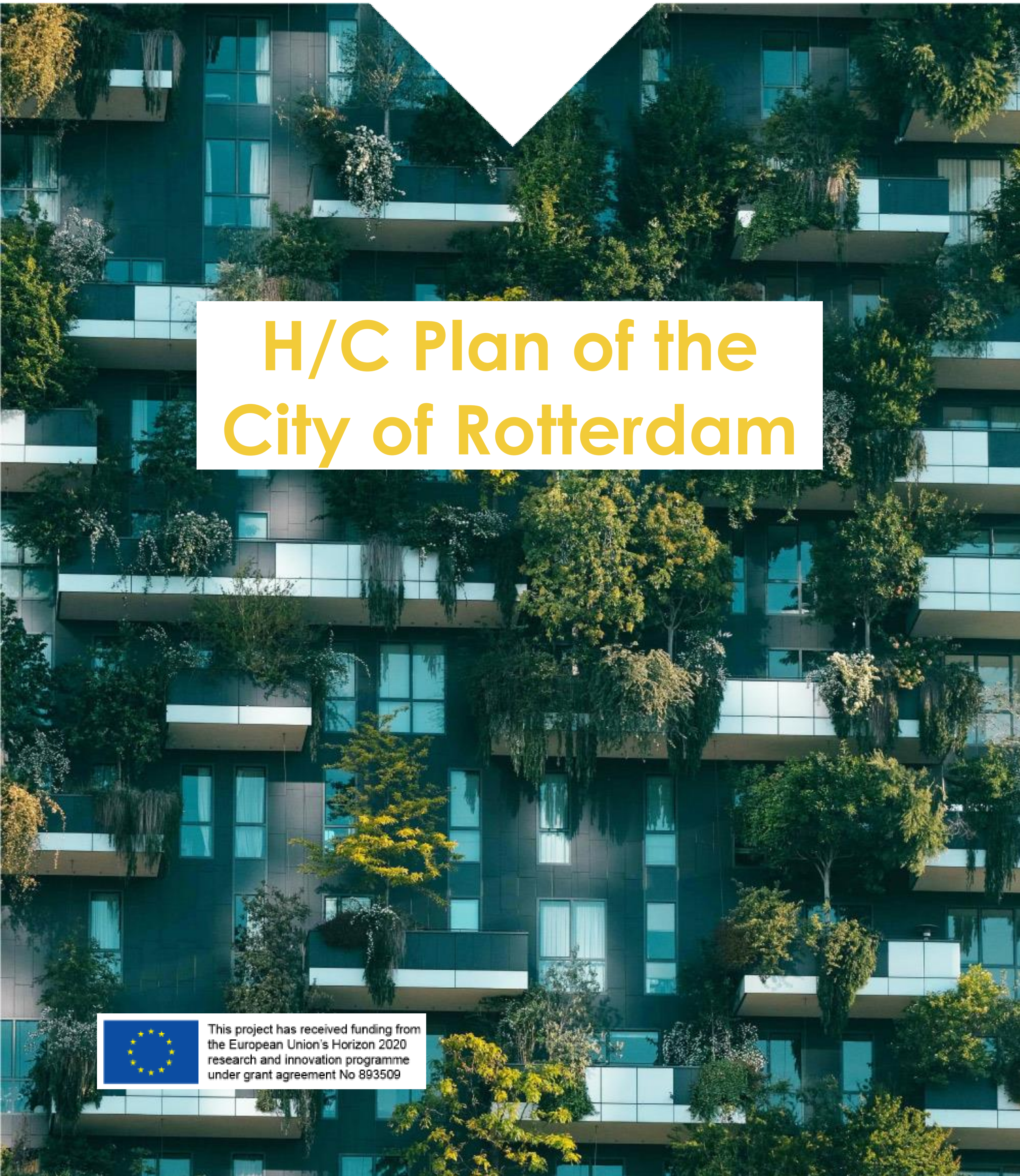
As a next step, integrated quarter concepts will be developed based on the calculations of the energy plan. The quarter concept approach means that all relevant information from the energy plan database will be analysed in more detail on a smaller scale with the aim to develop integrated quarter concepts (“Quartierskonzepte”). The preparation of the quarter concepts will be done in close cooperation with local house owners to ensure the implementation of the concepts.

Furthermore, retrofit managers in each quarter will implement measures of the integrated quarter concept in cooperation with local actors. The preparation of the quarter concepts and the retrofit managers are funded by the German government. Intergrated quarter concepts must include energy efficiency measures (retrofit, renewable heating), climate adaptation measures and mobility solutions. Furthermore, a concept of an Energy Agency is being developed.

At the same time, an analysis of existing legal instruments to implement the heat transition will be performed. The analysis will focus on the German Building Code (BauGB) and the Bavarian Building Code.

DECARB CITY PIPES 2050

H/C Plan of the City of Rotterdam



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 893509

H/C Plan of the City of Rotterdam

Introduction

In line with the Paris Agreement, European agreements and the Climate Act, the Netherlands want to significantly reduce CO_2 emissions in the coming decades. Therefore, Rotterdam wants to be gas-free and climate neutral by 2050.

In recent years, the city of Rotterdam has gained a lot of experience with the five 'district-oriented approaches going natural gas-free'. Fourteen exploratory studies in search of suitable districts for subsequent district oriented approaches, have also yielded valuable insights.

The energy transition is still in full swing. There is still much to be discovered and re-evaluated. The city, therefore, makes decisions in the knowledge that much will probably still change. That's why it has chosen an adaptive strategy. The city focuses on steps that are possible now and avoid steps based on too many uncertainties in the future. In this way, today's choices lay a solid foundation for the future: they are regret-free or no-regret choices. It also gives scope to respond to new developments, innovations and insights.

Currently, Rotterdam has 263,000 natural gas connections, which are mainly used for cooking, heating and hot running water.

We must therefore start on time to ensure that all buildings in the city are natural gas-free before 2050. We will do this in phases, so that the city remains accessible during the heat transition and we can make optimal use

of resources and people. To be able to make sufficient headway towards 2050, a number of components are required.

These will enable us to heat buildings with a clean heat alternative:

- The available technologies to provide a building with heat;
- The necessary infrastructure and spatial possibilities;
- The availability and development of sustainable heat sources;
- The degree of energy saving required to save CO_2 and to make buildings suitable for a heat alternative.

Each alternative to natural gas requires different adjustments and investments. This has consequences for the efforts that users and heat and electricity suppliers must make. We aim to achieve the most suitable and affordable solution for all parties.

Facts & figures for Rotterdam

The city of Rotterdam has seen a population grwoth of 9% since 1995. In 2021, 651,631 inhabitants lived in the city.

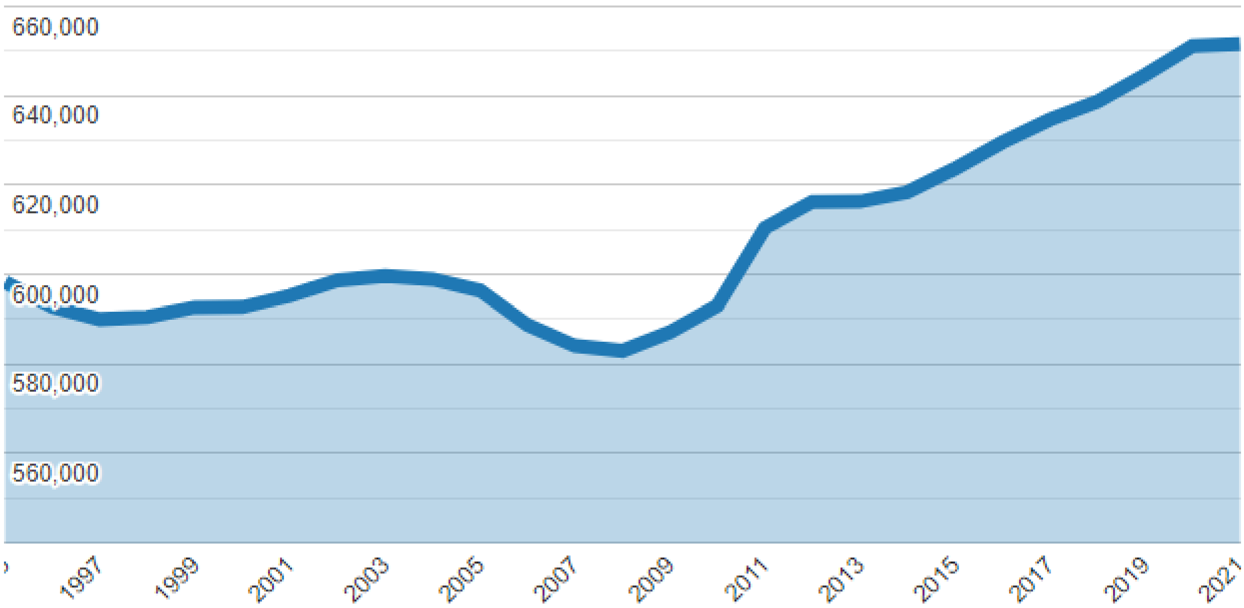


FIGURE 55: POPULATION GROWTH (1995-2021)

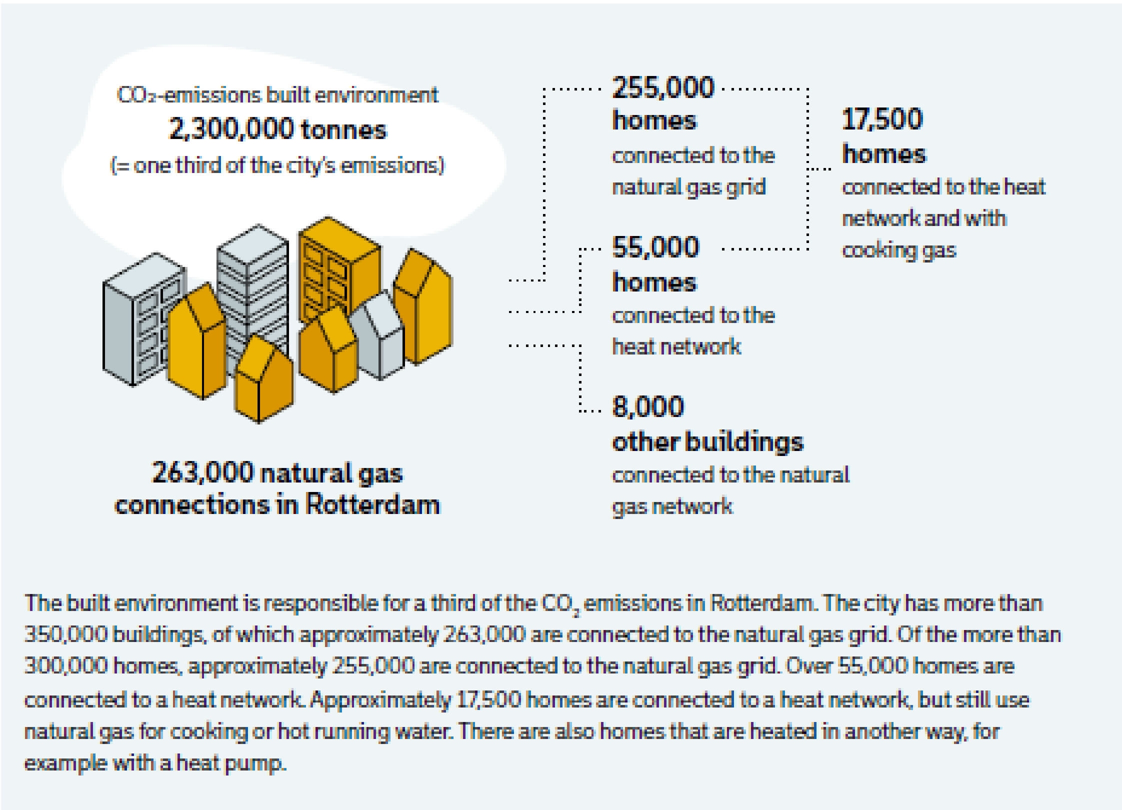


FIGURE 56: THE CHALLENGE OF MAKING ROTTERDAM NATURAL GAS-FREE

FIGURE 57: CURRENT ENERGY INFRASTRUCTURES FOR DISTRICT HEATING

Available heat sources

To make buildings natural gas-free, we need clean energy, both now and in the future. The most important clean energy sources in the Rotterdam region are industrial residual heat, geothermal energy, aquathermal energy, clean electricity from the sun and wind and sustainable gases (including hydrogen). The availability of these energy sources has been analysed on behalf of the municipality. Naturally, we are taking into account the energy demand from the region, as agreed in the Regional Energy Strategy.

Industrial residual heat

There appears to be sufficient sustainable heat available in the vicinity of Rotterdam. The potential supply of heat in our region is almost twice as large as the expected future demand for heat. There is a above all a lot of residual heat: in the harbour alone, there is currently much more residual heat available than we use. Residual heat – increasingly from sustainable sources – will therefore form an important part of Rotterdam's sustainable heat mix.

Geothermal energy

Geothermal heat is also abundantly available in the Rotterdam region. This is important because for a robust and reliable heat system it is important to use multiple sources for supply of heat networks.

Clean electricity from the sun and wind

Rotterdam has sufficient sustainable heat sources, but at the same time, there is a shortage of clean electricity in our region. Moreover, we expect the demand for electricity in the city and port to grow strongly due to, among other things, electric driving and the production of green hydrogen for industry. So we will also need clean electricity from outside the municipality, for example from offshore wind farms. To prevent a further increase in electricity demand, we are not encouraging electric heating with heat pumps. It is more efficient to use heat networks, because then we can use the available residual heat from the port. We want to make optimal use of this. Where a heat network is the most affordable and efficient solution, we will try to avoid electric heating solutions.

Sustainable gases

Sustainable gases, such as hydrogen and biogas, can also serve as fuel for heat. But their availability is limited in the short term and they are also very expensive. We prefer, therefore, not to use them for heating, but rather as a raw material for industry, as a fuel for industrial heat, for heavy and long-distance transport, energy storage and grid stability. These activities are more difficult to solve with other renewable energy sources. Indirectly, however, the combustion of sustainable gases in industry does produce residual heat for a heat network.

So, we do not expect sustainable gases, such as hydrogen, to become a viable alternative to natural gas for heating homes. The following applies to all sustainable energy sources: we will use high-quality sources as much as possible for a high-quality demand and we will be very economical with scarce sources. Biomass will therefore mainly be used for food and animal feed, construction materials and chemicals rather than as fuel. Our choices are explained in the municipal visions on hydrogen and sustainable biomass.

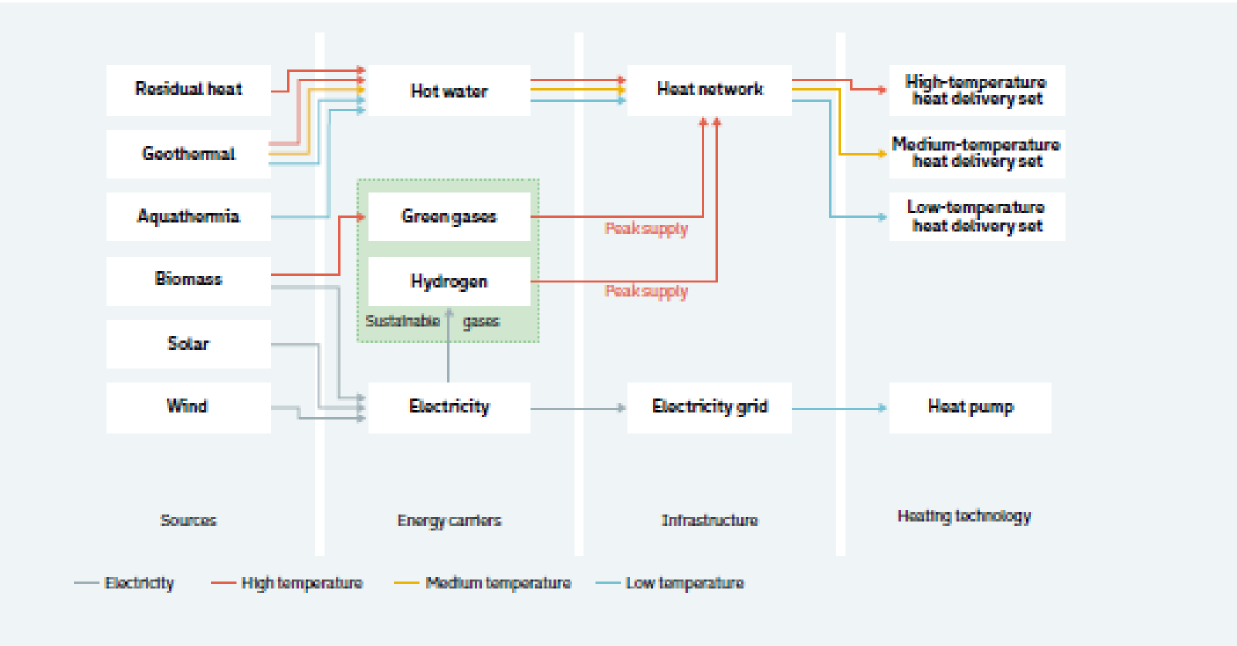


FIGURE 58: AVAILABLE ALTERNATIVE HEAT SOURCES TO NATURAL GAS

Process

The scope of our H/C plan is buildings with a natural gas connection (industry cluster harbour not included). The goal of the analysis is to identify promising districts for new district oriented approaches and to identify the preferred (most affordable) alternative heating solution per neighbourhood. For our analysis we involved housing corporations, grid operator, concession holders (heating companies), technical department City of Rotterdam, bordering municipalities (if relevant)

The steps we took are:

- Selection of exploration districts (2019): In 2018, we started a district orriented approach to natural gas-free heating in five districts.
- Exploratory study in 14 districts (2020)
    - District analysis: local characteristics and relevant tasks;
    - Technical analysis: insights into the heat system;
    - Business cases: insights into costs and benefits:
    - Planning: coordinating the work in buildings, in the topsoil and in the subsoil.
- Selection of promising districts (WHEN map) (2021)
- Improvement of the WHAT map (2021)
- In progress: improvement oft he WHAT map (2022) where we further analyse the heating and cooling demand, insulation, heating an cooling solutions, temperature, transport pipes, heating and cooling sources and storage.

Framework, principles, data & analysis

The Rotterdam WAT map of 2021 is part of the Rotterdam Transition Vision Heat 2021.

This map shows per neighbourhood:

- the most affordable alternative to natural gas at the lowest total costs (also known as social costs).
- How much cheaper this preferred alternative is compared to the second cheapest alternative.

We took an AGILE approach: goals not laid down in detail in advance, iterative, adjust gradually, bi-weekly meetings. Roughly chronologically:

FIGURE 59: ROTTERDAM´S AGILE APPROACH

Data we used:

- **Buildings:** basic administration data, m², energy label, surface windows/doors/roof/facade, isolation level
- **Network connection**: gas grid, heat network or both
- **Heat demand:** current use on street level
- **Costs district heating:** COMSOF-analysis results

- **Results:** per building the optimal internal and external transition costs

The Rotterdam Natural Gas Free Model (RAM) calculates per home the optimal internal (within the building) and external (energy system) transition costs.

ComSOF external transition costs district heating network: connection costs per home/cluster + costs per meter of pipe.

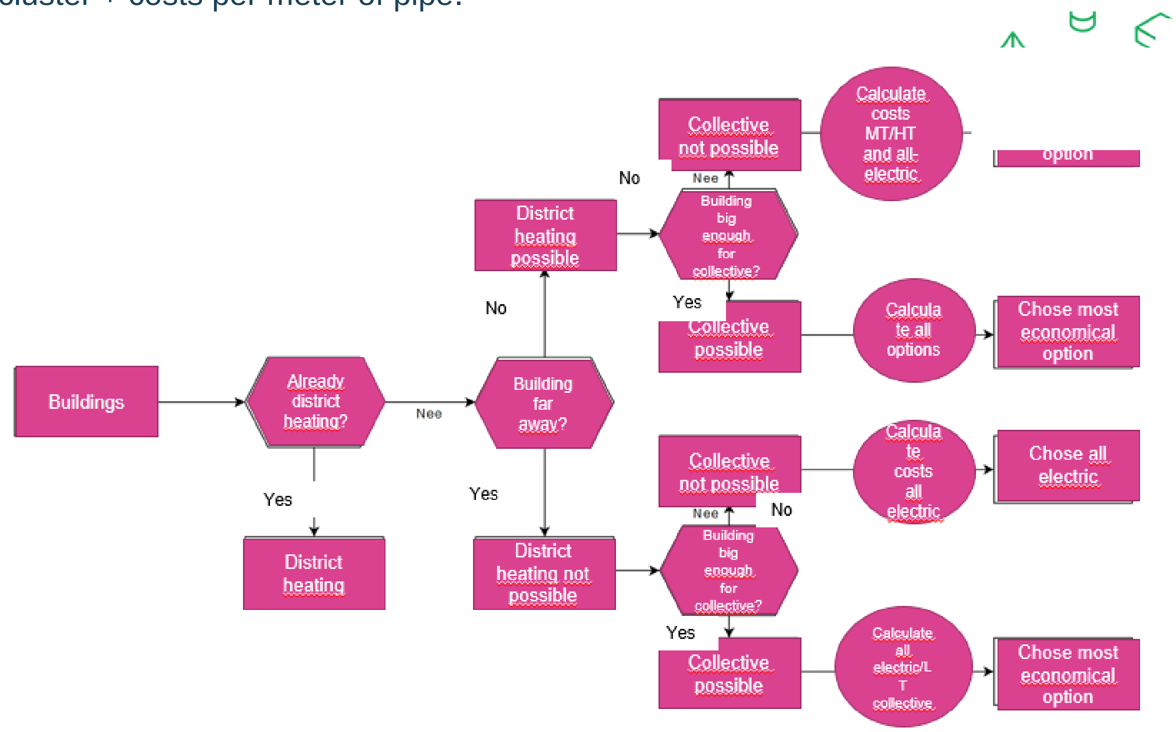


FIGURE 60: DECISION RULES USED

The calculation made uses a big set of assumptions and principles, examples of these assumptions and principles used for the WHAT map calculations are:

- District average
- 30 year average
- Average energy consumption per type of building
- Heat supply is assumed not to have a limit, there is enough waste heat from the port of Rotterdam and high potential for geothermal heat.
- Avoid electrification (based on clean energy strategy – Regional Energy Strategy Rotterdam The Hague)
- For DH cost efficient insulation is assumed for each household, average costs at buildingslevel for this kind or insulation are used.
- Cost of DH bases on average cost per meter DH
- For LT / electrical solutions individual Heatpumps are assumed and the current electrical grid does not need reinforcemend (assumption) .

H/C planning

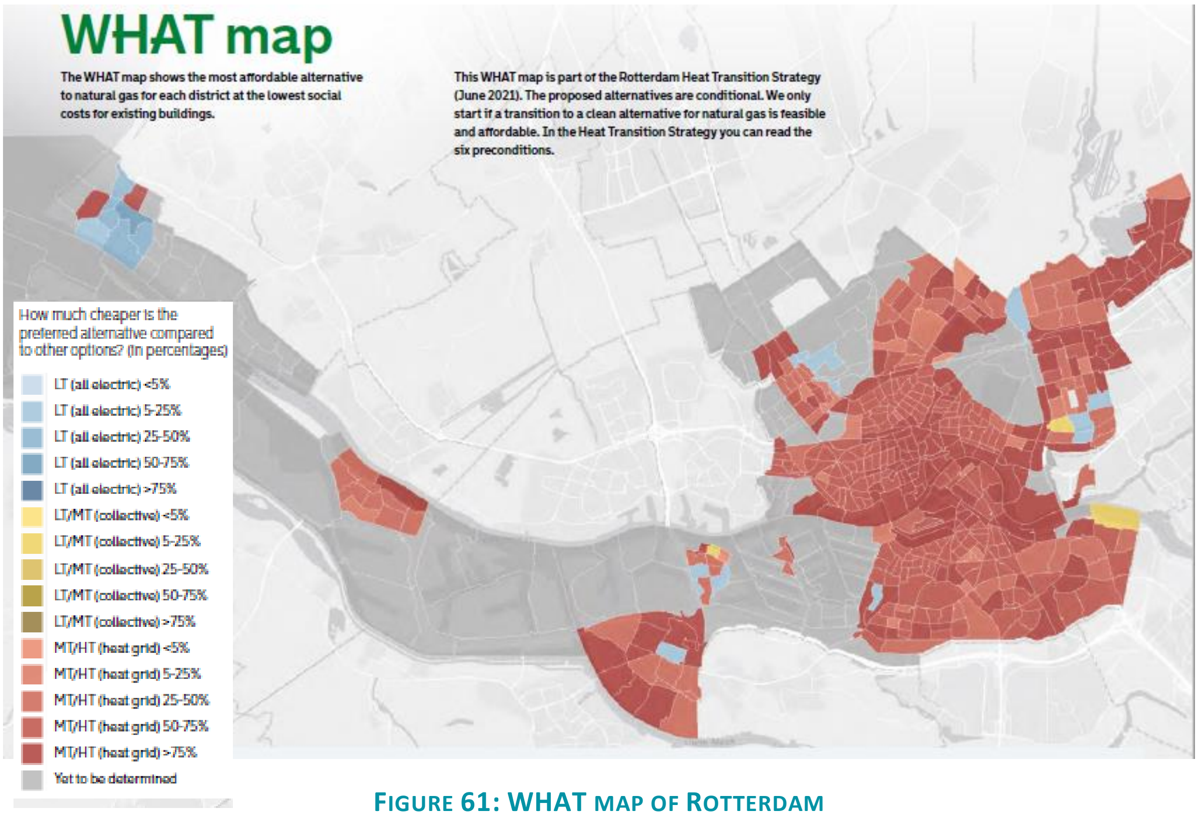


FIGURE 61: WHAT MAP OF ROTTERDAM

The WHAT map shows the most affordable alternative to natural gas for each district at the lowest social costs for existing buildings. The proposed alternatives are conditional, it gives direction to the most likely options, but is not yet a decision. The transition is only started if the clean alternative is feasible and affordable. The six precondition, as mentioned in the Heat Transition Strategy, are:

1. Compensation for implementation costs and sufficient implementation capacity of the municipality;
2. Sufficient investment and implementation funds as well as sufficient implementation capacity of housing corporations;
3. Solutions for the unprofitable portion and pre-financing of the construction of collective heat solutions;
4. Additional financing and subsidies for private individuals, tenants and home owners associations;
5. Sufficient powers for municipalities in terms of legislation and regulations; and
6. (Im)possibilities in spatial planning.

A heat network is the cheapest option

As the WHAT map indicates, in large parts of the city collective heating solutions are an attractive alternative to natural gas in terms of affordability for residents, landlords and businesses. A medium or high temperature heat network is the cheapest alternative for the majority of Rotterdam's districts. The initial analysis by the Netherlands Environmental Assessment Agency and the Openingsbod (opening offer) from grid operator Stedin confirm this.

This in itself is not surprising. In an urban environment, collective systems are often the socially cheapest alternative to natural gas. About one-fifth of the buildings in Rotterdam are already connected to district heating; we have been using heat networks since the 1950s. Further economies of scale mean that costs are lower and also more fairly distributed. Heat would then be distributed to homes via a heat network. The advantage of a heat network is also that it is suitable for using other sources of heat in the future, making it a no-regret investment.

Another sustainable alternative to natural gas is electric heating (all-electric). This is an individual solution per house, which is relatively expensive. Most existing houses in Rotterdam must be heavily insulated for this type of heating, making this solution, on balance, often more expensive.

Cooling

Due to the heating transition, the demand for collective heating is rising sharply. This is therefore a matter of considerable technical, organisational and legal attention. Less attention is paid to the expected increase in demand for cooling, although this will also require changes to our energy system. It is difficult to estimate the extent of the demand for cooling. The expected increase is partly due to climate change; the average temperature in 2050 is expected to rise from around 1.4°C to 3.3°C compared to now, and the number of summer days when it is warmer than 25°C will increase from 21 to possibly 35 days in 2050. In addition, new-build homes, but also existing homes, are increasingly well insulated, which increases the demand for cooling. The necessary cooling demand for existing and calculated new-builds in 2050 is 47 per cent higher for residential buildings and 5 per cent higher for non-residential buildings than in 2020. In addition to the necessary cooling, the demand for comfort cooling is increasing. What is a comfortable temperature differs from resident to resident. Age and health, but also the personal comfort of the resident plays a role in this. As we tackle the issue of cooling and as more cooling becomes available, the demand for comfort cooling will increase. This makes it difficult to identify the level of comfort demand. There are various technical solutions for meeting the increased demand for cooling. As with heating, the first step is to reduce the demand for cooling. These include sun blinds, green-blue roofs or greening the city.

Sustainable cooling can be generated by means of a heat pump, cooling from the ground or surface water stored in a GCHE or distributed via a collective cooling network.
The last two technical solutions are already being applied in Rotterdam. We want to minimise the use of air conditioning because of the negative impact it has on the environment, which it heats up, the noise it produces and the increasing demand for electricity.

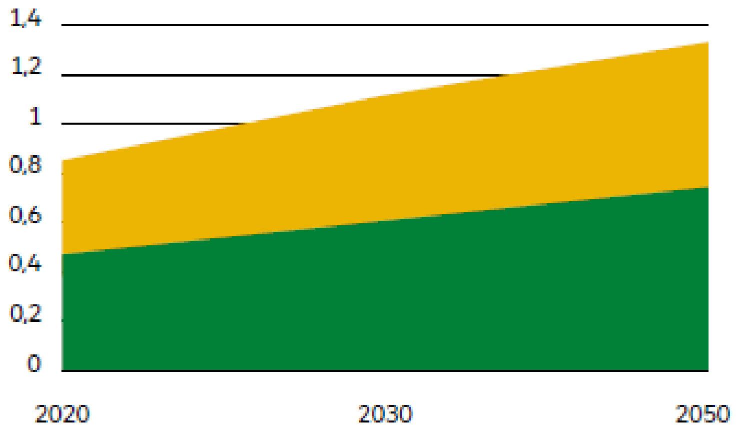


TABLE 16: COOLING DEMAND (IN PJ / YR) FOR UTILITIES (YELLOW) AND HOUSING (GREEN)

Promising areas for an integrated gas-free approach

In 2018, we started a district oriented approach to natural gas-free heating in five districts. Based on our experiences in these, we drew up the first version of the WHEN map in early 2020. On this map, we have designated fourteen districts where we believe a subsequent district oriented approach to natural gas-free energy is possible. We call these district the exploration districts.

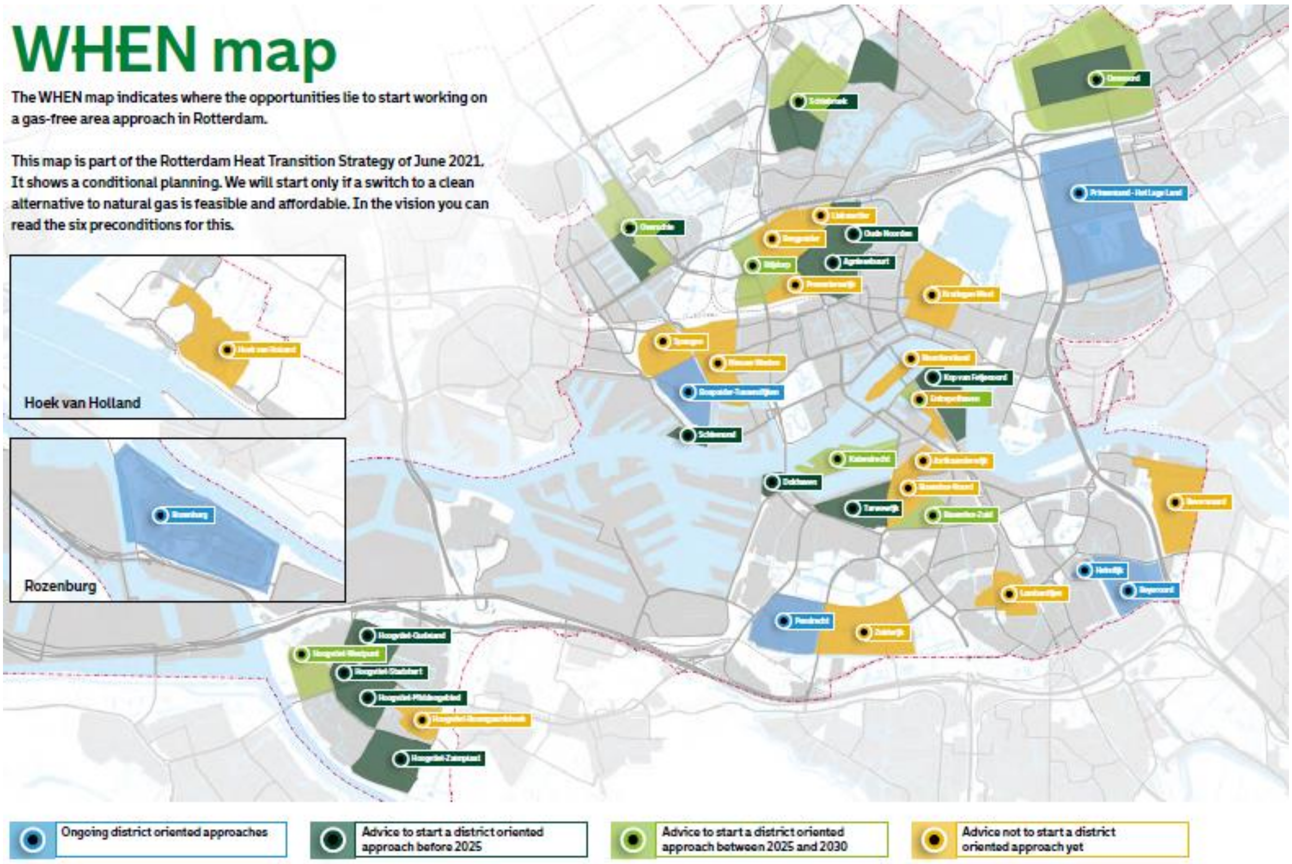


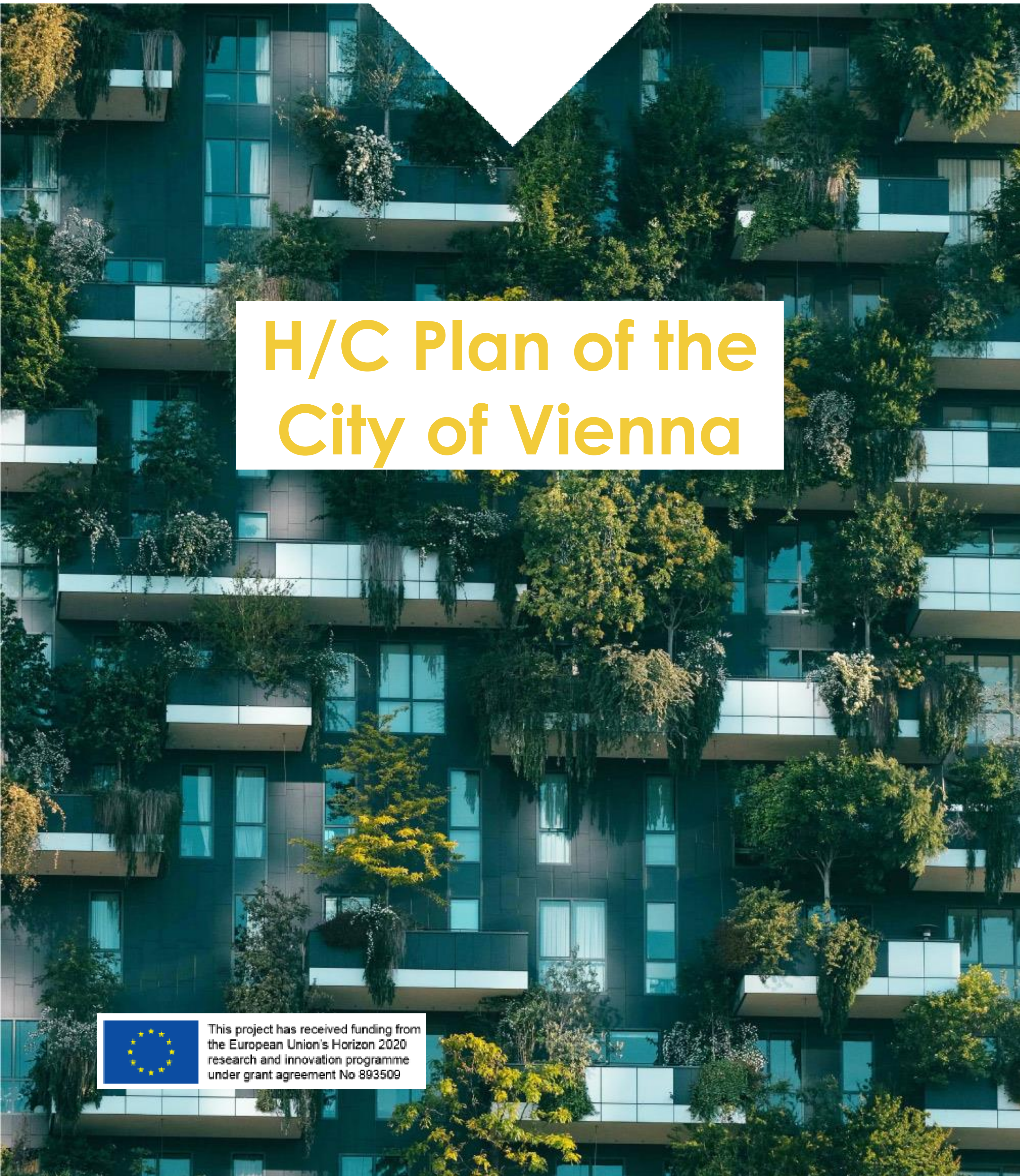
TABLE 17: WHEN MAP OF ROTTERDAM

Next step: Rotterdam Heating Cooling Strategy

- **Scope**: Working towards a collaboration between stakeholders with which we develop an adaptive strategy about the heating and cooling system. This strategy concerns efficient solutions for cross-district aspects of the heating and cooling system; sources, transport pipelines, storage, conversion, temperature and offtake.
- **Goal:** An adaptive strategy on the heating and cooling system that is shared and supported by all stakeholders.
- **Who is involved:** Stakeholders (heat companies, Warmtebedrijf Rotterdam (=Heat Company Rotterdam), The Regional Energy Strategy Rotterdam The Hague (RES), (potential) heat producers, housing associations, representatives of (potential) heat consumers and network company) and the Municipality of Rotterdam.
- **Steps**: In the project Rotterdam Heating and Cooling Strategy we analyze what system is needed to make the WHAT map possible. Our adaptive strategy is about how we work together with stakeholders towards this system. (In addition, this analyses can change over the years due to developments or new insights)

DECARB CITY PIPES 2050

H/C Plan of the City of Vienna



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 893509

H/C Plan of the City of Vienna

Introduction

The city of Vienna is the largest city in Austria, the fifth largest in the European Union and the second largest German-speaking city. Like many other cities across Europe, Vienna is facing continuous population growth. Furthermore, rising temperatures due to climate change is another challenge that urgently needs to be dealt with.

Compared to other provinces in Austria, Vienna has the lowest energy consumption per capita. Nevertheless, a lot of fossil energy is still used for the city's energy supply. In the heating sector, natural gas and district heating dominate the market.

Currently, great efforts are being made to eliminate the use of natural gas for heating. In addition, parallel efforts are being made to decarbonise the district heating system. Overall, there are more than 400,000 individual gas floor heating systems in Vienna, making the decarbonisation an even more challenging task.

In the Viennese Climate Roadmap (*Wiener Klimafahrplan*), central fields of climate protection and climate change adaptation were elaborated. These include the following matters in the energy sector (Magistrat der Stadt Wien, 2022):

- Expansion of renewable energy
- Covering the heating and cooling demand in new buildings without fossil energy
- Long-term phase-out of gas heating in existing buildings
- Thermal and energetic refurbishment of the building stock and efficiency improvements in heating systems
- Expansion of the electricity, gas and district heating grid infrastructure as well as storage facilities
- Continuation of integrated spatial and energy planning
- Reduction of cooling demand

Facts & figures: the context

Vienna is the largest city involved in this project, with a population of around 1,935,000 inhabitants in 2022 (Stadt Wien, s.a.a). This number is likely to continue to rise: Between 2018 and 2040, the population is expected to increase by 16.6% (ÖROK, s.a.). To better understand the city, some facts worth knowing are listed in the table below.

TABLE 18: OVERVIEW FACTS OF VIENNA

Type	Quantity	Source
Inhabitants	1,935,000	https://www.wien.gv.at/statistik/bevoelkerung/bevoelkerungsstand/
Total area	41,487 ha	https://www.digital.wienbibliothek.at/wbrup/download/pdf/3724138?originalFilename=true
Total number of buildings:	164,746 (2011)* [estimate for 2021: 185,000] Ownership: • Local authorities: 25,915; • Non-profit building associations: 17,156; • Other legal entities: 10,347; • Private individuals: 111,328	https://www.digital.wienbibliothek.at/wbrup/download/pdf/3724138?originalFilename=true
Total number of apartments	983,840 (2011)	https://www.digital.wienbibliothek.at/wbrup/download/pdf/3724138?originalFilename=true
Total dwelling area	69,233,000 m^2	https://www.digital.wienbibliothek.at/wbrup/download/pdf/3724138?originalFilename=true
Average living area per apartment	72 m^2	https://www.digital.wienbibliothek.at/wbrup/download/pdf/3724138?originalFilename=true
Length of district heating network	roughly 1,200 km (around 430.000 apartments and 7.700 business customers are currently connected)	Internal city data
Total final energy consumption	37,005 GWh/a	MA 20 (2021)
Total final heat consumption	18,243 GWh/a	MA 20 (2021)
Energy consumption per capita	19,502 kWh/cap*a (Austrian average: 35,564 kWh/cap*a)	MA 20 (2021)

*Remark: The latest register data assessment was published in 2011. (the new register data assessment will be available in 2023)

The total final energy consumption in Vienna accounts for 37,005 GWh/a. As Figure 62 illustrates, half of the energy used in the city is attributed to heat applications, 38% to mobility and 12% to electricity specific applications.

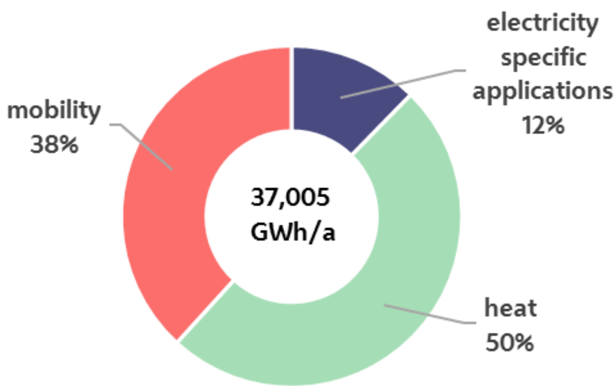


FIGURE 62 : TOTAL FINAL ENERGY CONSUMPTION BY APPLICATION (MA 20, 2021)

Natural gas and oil currently still dominate the total energy consumption accounting for 74%. As Figure 63 shows, the most important energy sources for heating are natural gas (40%) followed by district heating (33%) and electricity (20%) (MA 20, 2021). Oil and coal play only a minor role in Vienna´s heat supply.

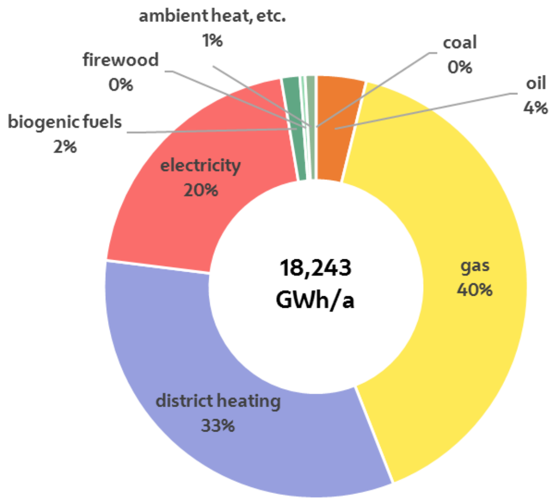


FIGURE 63 : TOTAL FINAL HEAT CONSUMPTION BY ENERGY SOURCE (MA 20, 2021)

The supply of district heating with renewable energy remains a challenge in Vienna. Figure 64 shows the distribution of energy sources used for district heating. Natural gas still has the largest share (39%), followed by cogeneration (35%) and waste incineration (11%). It is, however, important to note that there are strong seasonal fluctuations in heat supply. Waste incineration is used to cover the base load. The peaks, in turn, are covered by gas (especially in the winter months).

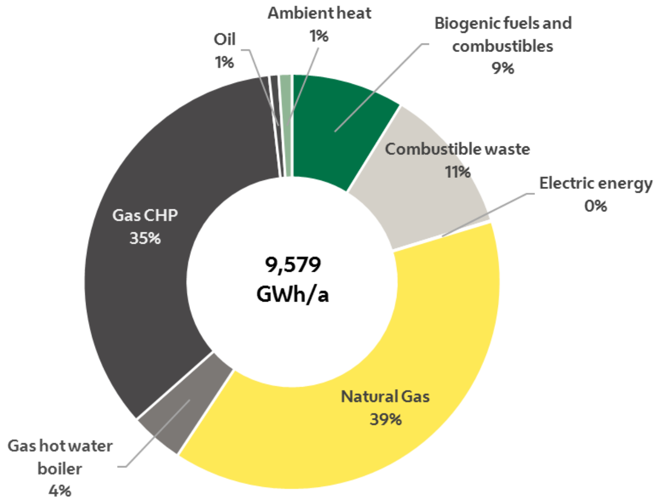


FIGURE 64 : DISTRICT HEATING GENERATION BY ENERGY SOURCE (MA 20, 2021)

Figure 65 illustrates the most essential energy flows in the city of Vienna, starting from its gross inland energy consumption to its final energy consumption by end use.

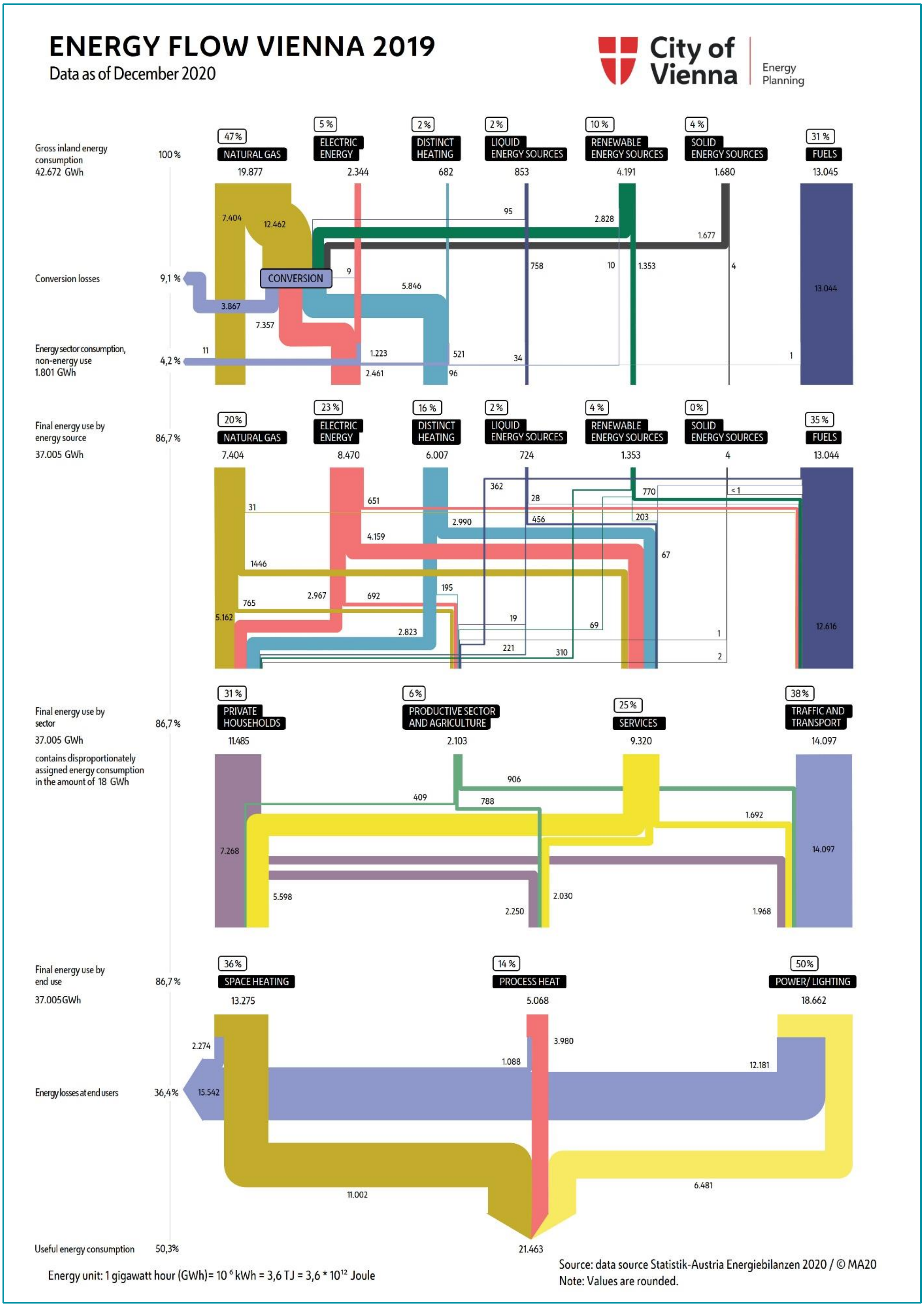


FIGURE 65 : ENERGY FLOW VIENNA 2019 (MA 20, 2020)

With an annual average of 19,502 kWh per inhabitant, Vienna has the lowest energy consumption per capita compared to other provinces in Austria with an average of about

35,564 kWh per inhabitant (MA 20, 2021). But this fact is mainly related to the urban structure compared to the dominant rural structure of other provinces.

Vienna's gas grid currently covers approximately 90%, its DH grids roughly 50% of the city. The network infrastructure in Vienna is primarily operated by the city-owned net provider Wiener Netze (*Wiener Netze* as part of *Wiener Stadtwerke*).

Wiener Netze owns and operates the primary district heating network (on high temperature level of up to 160 degrees Celsius). The secondary network (between 65 and 85 degrees Celsius) as well as the "business" is maintained and operated by the biggest utility in Austria *Wien Energie*. The energy provider Wien Energie is also in charge of distribution and sales. The district heating network is closed for external utilities – and thus can only be used by *Wien Energie*. However, there are four small district heating networks in Vienna, owned and operated by a public Austrian utility, *KELAG*. The main energy source for these DH networks is gas.

Within the Vienna City Administration, all energy planning competences (e.g. energy zoning, PV programme etc.) and general energy-related issues of decarbonization in the city were consolidated in the Municipal Department 20 - Energy Planning in 2011.

Please note that future developments and scenarios for Vienna on the path to carbon neutrality will be described in detail in Deliverable 2.6 "H/C outlook 2050 in each participating city and cross-city synthesis".

Process

A key component in the process for developing the H/C plans, was the political decision in 2020 on city level on the goal of reaching carbon neutrality by 2040. The city government coalition agreement (of the so called "Fortschrittskoalition") of 2020 laid out the following main goal for the heating and cooling sector:

> "By 2040, the phase-out of fossil fuels for heating, cooling and hot water production will be completed." (Stadt Wien, s.a.b)."

Based on this coalition agreement, an extensive process ("Wiener Wärme und Kälte 2040") on how to decarbonise Vienna's heating and cooling sector by 2040 was set up within the city. An important role in this decarbonisation process is played by Vienna´s local working group (LWG), which comprises all relevant stakeholders at the city level dealing with energy issues (e.g. city administrations, utility (Wien Energie), DSO (Wiener Netze) etc.). The local working group (which also developed the H/C plans) was set up in 2021. In addition to a steering group, topic-specific working groups (WGs) were established, on the following topics:

- Technical issues (data, building typologies, …),
- Legal issues (how to deal with individual boilers etc.),
- Financial issues (funding, subsidies etc.),
- Communication and stakeholder involvement.

The H/C plans are an interim result of this process. They were developed within and in intensive exchange with the members of the local working group. The procedural steps towards the H/C plans are shown in Figure 66.

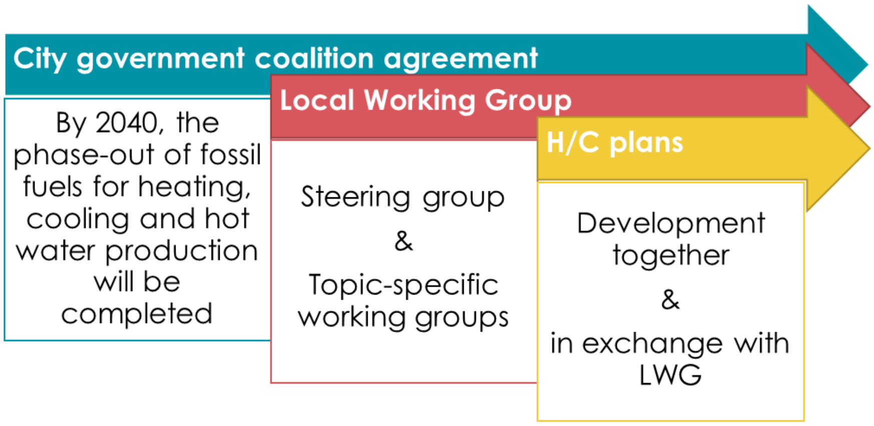


FIGURE 66 : SCHEME OF THE PROCESS TOWARDS H/C PLANS (OWN ILLUSTRATION)

Framework and principles

The following principles and issues were used and addressed in developing H/C plans for the City of Vienna:

District Heating as THE essential backbone

District heating (DH) is an essential backbone of Vienna's future heat supply. Currently, DH already supplies more than 1/3 of Viennese households with heat (this equals roughly 430,000 apartments and 7,700 business customers). Thus areas are assessed, in which DH can either be densified or extended. Scenarios regarding the future of DH can also be found in a recent study published by the main utility of the city: https://positionen.wienenergie.at/studien/decarb-studie/.

The challenge of parallel infrastructure

A particular challenge is the parallel infrastructure of gas and district heating, since there are a lot of buildings currently connected to both. In some buildings, gas is only used for cooking, while DH is used for heating. In some buildings gas is still the source for hot water preparation while DH is used for space heating. The city of Vienna is currently developing strategies to alleviate this unwanted and expensive situation.

Decarbonising DH

Vienna´s DH system currently still heavily relies on natural gas as its energy source. So the question of how to decarbonise the district heating is of utmost relevance for the city. This can be accomplished via large central heat pumps, the integration of waste heat and deep geothermal energy.

Criteria for DH areas and urban typologies

The biggest challenge for the city is the decarbonisation of the existing building stock. Since grid-bound heat supply requires the development of criteria for delimiting individual local DH areas (for instance low-temperature decentralised DH networks), comprehensive data and information is needed regarding the building stock of the city. The main idea behind using energy (geo)data is to deepen knowledge on building and H/C landscape typologies. Such typologies can then be used to develop H/C maps. Furthermore, they help in identifying which and how many buildings will be proper for which technical solutions. This allows

funding programs to be specified and economic impacts and requirements to be derived, including manpower, resources and budget needs.
The typologies and the draft H/C plans as laid out in this document will substantially support the city's path to conceptualise the future of heating and cooling in Vienna. Thus, a commitment was formed between Wiener Stadtwerke (WStW) and the city of Vienna to develop a H/C plan in close coordination. Based on these plans, a specific concept for decarbonisation strategies will be finalised by the end of 2022. The concept is developed together with the LWG.

As already mentioned, one of the main elements towards the decarbonisation of the building stock is DH. District heating will be the preferred option in densely built areas of the city – especially in the inner city, preferably with a connection rate close to 100%.

The *Goals, Framework and Principles* can be summarised as follows:

- Identification of **buildings which are already connected to district heating as well as gas** (parallel infrastructure within the building), with a potential for 100% DH supply (thus, some sort of quick wins towards decarbonising existing buildings).
- Identification of areas for densifying [connecting buildings to existing pipes] or extending [new DH infrastructure] the **central district heating** network (primary network with temperatures up to 160°C and secondary networks with temperatures between 65 and 85°C).
- Identification of areas suitable for **local district heating networks** (from medium to low temperature heating, including anergy grids).
- Identification of areas for **renewable decentral solutions** (heat pumps that use ambient heat, e.g. for single-family houses or detached houses)
- Derivation of solutions on **how to deal with remaining gas consumers** – e.g. use of (green) gas for process heat (high temperature) and/or for peak load coverage of district heating and electricity generation
- **Decarbonisation of central DH network** (with main sources being deep geothermal energy, waste incineration, waste/residual heat [data centers, supermarkets, waste water …], large heat pump applications and green gas) which includes also the need for heat storages in the urban area

Figure 67 visualises the framework and principles used. The central DH network is divided into the primary network (large red bubble) and the secondary network(s) connected to it (smaller red bubbles). Separated local DH networks are pictured in green. These are intended to contribute to the decarbonisation of the building stock through grid-bound heat supply.

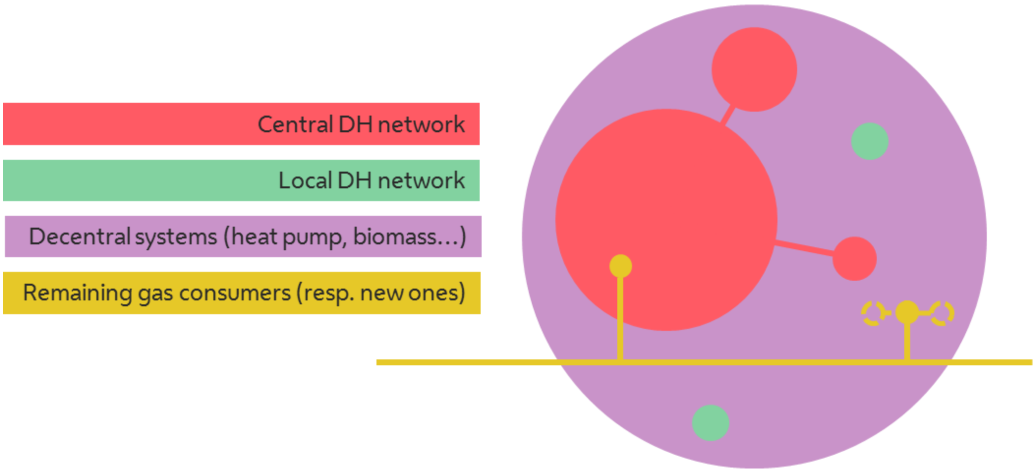


FIGURE 67 : VISION FOR DECARBONISING VIENNAS' BUILDING STOCK (BASED ON H/C OUTLOOKS 2030/2050)

Decentral solutions such as individual heat pumps are to be implemented in areas where DH is not feasible, e.g. in low-density areas in the outskirts of the city that are mainly dominated by single and detached houses or for buildings where a DH connection is just not possible. An important question that remains to be answered concerns the remaining gas consumers or the new gas consumers and the limited role of green gas in the heating and cooling sector.

The role of cooling in Vienna

In comparison to the heating demand in the city of Vienna, the total cooling demand is comparably low. When preparing the Smart City Strategy of Vienna, among other things, cooling demand quantities were determined. Accordingly, the cooling demand in the building sector was calculated at around 350 GWh/a. In comparison, the heating demand was estimated with 15.5 TWh/a.

It is also important to emphasise that the need for cooling will increase significantly in the future, while heat demand will decrease respectively. At present, however, the decarbonisation of the energy system is a question of heating, not cooling, as cooling is mainly accomplished through electricity. Hence, the decarbonisation of the electricity supply is another important issue, but is however not the focus of the Decarb City Pipes project. In addition, the expansion of PV systems in Vienna up to 800 MWp until 2030 (see https://photovoltaik.wien.gv.at/) will support the renewable operation of cooling generation. Nevertheless, there exists already a new district cooling (DC) network (16 km length and 130 MW) operated by *Wien Energie*. The focus of DC are business customers including hospitals, office buildings and hotels. Especially in the inner city there is a plan to provide a comprehensive DC network. Another focus of the city is climate adaptation, e.g. through greening and sustainable urban planning, which ultimately leads to a reduction of active cooling. This leaves the following main strategies in the city, which are:

- Estimate the expected cooling demand in detail
- Protection against overheating in summer:
    - Passive measures (architectural shading, external sun protection,...)
    - Active year-round conditioning of buildings: low-temperature heating systems and concrete core activation (excess heat in summer in thermal storage mass in combination with geothermal probes)
- No focus on district cooling – nevertheless it will be part of the decarbonisation strategy how to deal with DC in the future
- Find the most efficient technical solutions for different types of buildings

In the context of framework and principles, the cooling demand was not part of the maps presented in this deliverable.

Analyses data and aggregation

The basis for the analyses preceding the development of the H/C plans is a geodata model from the research project *GEL SEP (Spatial Energy Planning for Energy Transition)*, including building specific data such as the building period, type of use, gross floor area, type of heat supply and many more. In addition, the heat demand of each building in Vienna was calculated. Besides building data, the results also include a heat density map in a 5x5 m raster, and heat source layers, e.g. on geothermal energy potentials.
Raw, primary data was first collected from various sources and processed at the *Municipal Department 20 - Energy Planning.* In some cases, the data first needed to be georeferenced or spatially aligned. This processed data was then made available to the research consortium. In order to (better) understand the available data, explanatory and exchange sessions within the consortium took place. The data was further processed by the projects scientific partners, with the intention of generating useful results for practical planning in the administration. Results were then again distributed to the consortium in the form of geodatabase files (GDB). This data is to be regularly updated by consortium members during the project duration.

After screening the data, essential elements were delivered to *Wiener Netze* (network provider). Within the local working group, the working group on technical issued focused on developing building typologies and mapping of geospatial data. *Wiener Netze* further developed economic and technical parameters, derived a scheme and provided data, from which areas to focus on DH and other renewable supply solutions were derived. DH in this context includes solely the central district heating system. For the development of the H/C maps, the following main criteria were taken as a basis:

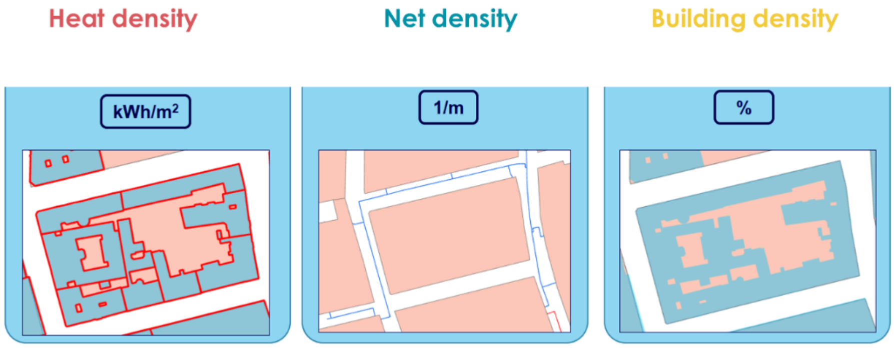


FIGURE 68 : THREE ESSENTIAL PARAMETERS FOR THE MAPPING (OWN ILLUSTRATION BASED ON THE WORK OF WIENER STADTWERKE)

The heat density reflects the modelled annual heat demand per m^2 of each building block, expressed in kWh/m^{2}a. A simple differentiation is made between high, medium and low heat density. The net density represents the district heating network (pipe) density with the parameter 1/m in reference to a census area (either “high” or “low”). The basis for the calculation is the current district heating network in metres.

The building density is the final parameter, expressed in % of built-up area of the census area (differentiation between “high” and “low building density”). In the future this will be extended by also including the gross floor area density.

In addition, the network operator considered the capacity and condition of the existing DH infrastructure. Further details on the categorisation and the underlying data are provided in the next chapter “H/C planning”.

The corresponding spatial resolution for all parameters is the census area (in most cases it contains 3 to 7 building blocks) and the street level. The aggregation levels for the H/C maps are either the building block or the census area (which is a statistical count area). The H/C maps include areas for:

- Central district heating supply,
- decentral local microgrids/DH and
- areas for single renewable energy solutions such as heat pumps.

The next chapter provides more information on H/C planning, including the current draft H/C maps.

H/C planning

The heating demand is based on the data model provided by the city of Vienna. Details on this can also be found in the Appendix. Essential factors were derived from the research project GEL SEP (Spatial Energy Planning for Energy Transition), including:

- Building period (construction age)
- Type of use
- Gross floor area
- Type of heat supply
- Funded refurbishment activities (also regarding historical building protection zones)
- Geometry of the buildings derived from a digital surface model (DSM) and a digital terrain model (DTM)
- Assignment of energy indicators developed by Technical University Graz (based on real consumption data)

Vienna’s network operators enhanced the model with their calculations on connection density, already connected buildings as well as with information on pipes (including data on hydraulics and capacity, e.g. performance of the primary network as well as aerial converters towards secondary pipe network).

The following three main criteria were used for identifying the preferred option for each census area:

- **Heat density** (for the census area in m²)
    - High: > 100 kWh/m²
    - Medium : 40 – 100 kWh/m²
    - Low : < 40 kWh/m²
- **Network/pipe density** for each census area / street level in 1/m
- Minimum threshold for the **build-up area** of the census area: 34%

Furthermore, minimum thresholds for the dimensions of primary pipes and secondary pipes were defined by *Wiener Netze* internally. A visualisation of the decision process (decision tree) towards district heating areas, heat pumps areas and others can be found below:

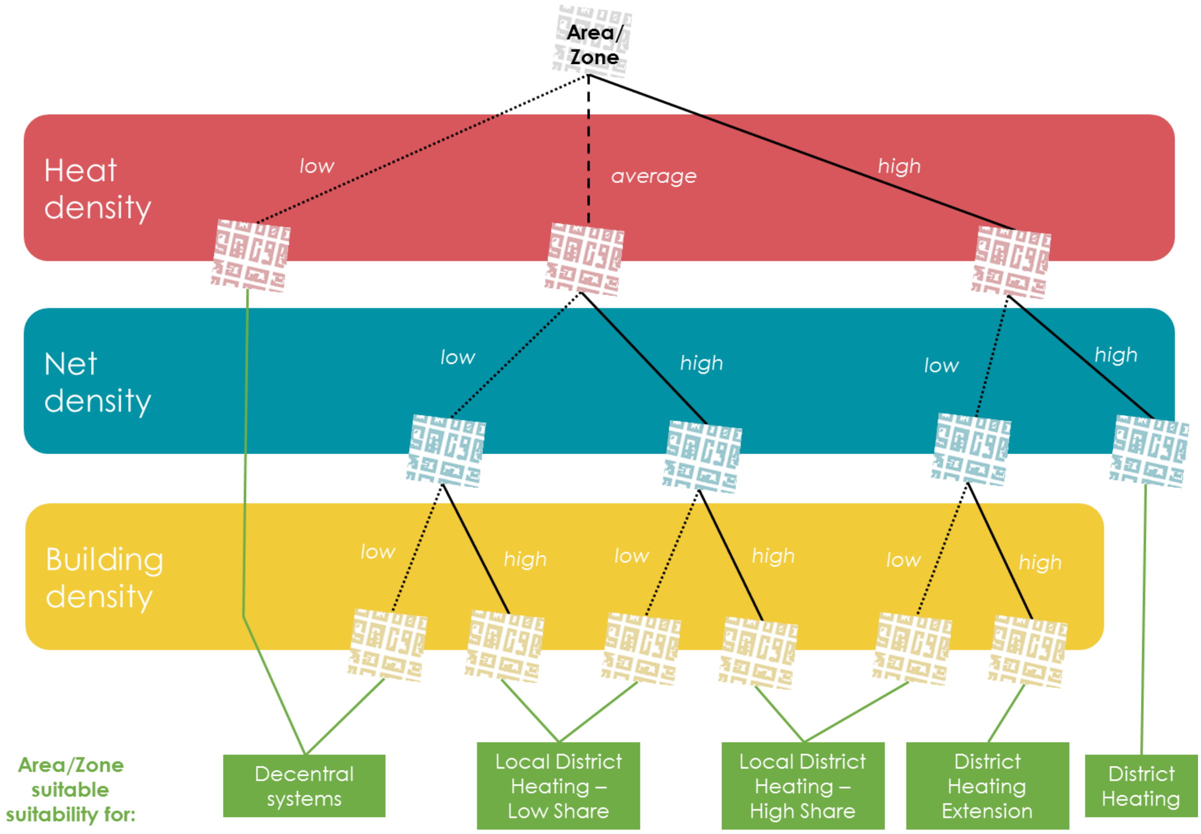


FIGURE 69 : DECISION TREE FOR RENEWABLE SUPPLY SOLUTIONS USED IN THE H/C MAPS (OWN ADAPTATIONS BASED ON INTERNAL DRAFT OF WIENER STADTWERKE)

The draft H/C maps include preferable decarbonisation solutions as shown in the maps at the end of the Viennese section in this deliverable.

The first map shows the results on statistical count areas, the second map the ones on building blocks. As a result, the areas were divided into the following categories:

- **District heating** (Dark red areas: Central DH is broadly established; high potential to connect additional buildings to DH)
- **District heating – Extension** (Light red areas: Central DH established but less common; potential for all remaining buildings to be connected)
- **Microgrid/DH – High share** (Dark yellow areas: High share of existing DH, remaining areas are only suitable for central district heating to a limited extent; suitability for microgrids is high)
- **Microgrid/DH – low share** (Light yellow areas: Low share of existing DH, remaining areas are only suitable for central district heating to a limited extent; suitability for microgrids is high)
- **Renewable energy single solutions** (Green areas: Not suitable for grid-bound heat supply; single solutions preferred, such as shallow geothermal energy, groundwater, ambient heat, waste heat)

The following draft maps show the distribution of these spatial categories for the entire city and the inner city. As can be expected, in the dense areas of the inner city, district heating will be of utmost priority.

In most of the “red” areas, DH is already available or quite easy to extend, while the potential for renewable energy sources is low.
The yellow or orange areas are suitable for separate microgrids (local decentral heating networks). This might be because the density is not high enough for the central district heating network, there are lots of new or refurbished buildings, there is a low performance of the DH infrastructure (age and capacity of the pipes and transformation stations) or there are some “special” buildings with individual solutions like hospitals. At the same time, these areas comprise enough potential for integrating waste heat or other renewables. Additionally, district heating could supply only parts of these types of areas or function as a supply backup.

In the remaining green areas, there is a potential for renewable single heating solutions. Nevertheless, in some of the non-red areas some buildings are also already connected to district heating.

Overall, this approach should help to densify the scattered district heating network infrastructure.

In parallel, **decarbonisation types of buildings** were defined (see Figure 70). There are three main categories of residential buildings:

- single family or detached houses
- multifamily houses (3 to 9 apartments)
- apartment complexes (more than 10 apartments)

The most common energy supply solutions for each type were defined according to its building period. In addition, a distinction was made between already refurbished and unrefurbished buildings. In general, it was assumed that buildings constructed after 2001 have not yet been refurbished. Hence, these buildings are included as new buildings. There is an ongoing discussion about the energy demand depending on the construction period. However, this may not be so important because almost all buildings have already undergone many refurbishment measures (new roof, windows or facades/adaptations of the heat supply/insulation). Hence, no building would have the “original” energy demand according to its construction period.

Finally, decarbonisation types (= best option how to decarbonise the building) were derived for each building type. Based on this, the number of buildings and gross floor area for each category was then calculated. The typology was used to better understand the building stock in Vienna and to finally derive criteria to develop the H/C plans as well as calculate needed resources (investment, companies, devices, …).

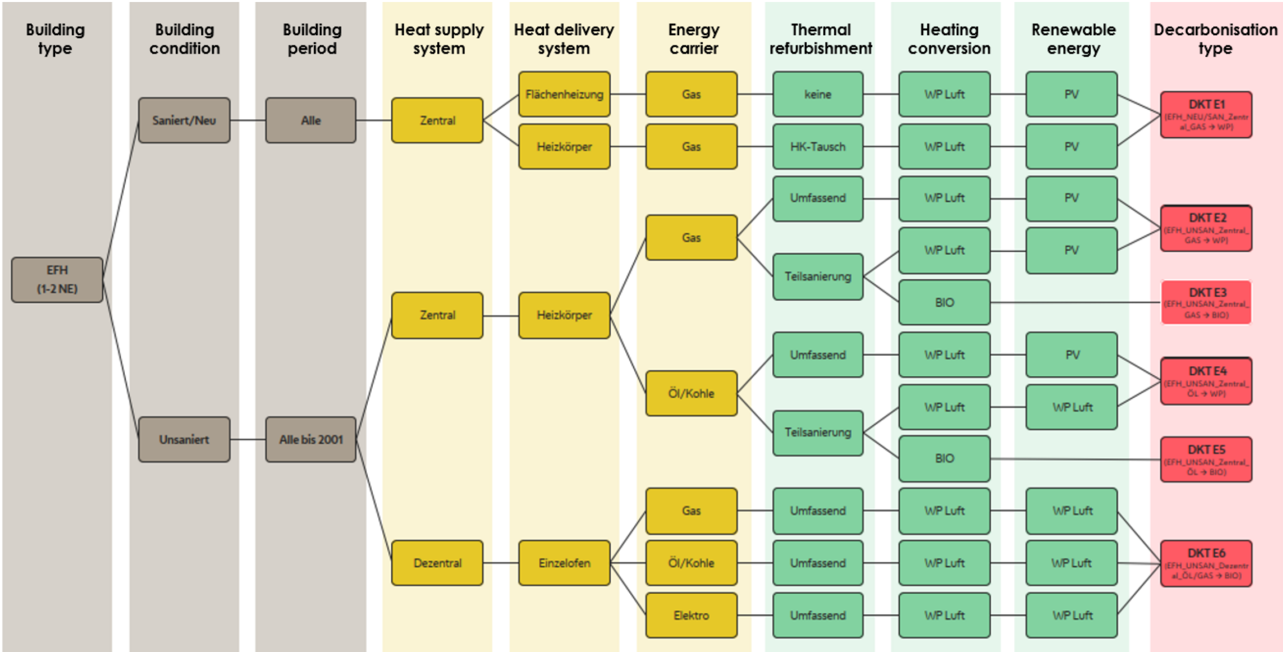


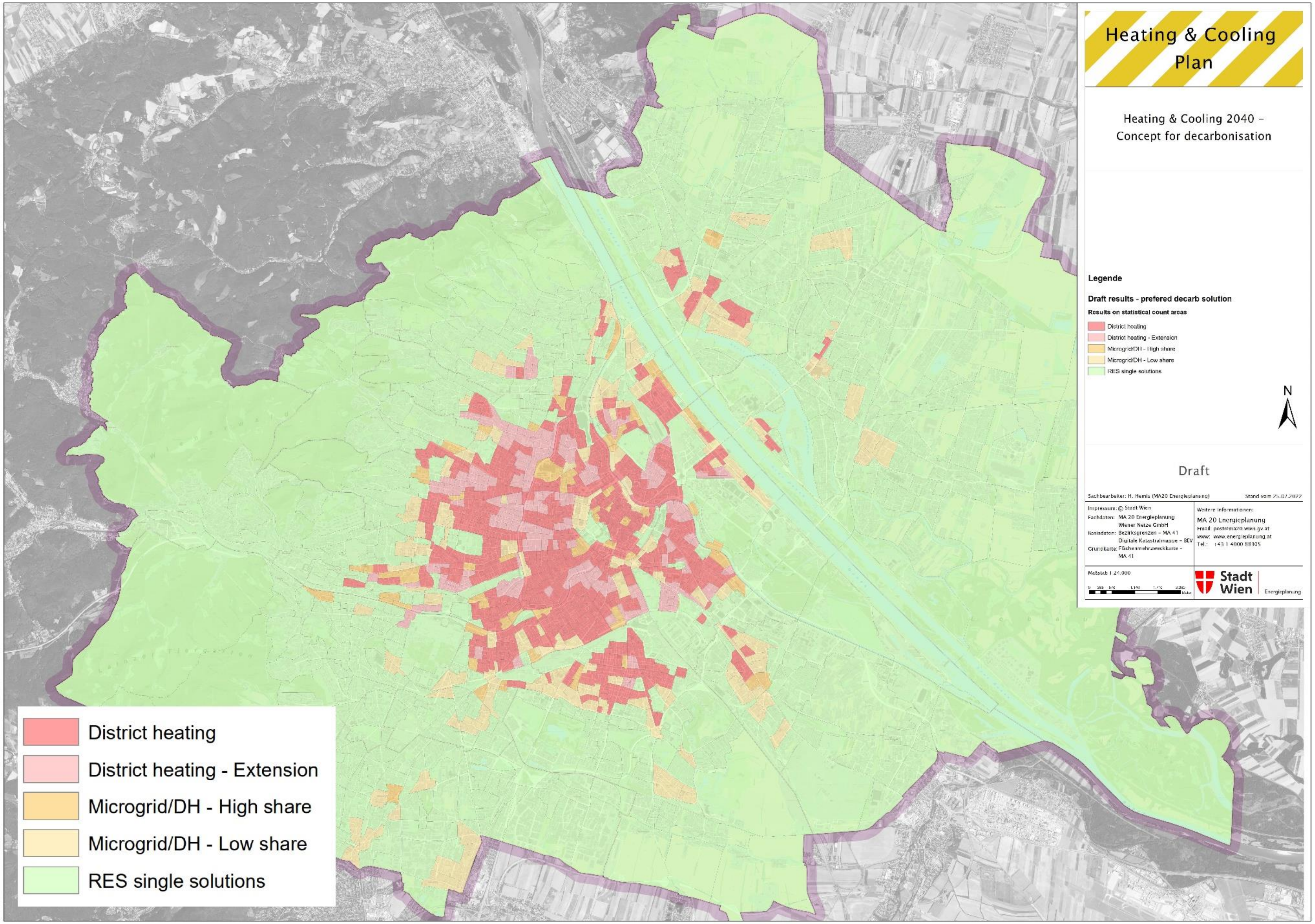
FIGURE 70 : DECARBONISATION TYPES, AS PRESENTED DURING PROJECT WORKSHOP ON H/C MAPPING (CITY OF VIENNA)

It is important to note, that the H/C plans shown below are dynamic. Adjustments are carried out continuously. Built on the already existing plans, the following list shows potential next steps for Viennas' H/C planning:

- Continuous integration of the updated data model (updates of basic data like energy certificates or building register)
- Validation of all data (calculated energy demand versus real consumption data, gross floor area, etc.)
- Further upgrades/improvements of the data model
- Considering details of the DH capacity for each area (calculation for each separate pipe)
- Calculation of the energy demand for all buildings in the zones of the energy zoning plans, which are not yet connected to DH
- Calculation of the energy demand and needed heat load for all suitable DH areas (matching the potentials of DH to the needed energy of each area)
- Development/improvement of criteria to identify microgrid areas
- Identification of buildings with dual grid-bound supply (district heating and gas)
- Estimation of renewable energy potentials as well as residual/waste heat for each property/building block
- Identification of priorities for decarbonised energy supply options for each area (census area/building block) or building – Revision of existing zones and definition of new zones
- Introduction of time frames: e.g. zone 1: extension of DH till 2027, with simultaneous discontinuation of gas supply, zone 2: installing renewable microgrids until 2035, etc.

The final results will be processed, amongst others, in new H/C map(s), which will be developed by the end of 2022 or 2023. These new maps will be also related to an implementation program based on the heating and cooling concept.

On the following pages, the first drafts of the H/C plans for Vienna are shown. The first map highlights the preferred decarbonisation solutions aggregated to statistical count areas. Statistical count areas are also shown in the second map, only at a larger scale. The third and final map shows the same results, however visualised on a building block level.


Heating & Cooling Plan
Heating & Cooling 2040 – Concept for decarbonisation
Legende
Draft results - prefered decarb solution
Results on statistical count areas
District heating
District heating - Extension
Microgrid/DH - High share
Microgrid/DH - Low share
RES single solutions
N
Draft
Sachbearbeiter: H. Hemis (MA20 Energieplanung)
Stand vom 25.07.2022
Impressum: © Stadt Wien
Fachdaten: MA 20 Energieplanung
Wiener Netze GmbH
Basisdaten: Bezirksgrenzen – MA 41
Digitale Katastralmappe – BEV
Grundkarte: Flächenmehrzweckkarte – MA 41
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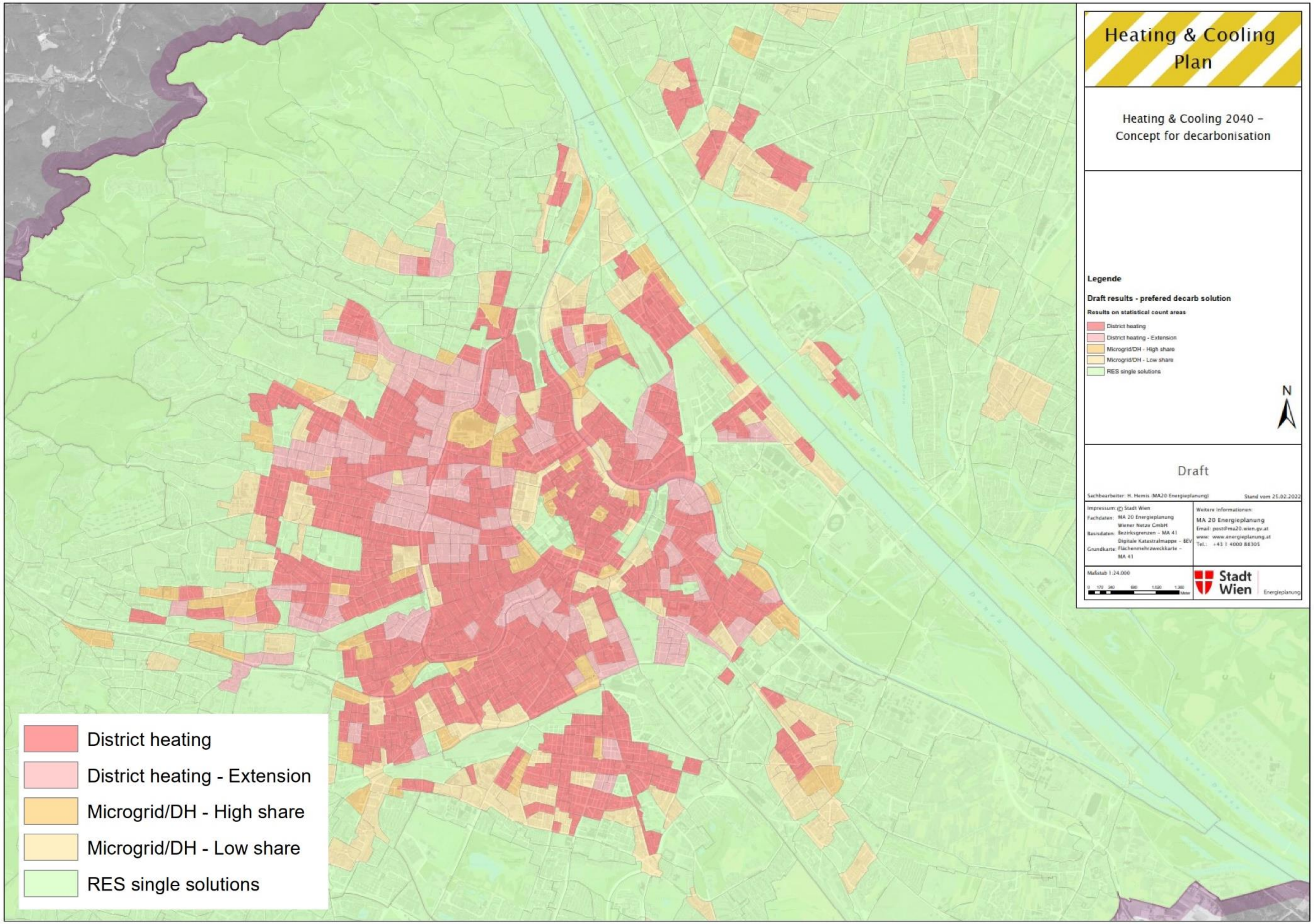
Energieplanung
District heating
District heating - Extension
Microgrid/DH - High share
Microgrid/DH - Low share
RES single solutions



Heating & Cooling Plan
Heating & Cooling 2040 – Concept for decarbonisation
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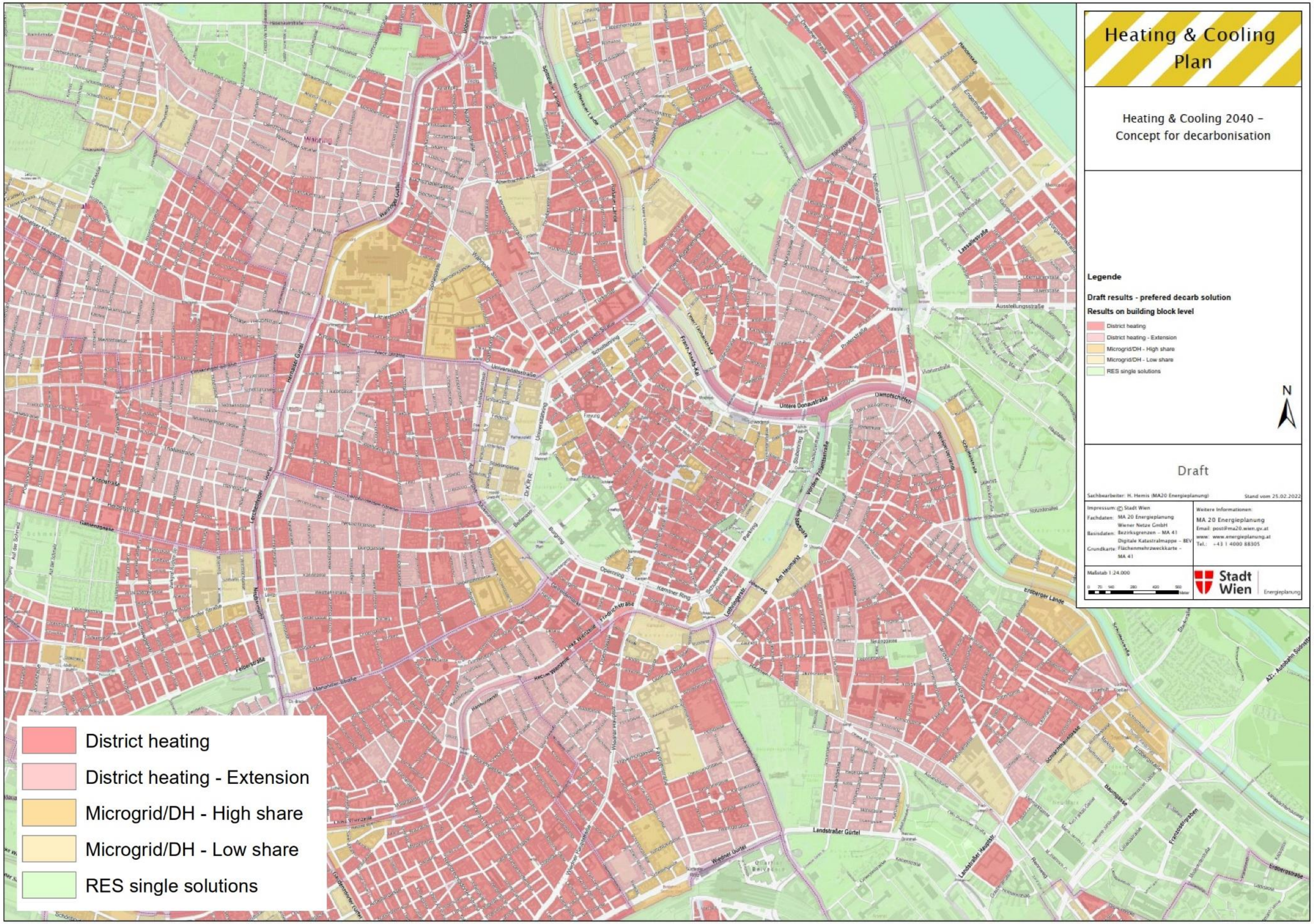

Heating & Cooling Plan
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References

MA 20 (2021): Energie! Voraus – Energiebericht der Stadt Wien. https://www.wien.gv.at/spezial/energiebericht/files/Energiebericht2021.pdf (accessed on 25 April 2022).

MA 20 (2020): Energy Flow Vienna 2019. http://ma20.23degrees.io/assets/print/energyflow-vienna-2019.pdf (accessed on 25 April 2022).

Magistrat der Stadt Wien (2022): Wiener Klimafahrplan – Unser Weg zur klimagerechten Stadt. https://www.wien.gv.at/umwelt-klimaschutz/klima-fahrplan-2040.html (accessed on 13 May 2022).

ÖROK (s.a.): ÖROK-Regionalprognosen 2021-2051: Bevölkerung. https://www.oerok-atlas.at/#indicator/65 (accessed on 25 April 2022).

Stadt Wien (s.a.a): Bevölkerungsstand – Statistiken. https://www.wien.gv.at/statistik/bevoelkerung/bevoelkerungsstand/ (accessed on 25 April 2022).

Stadt Wien (s.a.b): Die Fortschrittskoalition für Wien. https://www.wien.gv.at/regierungsabkommen2020/ (accessed on 25 April 2022).

Data used

Raw data input

The following data was used for calculating the *energy demand* and identifying the energy system for each building:

- Building register (information such as construction period, gross floor area, type of use etc.)
- Energy certificates of buildings (e.g. to identify the type of heat supply)
- POI of open government data (OGD) – important uses like hospitals or schools (complemented or replaced the information of the building register by using priorities of uses)
- Funded refurbishment activities
- List of historical buildings (protection zones)
- Geometry derived from a digital surface model (DSM) and a digital terrain model (DTM)
- Assignment of energy indicators (based on real consumption data)
- Digital cadastral map (building footprints and important building related IDs)

Additionally, the following *infrastructure* data was used:

- Central pipe cadastre for gas supply
- Central pipe cadastre for district heating

Data on *energy potentials* (these need to be completed for the next update of the maps):

- Shallow geothermal energy potentials
- Solar energy cadastre
- Air heat pump potentials
- Wastewater heat potential

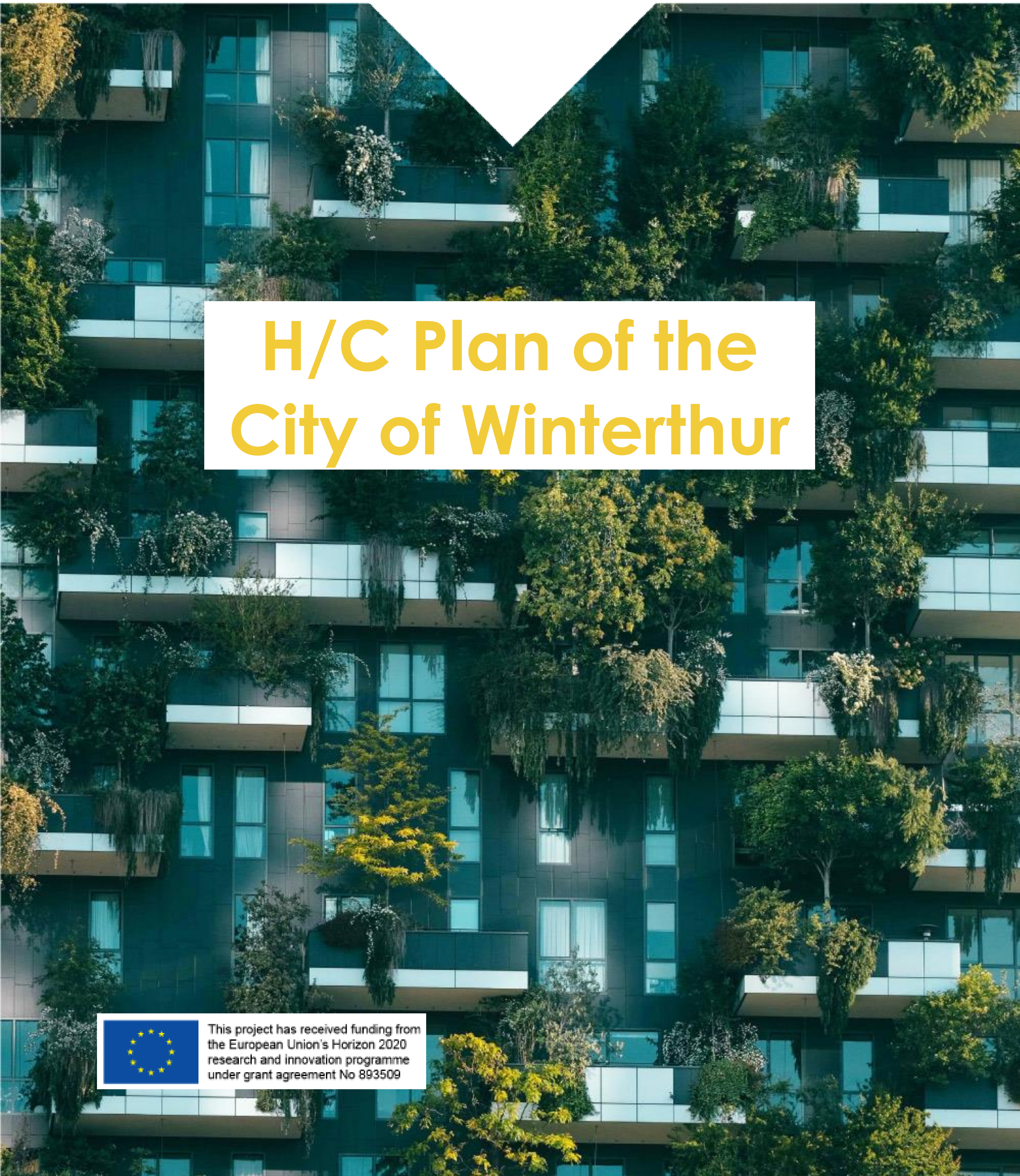
- Waste heat potential
- Hydrographic survey point data

The list mentioned is an excerpt of the most important data bases, but does not fully represent the elaborated data model. It represents the basic data, which was enhanced by *Wiener Netze*. The network operator complemented the model with internal data, e.g. with the length of different pipe systems and already connected buildings to the district heating network.

The next step will include a detailed calculation for each area using the existing capacity, the condition of each DH station in the buildings and the potential to enhance the pipe infrastructure.

More details on the data used, are to be found in the upcoming Deliverable 2.4. “Report on data availability, data sovereignty, quality and exchange in the participating cities and policy recommendations”.

H/C Plan of the City of Winterthur



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 893509

H/C Plan of the City of Winterthur

Introduction

Winterthur is located in the northeast of Switzerland, about 20 km northeast from the City of Zurich.

Winterthur has its own utility, which provides electricity, water, gas, heat and waste-water-treatment.

The first district heating was built in 1985 with the waste heat from the incineration-plant.

The first H/C-plan was released in 1998. In 2011, it was revised for the first time. Starting in 2020, the H/C plan is being revised for the second time.

The legal framework, however, significantly changed since the first and second edition of the H/C plan.
Now, the net-zero emission target is to be achieved in 2040 (confirmed by a popular vote in November 2021).

That translates into reducing GHG-emissions to 1t CO_2 maximum per inhabitant in 2033.
Currently, the heat supply a equals 300 kg CO_2/person.

Facts & figures for Winterthur

- Inhabitants: 116,000 (6th largest city in Switzerland)
- Number of buildings: 25,089
- Building with residential use: 16,684 (66.5% from all buildings)
- Average building age: 70 years (year of manufacture 1951)
- Median building age: 60 years (year of manufacture 1961)

The heating demand of Winterthur for the year 2019 was 986 GWh from which 68% were covered by fossil sources. An estimated potential of 1,670 GWh/a from waste heat, shallow geothermal energy, groundwater heat, wood and ambient air could replace fossil sources and cover 100% of the heat demand with renewable energy.

Process

Winterthur commissioned PLANAR AG für Raumplanung, an extern planner team, to revise its H/C-Plan. In a first step, a local working group was formed with various stakeholders from the energy department, utility company and selective municipal councils to accompany the process.

The heat demand per building was collected by using the data mentioned in the appendix of this chapter. By applying a general retrofitting rate and a retrofitting success per building period, we obtained the heating demand for the year 2033. The cooling demand was determined using the statistics of the business structure (STATENT) and sector-specific cooling demand estimates. The heat potentials were also collected.

Subsequently, the results were discussed with the local working group and adjusted.

Furthermore, the existing infrastructure for heat utilization and supply was collected and analysed. Based on the analysis of this basic data, an energy plan was compiled.

Again, based on this basic maps (heat demand density, infrastructure, potentials), the H/C-plan was developed. The areas were divided into DH-areas and areas for individual heat supply. The draft of the H/C-plan was discussed in the local working group and with the city council. Adjustments to the plan were made in several rounds within the local working group.

With the H/C-plan, the city is pursuing the goal of using local potential supply by expanding district heating in the city, for example, by using common district heating and waste heat use from waste water treatment plants. A part of the waste water heat potential is already used in a district heating of a neighboured municipality.

Framework and principles

Climate Goal

In November 2021, the population of the city of Winterthur approved the zero-emissiongoal 2040.

Gas grid

This goal forces to reduce the existing gas grid. In Switzerland the potential of biogas and power-to-gas is estimated to be 30% of the amount sold as of today. In Winterthur, hydrogen is not considered as a solution for room heating but only for industrial processes and trucks, where alternatives are rare. This is not yet part of the H/C-Plan as the full potential is yet unknown.

Over the next decades, various parts of the gas network will be decommissioned (2030, 2033 and 2040). In industrial areas, where gas will be provided on a long-term basis, natural gas shall be replace with biogas or power-to-gas by 2040. This gas will be used in processes and as peak capacity in district heating.

The heat demand in the decommissioned areas will, in dense areas, be met through the expansion of heat networks. On the one hand, this means that the number of connections to the existing district heating networks will need to increase. On the other hand, new heat networks are to be built. In sparse areas individual solutions are foreseen.

District heating

District heating areas were defined by using a heat density factor. A heat density of more than 400 MWh/ha/a (based on the modelled demand for 2035) is considered suitable for DH. In the other areas, the renewable solutions will be heat pumps using surface geothermal heat or ambient air.

Legal framework: mandatory connection

To obtain enough connection density to the district heating, owners can be forced by law to connect to the DH. In the last years, however, only three owners have had to be forced to connect in Winterthur.

Efficiency

To reduce the energy demand, a retrofitting rate of at least 1.2% of the buildings per year is to achieve (currently: 1%) but the more the better.

Working process

Besides the energy unit of the city administration (which is also taking part in the Decarb City Pipes 2050 project), also the Stadtwerke Winterthur (the city owned utility) participated in the local working group. The people responsible for the gas grid, district heating and the incineration plant took part in the developing process. To also include a future perspective, urban and spatial planner as well as the geoinformation unit was involved.

In total, seven meetings of the local working group were held, two meetings with the commission board in charge of energy and environment issues (Kommission für Umwelt und Energie) and one meeting with the city council board (all elected executive members).

Analyses of data and aggregation

The result of this data analysis were three maps, which form the basis of the H/C-Plan. The data available for this process are described in the appendix of this chapter.

Heat demand density

The heat demand per building was aggregated to show the density per hectare.

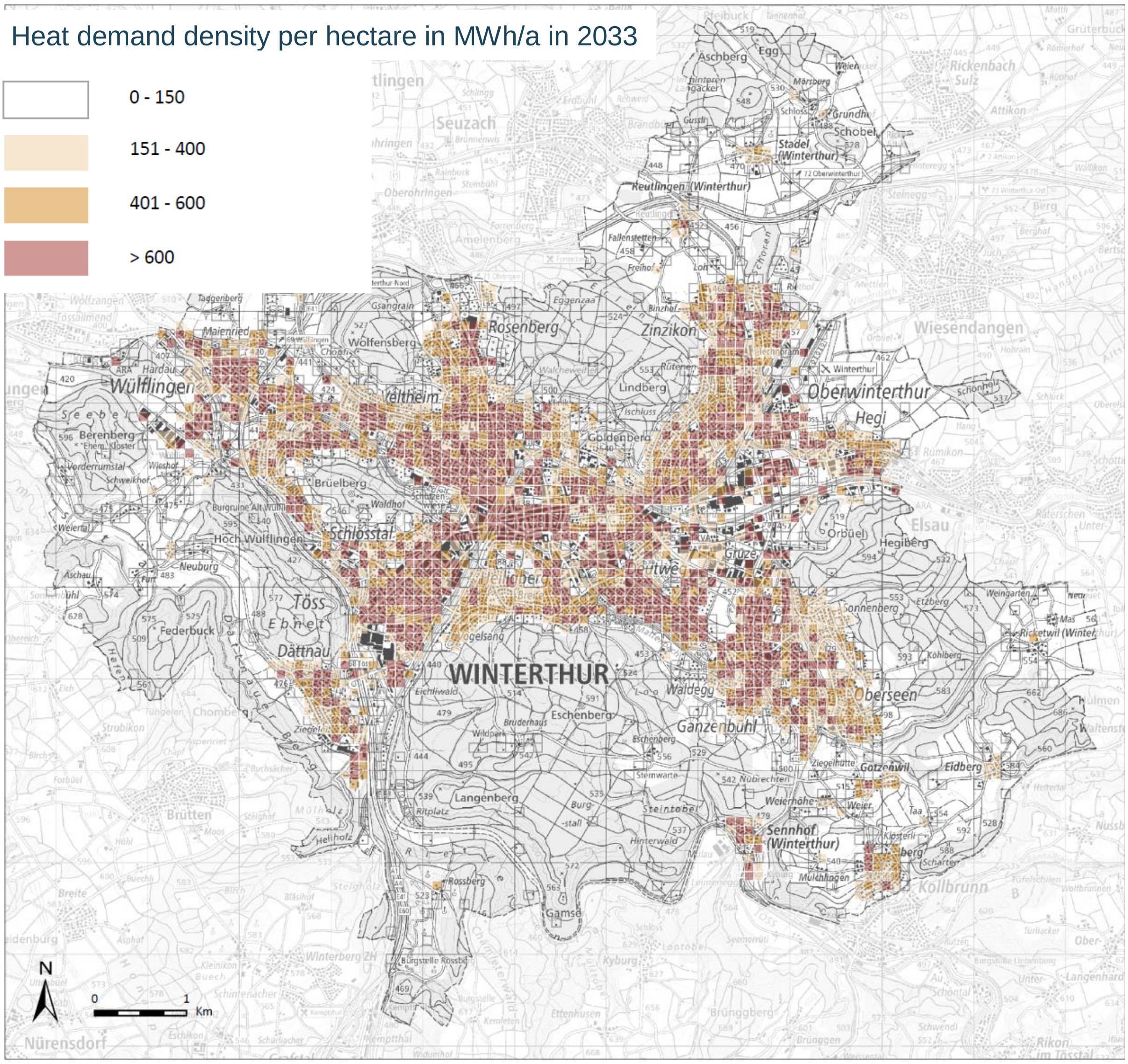


FIGURE 71: HEAT DENSITY PLAN

Cooling demand:

The cooling demand was determined by using the statistics on company structures (STATENT). Depending on the sector, the cooling demand was estimated and added up per hectare. The approach was based on broad categories and was not quantified.

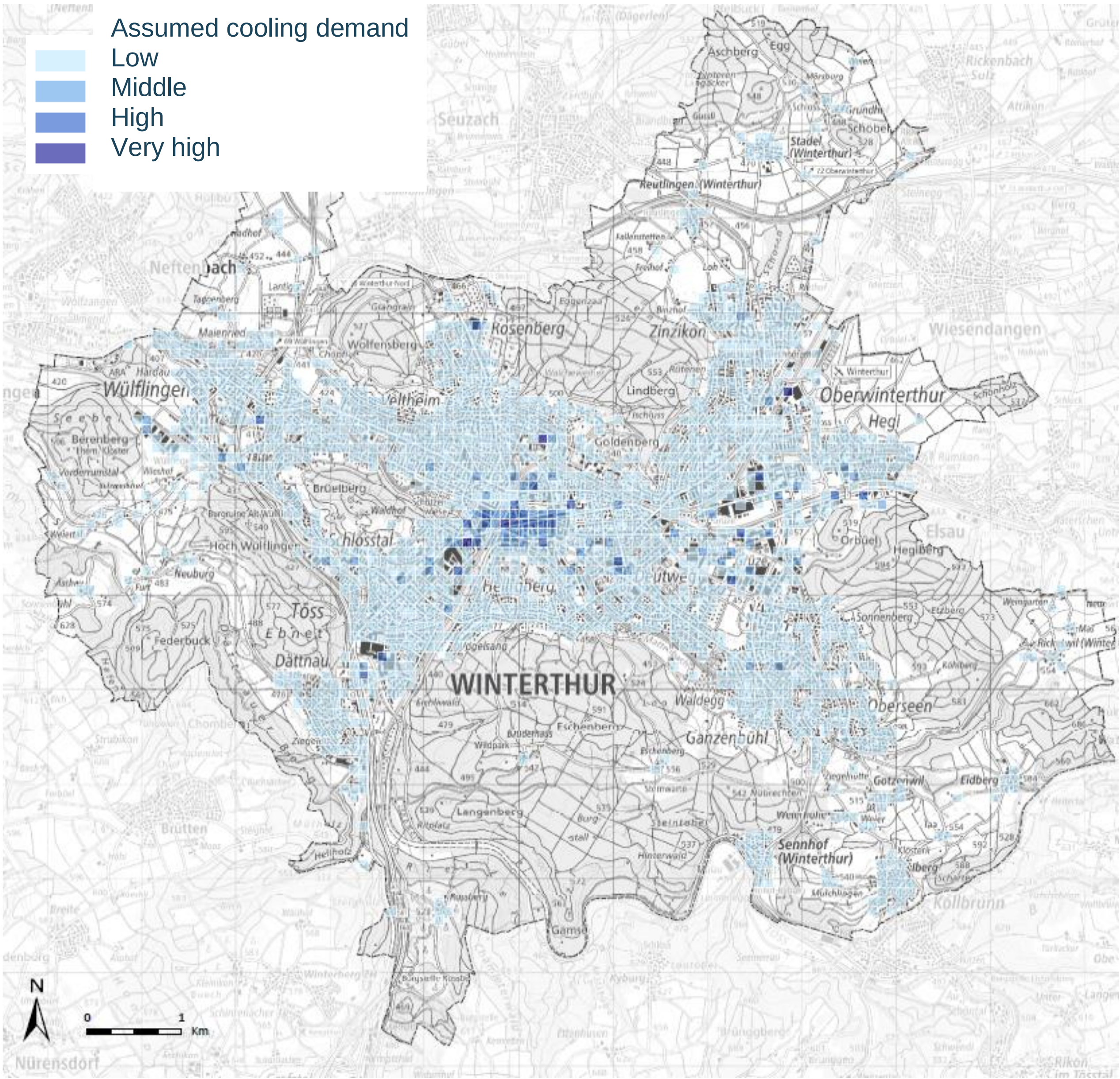


FIGURE 72: COOLING PLAN OF WINTERTHUR

Potential-maps:

In Switzerland, the cantons provide maps showing where the use of groundwater and shallow geothermal energy is permitted. This data needs to be put together with other heat sources like

- Water treatment plant
- Waste incineration plant
- Industrial waste heat (data center)
- Existing geothermal probes

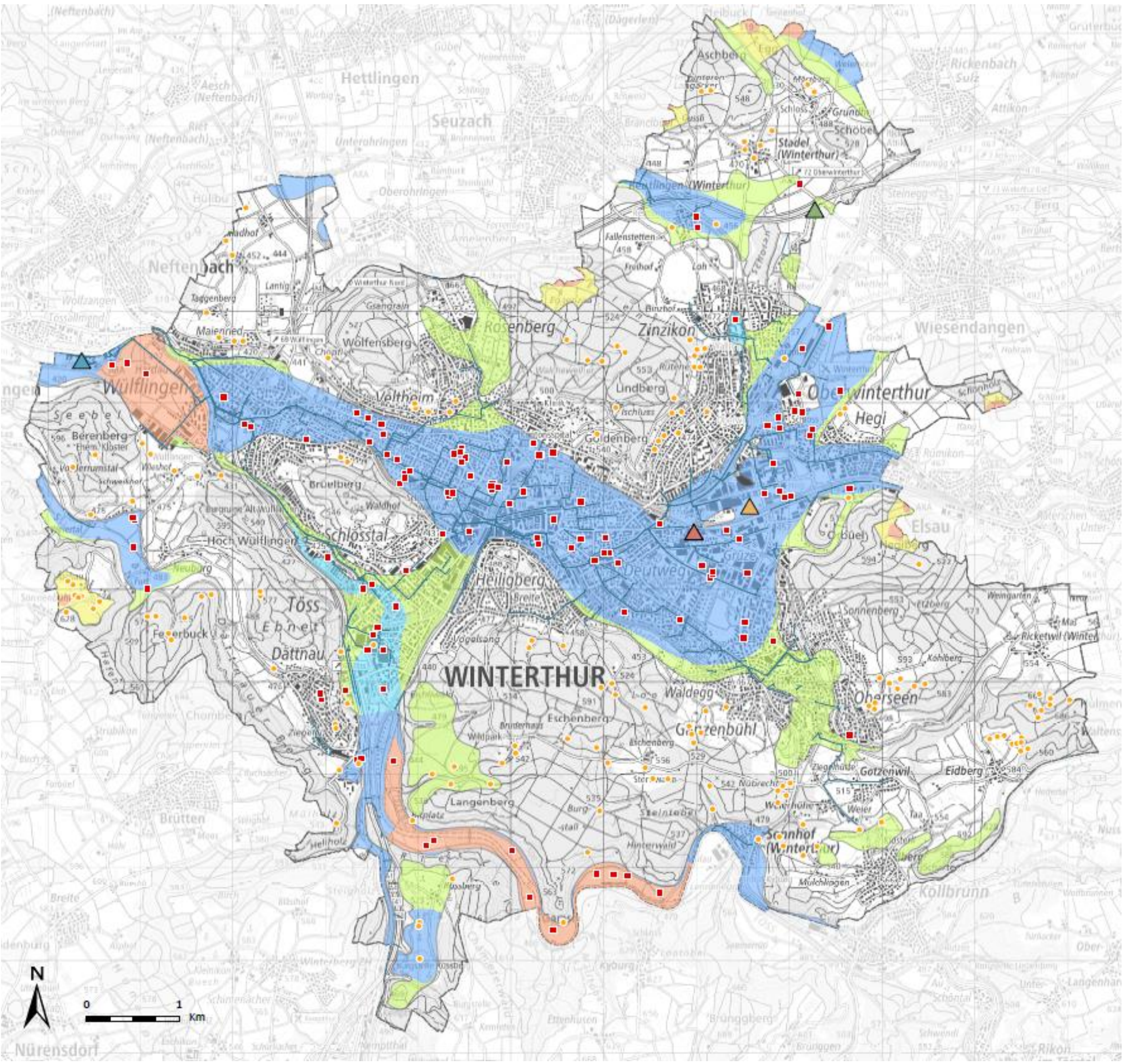


FIGURE 73: POTENTIAL MAP FOR GROUNDWATER USE
GROUNDWATER PERMITTED (DARK BLUE), UNDERGROUND USE CONDITIONALLY PERMITTED (BLUE, GREEN), UNDERGROUND USE NOT ALOUD (RED), SHALLOW GEOTHERMAL USE PERMITTED (NO COLOUR)

Infrastructure map

Existing infrastructures in Winterthur are:

- District heating (green)
- Gas grid (yellow)
- Waste treatment plant (red triangle)
- Waste water treatment plant (blue triangle)
- Biogas plant (green triangle)
- Data center (yellow triangle)
- Sewage pipes > 800mm (blue)

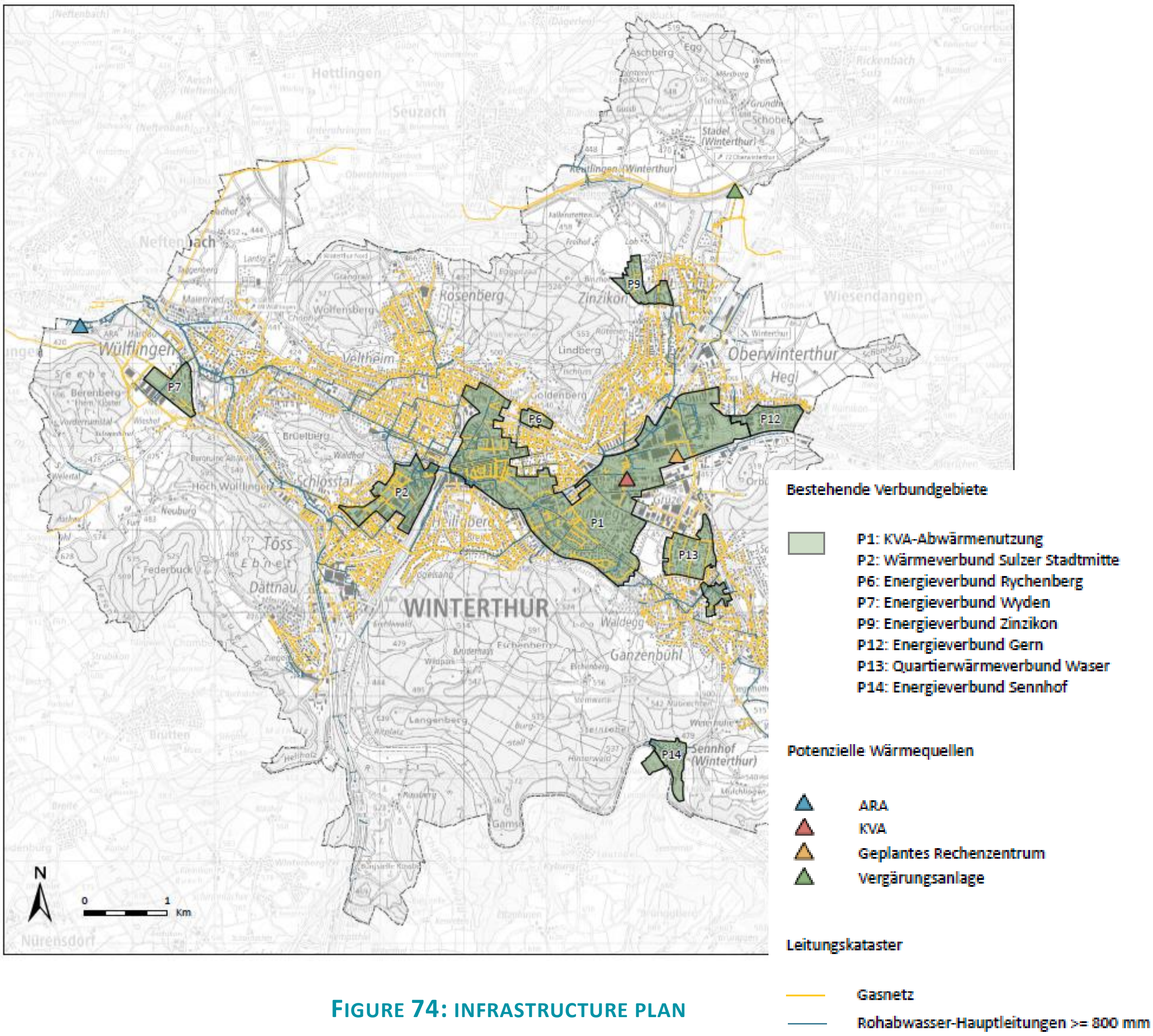


FIGURE 74: INFRASTRUCTURE PLAN

H/C planning

Based on all the above-mentioned analyses, the H/C plan for the city was created. Existing infrastructures form the backbone of planning ahead. With regard to the future of the existing gas grid, it was decided to focus using gas in high temperature processes in industrial use and for peak capacity for district heating.

Furthermore, the following aspects were regarded:

- A district heating in urban areas in Switzerland is considered economically profitable with a heat density of more than 400 MWh/ha*a (based on future demand scenarios). This benchmark serves as a deciding factor when choosing DH areas.
- Sample of possible supply in different areas (existing potentials).
- Subordinated: What is the dominant building-standard (high or low flow temperature needed)?
- Heat source strategy: In order to be able to use waste heat also in summer, the coupling of different DH networks is planned. In this way, the waste heat can supply a larger network in summer. In winter, other renewable energy sources in periphery supplement the heat input to the network.

The canton of Zurich lists the use of the following heat sources as a priority:

1. Waste heat
2. Spatially set, environmental heat (groundwater, geothermal heat)
3. Other environmental heat (sun, air) and wood

The following chart shows the decision process for finding the areas for district heating and its level of flow temperature:

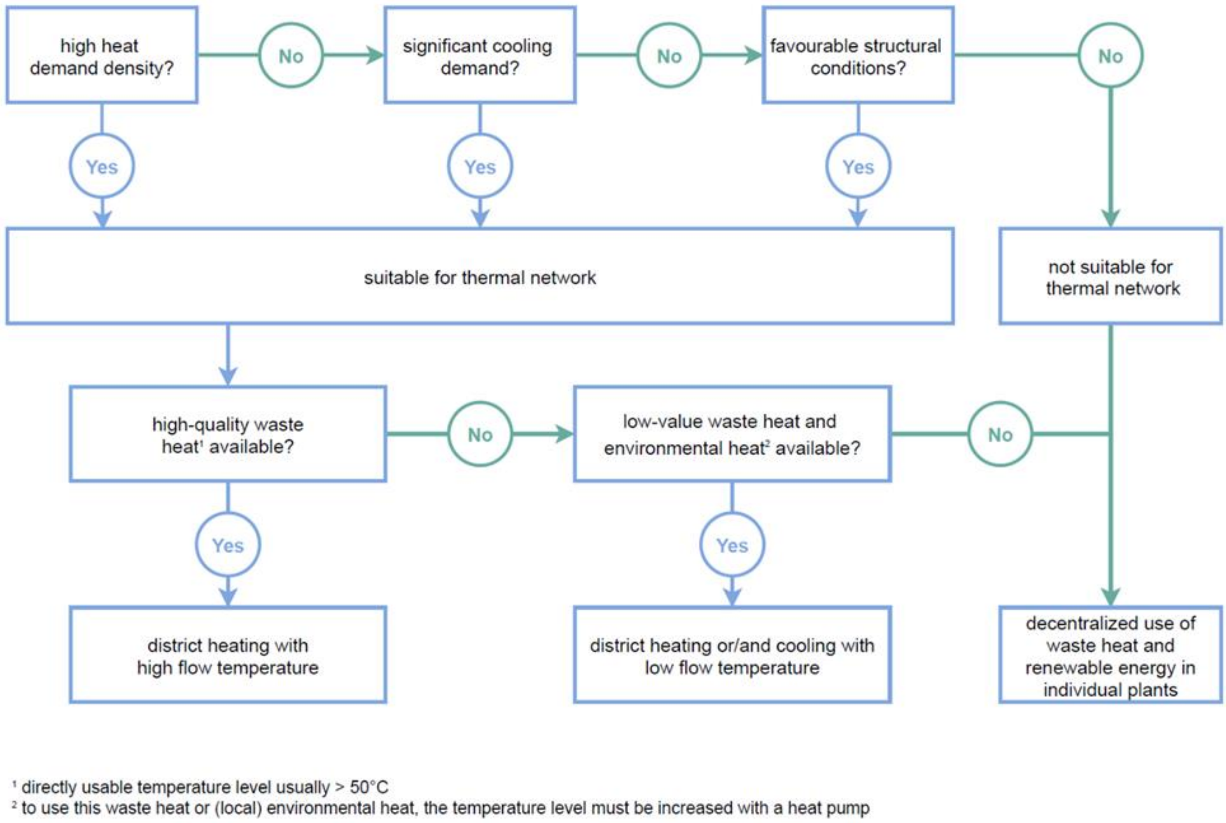


FIGURE 75: DECISION SCHEME

The energy sources have not yet been definitely determined, as this requires a more in-depth study, which should be available by the end of 2022. However, the possible energy sources have been identified and recorded as options.

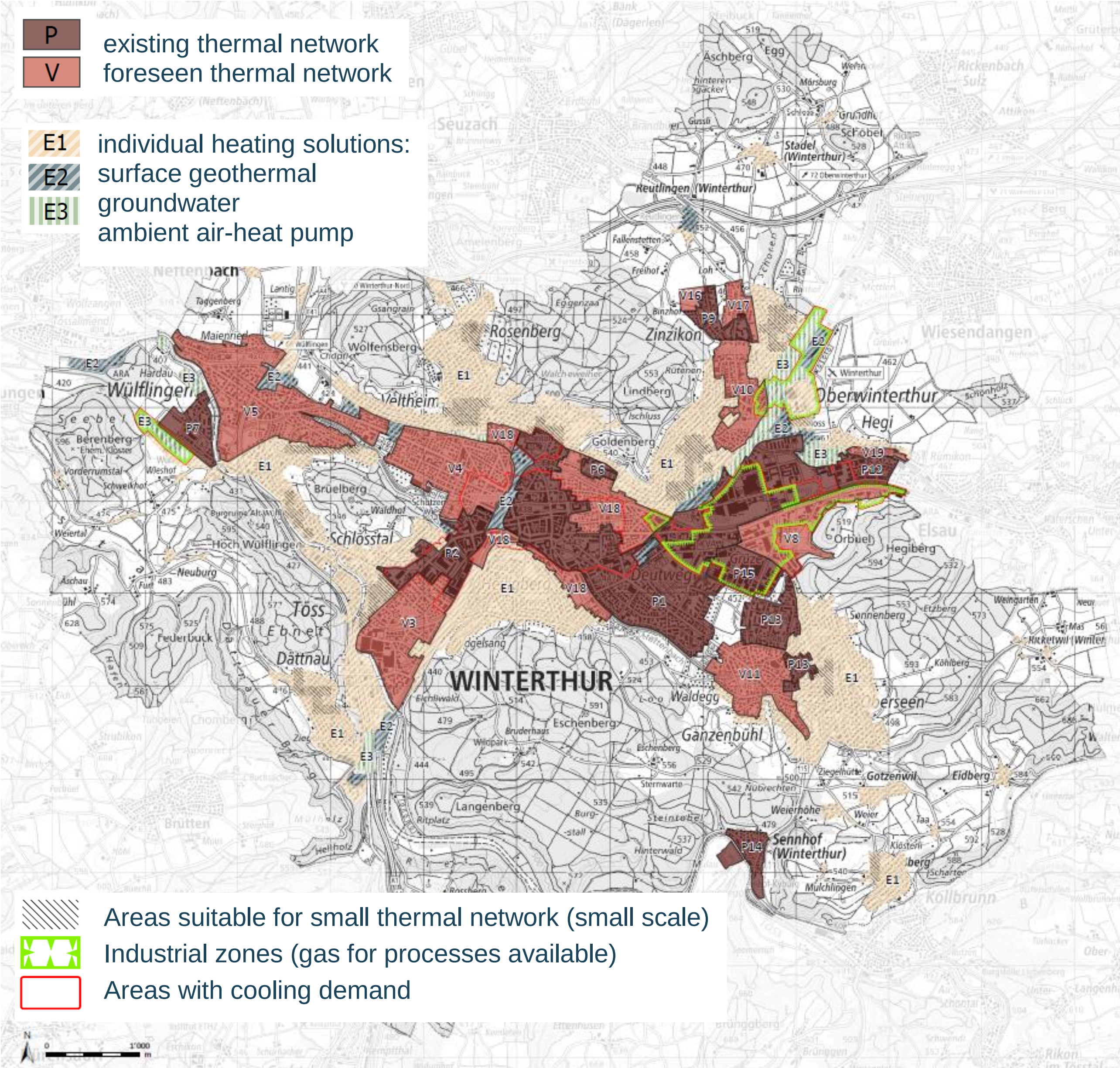


FIGURE 76: H/C PLAN OF WINTERTHUR

Next Steps

Transition

For each area, an action plan was created, which are currently in a consultation process. One of the main action set was to commission a technical study to define the supply side and to elaborate a detailed roadmap. This study will determine the energy sources and set a timetable for the implementation of the energy plan. Moreover, the study will check possible links to the district heating.

By linking various new district heating to the waste incineration district heating network, we hope to make better use of waste heat in summer by using it for hot water supply in other networks. In winter, external connections are fed by environmental heat, while the waste incineration plant supplies the main area.

Starting with pipe construction

A first priority is to expand the existing pipeline network. For the time being, heat is still being supplied by the waste incineration plant, where peak coverage is based on fossil fuel. Thus, as a second priority, new district heating centres based on renewable energy sources shall relieve the waste incineration plant and, above all, the fossil fuel peak load.

Framework measures

The process for planning, permits, and construction currently requires at least three to five years. This time should be shortened through better internal cooperation between the municipal offices.

Financial and human resources will need to be ensured and enhanced to fully support the implementation of the H/C-plan (construction of about 100 km of pipelines and three to four control centres).

Political implementation, next steps:

- Internal consultation.
- Decision of municipal council.
- Decision of parliament.
- Authorisation by cantonal departement for construction.

Data use

Availability and quality of data

- **Gas**: metered per flat/building (clustered to one building point)
- **District heating**: metered per flat/building (clustered to one building point)
- **Fuel oil**: installed power (data from chimney sweepers). Demand calculated with mean full load hours.
- **Heat-pump**: electricity metered. Demand calculated with mean (operating factor)
- **Wood**: installed power (data from chimney sweeper). Demand calculated with mean full load hours.
- **Electricity heating**: installed power. Demand calculated with mean full load hours
- **Building data from building and housing register** (maintained by city, mandatory for all municipalities in Switzerland)
- **Cooling demand**: STATENT Statistics of company structures show georeferenced sector affiliation of companies. Estimation on cooling demand per sector.

Missing Data

- Good data on heat demand of processes and not residential building

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