D6.3 Heating and cooling strategies for pilot cities – San Sebastián

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Project Information

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Legal notice

The Hotmaps project

The EU-funded project Hotmaps aims at designing a toolbox to support public authorities, energy agencies and urban planners in strategic heating and cooling planning on local, regional and national levels, and in line with EU policies.

In addition to guidelines and handbooks on how to carry out strategic heating and cooling (H&C) planning, Hotmaps will provide the first H&C planning software that is

- **User-driven**: developed in close collaboration with 7 European pilot areas
- **Open source**: the developed tool and all related modules will run without requiring any other commercial tool or software. Use of and access to Source Code is subject to Open Source License.
- **EU-28 compatible**: the tool will be applicable for cities in all 28 EU Member States

The consortium behind

Scientific partners

Pilot areas for developing and testing the tool

Bistrita Municipality

Executive Summary

In the course of the Horizon 2020 project Hotmaps, a database and toolbox for strategic heating and cooling planning has been developed. Also, strategic heating (and cooling) planning in 7 pilot areas has been performed using the developed Hotmaps toolbox to demonstrate its usability in the strategic planning process.

This document presents a heating strategy for the city of San Sebastián developed within the Hotmaps project. This document has been elaborated by Fomento San Sebastian, which is a public municipal company dedicated to the promotion and the economic and social development of San Sebastian, and partner of Hotmaps project.

This strategic planning document has been derived following a commonly defined strategy process and using the Hotmaps toolbox for quantitative scenario analysis. The strategy process hereby included the following steps: an analysis of barriers and drivers, a stakeholder analysis, the mapping of the existing heat demand and available resource potentials, the development of scenarios for heating demand and supply in the city in the year 2050 and the discussion of these steps and their outcomes with relevant persons in the city. The outcomes of this process are described in this document.

Donostia - San Sebastián is a city of around 180 tsd. inhabitants on the Atlantic coast in the north-eastern part of Spain. Currently around 600 GWh/yr of heat is needed for space heating and hot water generation in the buildings of the city. At the moment this demand is nearly entirely supplied with natural gas.

In the course of the analysis, various scenarios for future heat demand and supply for the city have been developed. Hereby the costs and potentials for heat savings in buildings, for decentral heat supply and for the supply of district heating have been investigated. The results of the analyses in these different parts of the heating system have been compiled to consistent scenarios for the entire city.

The quantitative scenario analysis shows that district heating should be considered as a potential future option for supplying remarkable parts of the buildings' heat demand in the city, renovation strategies would be interesting to reach certain saving objectives, and further studies should be carried out to analyse in more detail the conclusions and recommendations presented in this document.

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List of terms and abbreviations

CELSIUS	7th Framework Programme funded European Project aimed at helping cities plan, develop and optimise their district heating and cooling networks
CHP	Combined Heat and Power
Civitas	A network of cities for cities dedicated to cleaner, better transport in Europe and beyond
CM	Calculation Module (in the Hotmaps toolbox)
COP	Coefficient of Performance
CO2	Carbon Dioxide
CTE	Technical Code of Buildings in Spain
DH	District heating
DHW	Domestic hot water
Hiri Berdea	Environmental Strategy
EEG	Energy Economics Group, Institute of Energy Systems and Electrical Drives, TU Wien
Enertile	Model to analyse the energy supply, of the Fraunhofer ISI
EU	European Union
EUCO30	Model for an energy efficiency target of 30% developed by the EU Commission
Fraunhofer ISI	Fraunhofer Institute for Systems and Innovation Research
FSS	Fomento de San Sebastián
GFA	Gross Floor Area
GHG	Greenhouse Gas
GIS	Geographic Information System
GWh	Gigawatt hours
HDD	Heating Degree Day
IDC	ICT Development Index
IEA	International Energy Agency
INEA	EU Innovation and Networks Executive Agency

Invert/EE-Lab	Dynamic bottom-up techno-socio-economic simulation tool that evaluates the effects of different policy packages on the total energy demand, energy carrier mix, CO2 reductions and costs for space heating, cooling, hot water preparation and lighting in buildings.
LCOH	Levelized costs of heat
MFH	Multi-family houses
MW	Megawatt
MWel	Megawatt electricity equivalent
MWh	Megawatt hours
MWth	Megawatt heating equivalent
progRESsHEAT	A Horizon 2020 funded project supporting the progress of renewable energies for heating and cooling in the EU on a local level
PRIMES	Partial equilibrium modelling system that simulates an energy market equilibrium in the European Union and in each of its Member States
PV	Photovoltaic
RES	Renewable Energy Share
SEAP	Sustainable Energy Action Plan
SET-Nav	EU Horizon 2020 co-funded project “Navigating the Roadmap for Clean, Secure and Efficient Energy Innovation”
SmartCity Plan	Strategy to transform the city into a sustainable Smart City
TU Wien	Technische Universität Wien
WWTP	Wastewater Treatment Plant

1 Introduction to San Sebastián

Donostia-San Sebastián, as the capital of the Province of Gipuzkoa, is a municipality with an area of 60.89 km2 and a resident population slightly over 186,000 inhabitants. In 2014 a consolidation of the population occurred that could be signalling a turning point in the dynamics of the population since it does not seem to be producing significant increases in the coming years, unlike what happened in previous years.

- Location: South-Western Europe
- Size: 60.89 km2
- Population municipality (inhabitants): 186.667
- Metropolitan area (inhabitants): 436.500

Figure 1: Panoramic view of Donostia - San Sebastián and La Concha bay seen from Mount Igueldo

Geography

Donostia-San Sebastián is a coastal city and a municipality located in the Basque Country, Spain. It lies on the coast of the Bay of Biscay, 20 km from the French border. The capital city of Gipuzkoa, the municipality's population is 186.667 with its metropolitan area reaching around 436,500.

Climate

San Sebastián features an oceanic climate (subgroup Cfb, marine west coast, according to the Köppen-Geiger climate classification) with warm summers and cool winters. Like many cities with this climate, San Sebastián typically experiences cloudy or overcast conditions for the majority of the year, typically with some precipitation. The city averages roughly 1,650 mm of precipitation annually, which is fairly evenly spread throughout the year. However, the city is somewhat drier and noticeably sunnier in the summer months, experiencing on average approximately 100 mm of precipitation during those months. Average temperatures range from 8.9 °C in January to 21.5 °C in August.

Fomento San Sebastián

The city of San Sebastián, through Fomento de San Sebastián, designed a Smart City Plan with an Action Plan for 2016-2020, in which a comprehensive plan has been established for the city's Smart strategy with the main challenge of establishing a strategic line with shared objectives and providing coherence and coordination to the public action.

Fomento de San Sebastián (FSS) is a local public society dedicated to the economic and social development and promotion of the city of San Sebastián, through innovation, knowledge generation and transformation, networking, and project fostering and management, all under sustainability criteria.

FSS is working with the development of renewable energies, energy efficiency and smart cities based on a series of strategic objectives, initiatives and implementation areas:

- Contributing to the design of the local environmental public policy in an integrated way.
- Promoting sustainable economic initiatives that boost energy efficiency and the use of renewable energies.
- Development of a local economic network linked to the smart sector.
- Transforming the proposed model into a referent at the European level.
- FSS has been promoting innovative initiatives in this area considered as economically sustainable, joining the environmental needs identified at the local and global level with the development opportunities identified by the organisation.

During the last years, the city has been leading a transformation towards a Smart City by leading projects and initiatives in the energy, ICT and mobility fields of the city. With that goal in mind, San Sebastián is in the implementation stage of the Smart City Plan 2016-2020 through innovative projects taking place in the city, highlighting the Replicate Lighthouse project and SmartKalea.

FSS has extensive experience in supporting innovation, in cooperation with research institutes, and business support to encourage innovation in production processes and the services and final products. FSS has also implemented different employment support programmes, using innovative tools.

San Sebastián is also actively working on other important issues for sustainable city development as Climate Change Strategy 2050, Covenant of Mayors, Sustainable Mobility Strategy, Science and Technology promotion, Green City, Friendly city, Commerce and Tourism Plan, etc.

2 Objectives and approach

The main objective of this Heating Strategy document is to analyse possible future scenarios of the heating system in San Sebastián based on the use of District Heating networks on a 2050 horizon and in line with the Smart Strategy and the Climate Change Plan.

The following paragraphs show the current situation of San Sebastián and the main objectives for the development of a Heating Strategy plan.

Background:

- A first public district heating (DH) is in operation since 2018 using biomass for heating and DHW of around 1500 dwellings in the Urumea Riverside District promoted by Fomento San Sebastián.
- There are two more DH installations in the city, one of them has been renovated including biomass boilers and new household connections.
- A strategic plan for heating and cooling in the region does not exist at the moment.
- Existing plans in the city: SmartCity Plan, Climate Strategy, Sustainable Mobility, Green City, Agenda 21, SEAP, etc.
- Demand for cooling is not remarkable in households, in offices and commerce during summer it is.

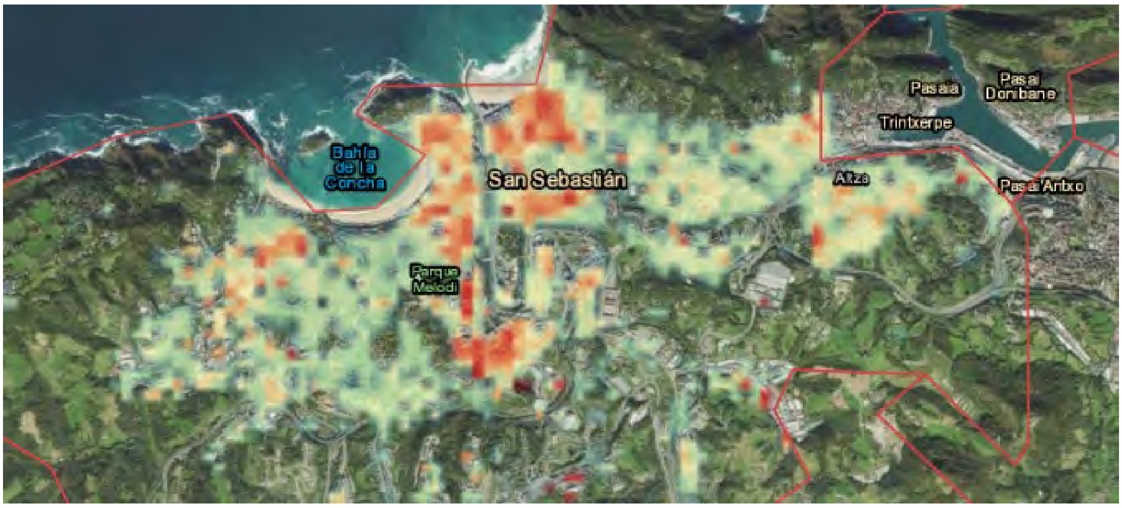


Figure 2: Heat demand density map of San Sebastián (Source: own calculations based on (TU Wien, e-think, 2015), (San Sebastian, 2018a), and (San Sebastian, 2018b), see description in chapter 4.1.1)

2.1 Themes to address in the planning process

The Hotmaps project is the first step for San Sebastián to start working on a Heating Strategy Plan, which is in line with other actions in the Municipality and very close to the retrofitting strategy to reduce the energy demand and the carbon emissions of the building stock.

Objectives of the strategy:

- Describe and map the current heating demand in the building stock of the municipality
- Identify locations in the municipality interesting for district heating.
- Identify scenarios for heating and cooling with a very high share of renewable energies.
- Compare high RES scenarios with different levels of district heating / individual heating in terms of costs, CO2 emissions and RES share
- Identify different scenarios with retrofitting interventions and new DH systems with related cost and carbon emission reduction.
- Show heat generation costs for different individual vs. different DH supply options from new installations (€/MWh)
- Define a general roadmap for the development towards low CO2 heating and cooling strategy in the Municipality.

These objectives are planned in a 2050 timeline, to have a strategy line for DH development in San Sebastián identifying the most interesting neighbourhoods to start.

The process for the Heating Strategy document is set within the Municipality as an internal process to start working on heating planning. This process and its result will be evaluated internally and will be the first step towards a heating system transformation in the city.

2.2 Approach

2.2.1 Overall approach for the strategy development

In order to reach the political targets of greenhouse gas emission reduction and energy efficiency at local as well as national and EU level, heating and cooling systems in San Sebastián have to be changed. A strategic analysis is needed to find technically, economically and resource-efficient solutions fulfilling these targets. In the course of the Hotmaps project, a strategy development process for decarbonising the heating system in San Sebastián has been performed, according to the following steps:

1. Description of the city and stakeholder analysis:
    - Definition of local, regional and national targets for GHG emission reduction and energy (see chapter 3.1)
    - Description of the existing heating and cooling system in the city (see chapter 4.3)
    - Analysis of stakeholders relevant to address when seeking sustainable decisions in heating and cooling transition (see chapter 3.2)
    - Analysis of barriers against and drivers towards a transition of the heating and cooling systems in the city (see chapter 5)
2. Mapping of demand, resource potentials and existing plants:
    - Mapping of the status quo of the heating and cooling system in the city including demand and supply points (see chapter 4.1)

- Analysis and mapping of resource potentials of renewable and excess heat sources in the city potentially usable in the mid to long term (see chapter 4.1)

3. First stakeholder meeting

   - Held on 5th April 2019
   - 2 participants of the environmental department of the city of San Sebastián
   - Topics discussed at the meeting: bottom-up vs. top-down heat demand calculation for the city, the Hotmaps database and toolbox and its data sources and available calculation modules, method for scenario calculation in course of the strategy process, potential scenarios and sensitivities to be calculated

4. Setting up scenarios:

   - Compilation of economic input data for the economic assessment of future heating alternatives (see chapter 4.3)
   - Calculation of various potential alternatives for heating demand and supply from renewable and excess heat sources (see chapter 6.1)
   - Assessment of the calculated alternatives regarding costs and emissions (see chapter 6.1)

5. Second stakeholder meeting

   - Held on 8th May 2020
   - 2 participants of the environmental department of the city of San Sebastián
   - Topics discussed at the meeting: the method, input data and results of the sensitivity analyses in the different parts of the heating demand and supply system in San Sebastián (heat savings, decentral supply, district heating network construction, heat supply to district heating), compilation of scenarios and resulting indicators (costs, emissions, energy) for the entire city of San Sebastián, preliminary conclusions out of the scenario assessment

6. Strategy formulation:

   - Prioritisation of alternatives and development of a roadmap for changes in the heating (and cooling) systems of the city in the next years (see chapter 6.2)

2.2.2 Technical approach to quantitative scenario assessment

To calculate scenarios of potential future heating demand and supply in the city and the relative costs and emissions, mainly modules developed in the Hotmaps project have been used. These calculation modules (CMs) were developed to analyse different parts of the heating and cooling system such as decentral heat supply, district heating distribution costs or district heating supply dispatch. Most CMs developed in the project have been integrated into the online version of the Hotmaps toolbox (Hotmaps, 2020). In the course of this analysis, stand-alone versions of all CMs have been used to allow more flexibility in the use of input parameters and automated calculation of a number of sensitivities. Furthermore, one calculation module has been used that is not part of the Hotmaps project development. This module is part of the **Invert/EE-Lab model** (TU Wien, e-think, 2015)and was used to derive cost curves of heat savings for the city. Also, the development of selected parts of the modelling environment used for the analysis has been performed in the course of two master theses at TU Wien. These were performed by Jeton Hasani and David Schmidinger.

Figure 3 shows the different CMs that were used in the analysis and the information that was created from or fed into the CMs.

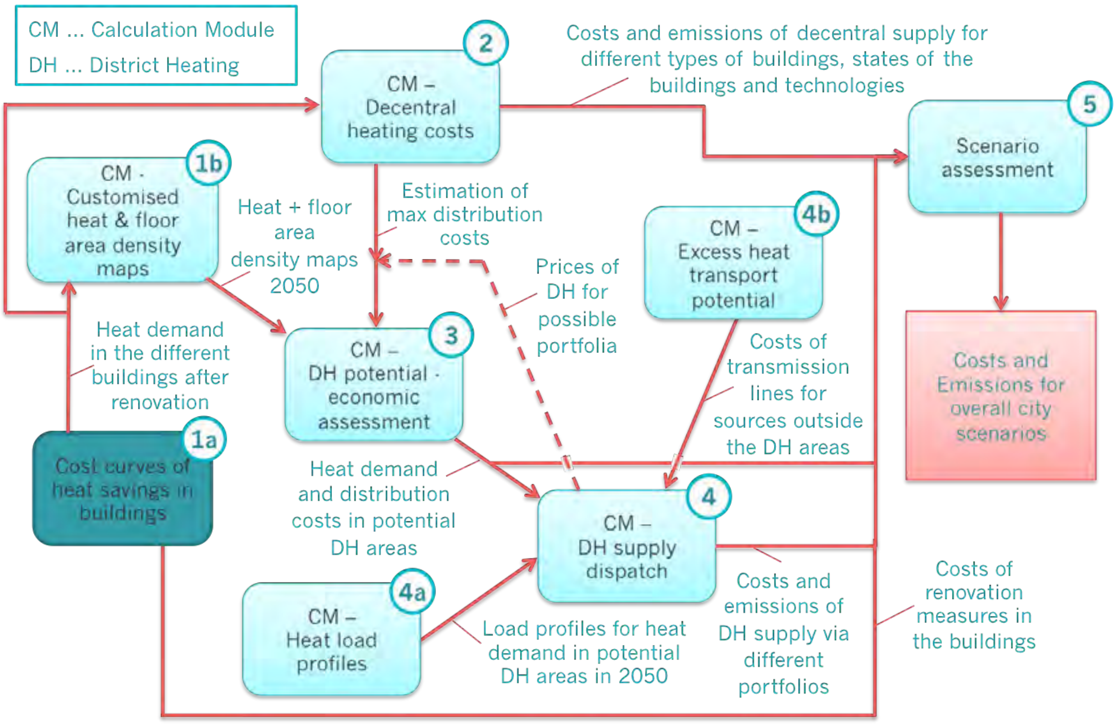


Figure 3: Method for calculating scenarios and sensitivities of heating demand and supply for this strategy process

The first step (1) in the analysis was to generate different scenarios of the state of renovation of the buildings in the city for the year 2050. This was started with setting up a database of the buildings in the city characterising their location, type, age, energy demand for space heating and hot water generation (see chapter 4.1.1 for further description). For all typical buildings in the city, various renovation packages, all reaching different relative savings of heat demand, have then been derived. Based on this data, the cheapest combination of building renovation packages, enabling to reach the 2050 predefined citywide saving targets, has been identified. For this reason, we used the renovation cost curve module of the **Invert/EE-Lab model** (TU Wien, e-think, 2015). Applying these results to the buildings' database of the city leads to different versions of the buildings' database reflecting different saving/renovation scenarios in 2050. A description of the data used for the renovation measures and the methodology applied is presented in chapter 4.3.4 The resulting databases were then fed into the **"CM - Customised heat and floor area density maps"** (Hotmaps Wiki, 2019a) (step 2) to generate heat demand and gross floor area density maps for different heat-saving levels in the city in the year 2050.

These heat demand and gross floor area density maps were further used to analyse the sensitivity of heat distribution costs in potential district heating (DH) networks (step 3). With the **"CM - District heating potential: economic assessment"** (Hotmaps Wiki, 2019b) the costs and location of potential DH networks were calculated for different saving levels, DH market shares, and thresholds for average heat distribution costs. The module hereby derives the size and location of a potential district heating system for a given threshold of average heat distribution costs in coherent areas of the system. The heat demand density map together with the market shares of DH in potential DH areas is the basis for estimating the heat potentially supplied by the DH system. The gross floor area density together with the heat potentially supplied is used to estimate the costs of the grid in the potential DH areas. A detailed description of the CM can be found in the Hotmaps wiki, a description of the data for the investment costs into the network infrastructure is presented in chapter 4.3.3.

With the **“CM - Decentral heating supply”** (Hotmaps Wiki, 2019c) the heat supply costs and related emissions from the application of decentral technologies were calculated for different types of buildings in San Sebastián, the different calculated states of renovation of the buildings and for various decentral technology options in each of these buildings (step 4). These costs have been used to calculate weighted average decentral heat supply costs for the different saving scenarios and a defined mix of decentral supply technologies. Chapter 4.3.1 shows the costs and efficiencies of the decentral technologies applied in the calculations. A description of the methodology for calculating the heat supply costs with the module is presented in the Hotmaps wiki.

The costs of supplying heat into the DH system were calculated with the **“CM - District heating supply dispatch”** (Hotmaps Dispatch Wiki, 2019) (step 5). This CM calculates the dispatch of different technologies installed in a potential DH system in order to reach minimum running costs while covering the heat demand in all hours of the year. For this strategy process, the dispatch and the resulting costs and emissions were calculated for various potential sizes of the DH network and related supply portfolios. A description of the technology data used in the analysis is presented in chapter 4.3.2 and of the modelled DH system sizes and related portfolios in chapter 6.1.2. A detailed description of the overall approach of the dispatch model can be found in the wiki of this model. The applied relation between the temperatures in the DH network, the heat sources and the Coefficient of Performance (COP) of different heat pumps are described in (Gumhalter, 2019).

An important input for the calculation of the DH dispatch is the load profile of the heat demand representing the heat demand of all consumers in the DH system for each hour of the year. These profiles are foreseen to change with decreasing heat demand for space heating due to renovation activities. Load profiles for future DH systems have been calculated with the **“CM - Heat load profiles”** (Hotmaps Wiki, 2018a) based on heat demand profiles of current DH systems according to the results of the different saving scenarios calculated in the first step of the analysis (also step 5).

In the last step (6) of the analysis, selected calculations of the different parts of the heating system in the city have been combined to consistent citywide scenarios of potential heating systems in the city of San Sebastián in the year 2050. For these scenarios, the following indicators have been calculated, split into different components such as technologies and system parts: the yearly costs of the heating system, the final energy demand, the CO2 emissions and the shares of DH and savings. For this step the **“CM - Scenario assessment”** (Hotmaps Wiki, 2020)has been used. The selection of the scenarios of the different parts of the heating system is presented together with the resulting indicators in chapter 6.1.2. A detailed description of this CM can be found in the Hotmaps wiki (Various Authors, 2018).

3 Target and policy instruments

3.1 Local, regional and national targets and policy instruments

Donostia-San Sebastián has an important trajectory in terms of smart city policy initiatives, sustainability and climate change mitigation. This is reflected in several documents and initiatives such as the SmartCity Plan, the Municipal Program to Combat Climate Change, Local Agenda 21, the Covenant of Mayors, Donostia Hiri Berdea 2030, the Sustainable Urban Mobility Plan, etc.

San Sebastián has a wide experience in specific areas of sustainability and smart cities carried out from different Departments and Municipal Companies, demonstrated by a long track-record of national and international achievements: top 5 of the smartest Spanish cities in the index of IDC - ICTs Development Index, for several years, Civitas award to sustainable transport in 2012, recognition as City of Science and Innovation in 2010 or the award of European Capital of Culture 2016, among others.

Figure 4: Factors taken into account in the definition of the Donostia / San Sebastián Smart Plan

The City Council has taken the lead in the interaction with social agents and the private sector consolidating a Donostia Smart City brand recognizable at European level.

Another important point is that the European policies are setting the main lines of work through the funding they are granting, and which represent an opportunity for the city itself. Europe increasingly seeks that cities lead the transformation process to a more sustainable society with a better quality of life, in the field of smart cities, energy efficiency and sustainable energy.

In this sense, the European project Hotmaps has established a collaboration framework between seven pilot cities and European leader organisations to develop Heating and Cooling Strategies for 2050 in these cities. This document presents the Heating Strategy for San Sebastián.

Regarding the specific framework in sustainability in San Sebastián, the following strategies and plans summarise the current work in the city approved by the City Council.

- Smart City Plan and its Action Plan 2016-2020 (2020 targets, Fomento de San Sebastián)
- SEAP (2011): Sustainable Energy Action Plan (2020 targets), available also on the Covenant of Mayors page for San Sebastián
- Climate Change Strategy 2050 (2050 targets, City Council)
- Sustainable Urban Mobility Plan 2008-2024
- Green Sustainable City (2030 targets)
- Energy Efficiency Municipal Directive in Buildings
- Agenda 21 action plan

The Green Sustainable City Plan and the Climate Change Strategy set important goals and targets for 2030 and 2050 with regard to use of RES, CO2 emissions reduction and heat demand reduction in buildings.

- Use of RES: > 25% in 2030 compared to 2007; > 80% in 2050 compared to 2007.
- Reduction in CO2 emissions: > 25% in 2030 compared to 2007; > 80% in 2050 compared to 2007.
- Lower heat demand in buildings: > 80% in 2050 compared to 2007.

Similar strategies and plans exist for the region of Gipuzkoa and the Basque Country.

Decided changes in the local energy system

San Sebastián has not worked yet at the development of a heating plan for the Municipality, and there is no heating plan for the city. To date, there are no plans to move from individual heating systems to District Heating networks.

The Hotmaps project is supporting Fomento San Sebastián in developing a first step in heating planning, setting this Strategy Document as the preliminary study of the main lines to be further analysed.

Fomento San Sebastián has promoted and developed the first public District Heating of the city in the district of Txomin-Enea. Fomento San Sebastián and the Municipality own the District Heating, and consequently the system operating policies are public. In fact, the DH development project is highly innovative for the city and region, as it is the first publicly owned DH system in the Basque Country. The economics and management of the District Heating model consist of a public-private collaboration with the aim to generate a management system that allows aligning public and private sector objectives, while guaranteeing public policies, energy prices stability and maintenance for final users. At the same time, the DH project delivers lower costs for final users. The energy supply of this DH in Txomin-Enea is based on biomass.

There is a Wastewater treatment plant (WWTP) in San Sebastián close to the Txomin-Enea neighbourhood. The heating potential of the WWTP was analysed to include it into the DH of Txomin-Enea, but due to regulation limitations, it was not possible to include it in the DH. It is still an excess heat potential to be taken into account.

The Waste Incineration plant in Zubieta has started its operation in 2020, the biggest amount of excess heat is still not used, which sets an interesting potential for DH networks. This plant is located in San Sebastián and managed by the Regional Government of Gipuzkoa, receiving waste from all the cities of the region.

Policy instruments in place

The Technical Code of Buildings in Spain (CTE - Código Técnico de la Edificación) is the main regulatory framework that establishes the requirements that buildings must meet in relation to the basic requirements of security, habitability, installations, energy efficiency, renewable energies, etc.

There is a local ordinance In San Sebastián, which establishes regulations and limitations for buildings, in terms of energy efficiency of the envelope and renewable energies. This ordinance promoted by the Environmental Department set that any intervention in the renovation of the envelope of the building must include insulation.

Regarding renewable energies in buildings, the CTE establishes for DHW that it must be supplied by at least 30% RES (e.g. solar thermal, biomass or also DH), and the local ordinance at least 40%. It is expected that the new CTE in Spain to be published during 2020 would establish a higher requirement, 70%.

3.2 Stakeholder Analysis

The Heating Strategy Document in San Sebastián is the first step for the Heating Plan for the Municipality and this work is focused on stakeholders from Fomento San Sebastián and the City Council.

Local stakeholders:

- Fomento de San Sebastián (FSS): the Economy Development Agency with a strong focus on renewable energies, energy efficiency, and smart city. A Smart City plan and an Action Plan 2016-2020 for San Sebastián had been carried out led by FSS. FSS has participated and collaborated with important European projects related to DH systems: CELSIUS and CityFied.
- Environmental department: in charge of the Agenda21, SEAP, Climate Strategy, etc. They coordinate and prepare the environmental strategy, energy efficiency regulation, and energy observatory of the city.

The Strategy Document will be deeply studied at technical level, and the local stakeholders will analyse if the Heating Plan for San Sebastián could be interesting for the city. In case the conclusions of this Strategy Document show an interesting roadmap, a political support could be analysed.

It is worth mentioning that the first public DH of San Sebastián in the Txomin-Enea neighbourhood was born on the public side through Fomento San Sebastián. FSS promoted and developed this project, and so local stakeholders from the Municipality are the key agents to support the Heating Plan in the city.

4 Description of energy demand and supply

4.1 Mapping of demand, resource potentials and existing plants

4.1.1 Energy demand in buildings

The basis for the bottom-up estimation of heat demand and the development of a heat density map for the municipality is a database of the buildings in the area. The database of the building stock is hosted by the Urban Development Department of San Sebastián and was provided for the work within this project. Hereby the status of the database from December 2018 has been used.

The building stock database exists in the form of a GIS shapefile containing polygons of 14,312 buildings in the municipality. Various attributes of the buildings are linked to the building shapes. However, not for all buildings in the municipality all attributes are available in the database. Furthermore, the type of buildings is not stated in the buildings database, only the type of plot is categorised. This allows distinguishing between residential and non-residential buildings, but not between different non-residential buildings. Therefore, the building stock database is combined with a database of non-residential buildings in the city of San Sebastián containing information on the type of use of the buildings. To distinguish between single-family buildings and multi-family buildings the size of the gross floor area of the residential buildings is used. As a further step, missing entries for the construction year are filled by using the average age of buildings of the same building type. This leads to a consistent dataset containing information on type, size, age and location of each building. Furthermore, this database also includes the number of inhabitants of each building. These values are further used to detect buildings' gross floor area (GFA) that is heated and not heated.

Figure 5 shows the distribution of gross floor area (GFA) of buildings with relevant heat demand in the municipality. Multifamily houses (building category 5) show to be the main part of the building stock with 73% of total GFA in the city (residential and service sector). The age of the buildings is nearly evenly distributed between the different construction periods. However, there exist a remarkable number of buildings built before 1969. Offices are the most relevant type of service buildings in the city, public and private offices together account for 24% of GFA in the service sector. However, buildings from the education and the health sector have also remarkable shares of GFA in the service sector with 20% and 18%, respectively.

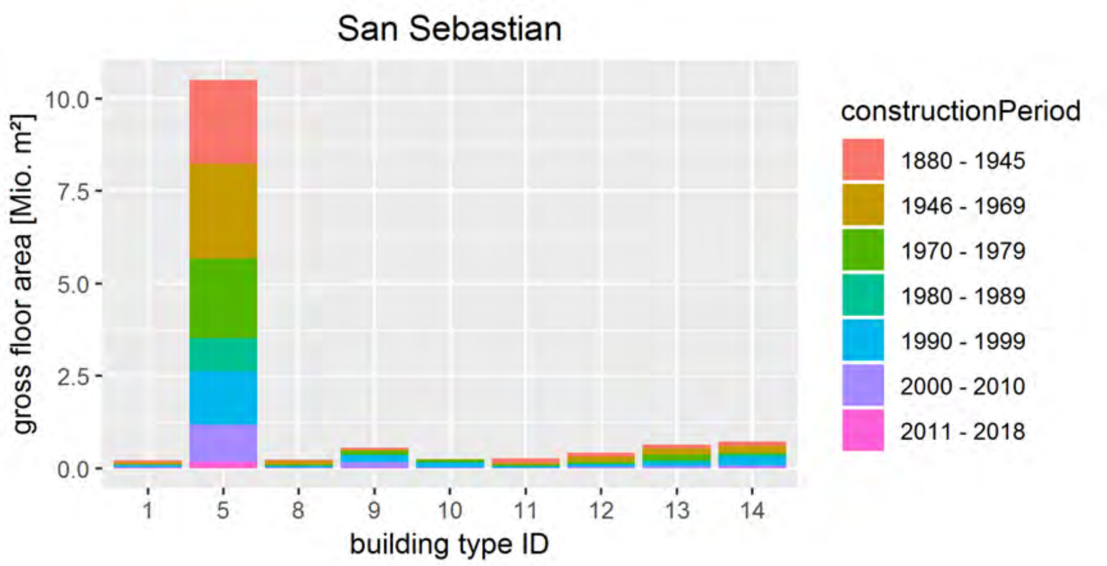


Figure 5: Gross floor area of buildings with relevant heat demand in the municipality of San Sebastián differentiated between building types and construction periods (Building type ID 1 and 5: single family and multifamily houses, other IDs: non-residential buildings, please see Table 1 for more details) (Source: own calculations based on (TU Wien, e-think, 2015), (San Sebastian, 2018a), and (San Sebastian, 2018b))

In a second step, statistical energy demand values per gross floor area (GFA) for space heating and hot water generation have been joined with the resulting building dataset. These energy demand (per GFA) values were taken from the database of the **Invert/EE-Lab model**[1] (TU Wien, e-think, 2015). The values reflect the energy demand for space heating and hot water preparation of typical types of buildings from different construction periods in Spain and are calibrated on the national building stock and the national energy balance. Before joining with the dataset of buildings in San Sebastián the demand per GFA values were climate corrected from the average Spanish climate to the climate in San Sebastián. For this the values of the heating degree days (HDD) from the Hotmaps database were used and elasticity of 60% was assumed. According to this approach the heat demand in buildings in San Sebastián is around 7% lower compared to the national average.

From the Invert/EE-Lab database we use the values of useful energy demand effective for the analyses. These values for space heating reflect the energy needed to keep the indoor temperature of the buildings at a certain set temperature and take into account various factors

[1] The Invert/EE-Lab model is a bottom-up simulation model of the energy demand for heating and cooling (H/C) in buildings. It calculates the energy demand based on detailed data of the buildings like dimensions, u-values of the buildings' envelope, climatic conditions and user profiles. Future development of the building stock is derived by simulating investment decisions in H/C relevant equipment like insulation, windows or heating and heat distribution systems. The model has been developed and applied in national and international research and consulting projects in Europe for over a decade. More information can be found on the Invert/EE-Lab website.

of user behaviour like higher indoor set temperatures for better-insulated buildings or that parts of the buildings and flats are not heated such as pantries or staircases.

The analysis showed that a remarkable share of gross floor area in buildings is not heated. Therefore, in the residential sector, a limitation of the heated gross floor area per building and inhabitant has been set with 40 m²/inhabitant. This means that for each inhabitant in a building a maximum of 40 m² of heated gross floor area is assumed. This is due to the fact that a remarkable number of buildings in the city exist with only a few persons living in the buildings. Such a limit has been defined in order to take this occupation into account.

In Table 1, the results of the bottom-up calculation of heat demand for space heating and hot water generation are summarised. It shows the large share of residential and especially multi-family buildings on the gross floor area as well as the heat demand in the city: Multi-family buildings account for 61% and single-family buildings for another 2% of total heat demand for space heating and hot water generation in the city. The heat demand from the buildings in the different important service sectors (offices, education and health) are in similar order with around 7-8% of the entire heat demand in the buildings of the city. The totals for the residential as well as non-residential sectors match very well with estimations of useful energy demand in the city based on the consumption of gas, oil and electricity for heating and hot water generation (see chapter 4.2).

Table 1: Number of buildings, gross floor area and useful energy demand for space heating and hot water generation for buildings in San Sebastián separated for different building categories (Source: own calculations based on (TU Wien, e-think, 2015), (San Sebastian, 2018a), and (San Sebastian, 2018b))

		number of buildings [-]	gross floor area [m²]	useful energy demand [GWh/yr]	
				space heating	hot water
1	single family houses	1,960	130,189	8	2
5	multi family houses	8,028	6,509,010	253	103
8	public offices	62	161,886	16	0
9	private offices	249	386,542	31	1
10	wholesale & retail	62	175,582	14	0
11	hotels & restaurants	113	190,292	18	1
12	health	77	416,003	38	11
13	education	146	453,563	41	2
14	other non residential	192	511,407	44	2
	Residential	9,988	6,639,198	260	105
	Non-residential	901	2,295,276	202	18
	Total	10,889	8,934,474	462	124

The resulting heat density map of the city is shown in Figure 2 in chapter 2.

4.1.2 Power and CHP plants

San Sebastián has a WWTP near the Txomin-Enea neighbourhood where Fomento San Sebastián has deployed the city's first public DH. The Loiola WWTP purifies wastewater equivalent to a population of 628,000 inhabitants. FSS has analysed in detail in a feasibility study the installation and the energy that could be reused from the WWTP to be included in the DH of Txomin-Enea.

In 2020 there is a waste incineration plant in operation in the municipality of San Sebastián, about 10 km from the city centre. This project is promoted and managed by the Regional Government that will receive waste from the entire province of Gipuzkoa. The plant has been designed with a total capacity to treat 242,362 t / year of waste and a nominal capacity of 201,968 t / year of waste.

4.1.3 Industry

San Sebastián is a service-oriented city, no big industrial companies are located in the city. There is a cement manufacturer but no excess heat for external uses is available, it has been already studied by the Municipality. There is an Ice-Skating centre, it has not been analysed and no data about excess heat is available.

4.1.4 Individual heating

The share of Natural Gas in the city is around 80% for individual heating, and the other 20% is mainly electricity, with few installations of gas butane and biomass. Probably there are no Oil installations.

There are three buildings with biomass: Talent House, Uba Aterpetxea, Ibai Ikastola. Regarding Geothermal energy, there are six buildings: PIA, ENERTIC, Etxetxuri, the Firefighter building, one Gimnasium, one single house.

4.1.5 Existing network infrastructure

In San Sebastián there is a natural gas grid, which covers the entire city. A private company runs this service.

There are five isolated DH installations in San Sebastián:

- Txomin-Enea neighbourhood: first publicly owned DH system and in operation since 2018 in a new urban area. The urbanisation will be completed in 2023 giving service to 1500 dwellings. Biomass DH.
- Bera Bera neighbourhood: private installation run with gas and cogeneration, renovated recently including a biomass boiler. It supplies heating and DHW to around 800 dwellings.

- Bidebieta: old installation run with gas, around 600 dwellings.
- Old Age Zorroaga Centre: DH installation for the building block for around 370 people. Fuelled with gas.
- Hospital: DH system runs with cogeneration. 1000 beds capacity.

4.1.6 Local renewable energy resources

A low-carbon heating and cooling system is based on the use of renewable energies, available excess heat sources as well as the incineration of waste. For this strategy, potentially available amounts of these energies have been estimated based on existing information from the city. These estimations are described here below.

A resource potential of high interest for the heat supply in San Sebastián could be the waste incineration plant that has been built in the South of the city in Zubieta/Gipuzkoa around 10 km away from the city centre. The plant has been finished and started operation in 2020. The plant is designed to operate 200 kt of municipal waste per year and is constructed with two lines of incineration both with 40 MW maximum thermal power (GHK, 2016). Currently, the plant generates only electricity for the supply to the electricity network. In the analyses in the course of this strategy, only the thermal use of the plant is taken into account. It is assumed that a thermal power of 28 MW for generating heat for district heating could be available. This is in line with waste incineration capacities per inhabitant in other cities like Vienna or Frankfurt.

In Loiola neighbourhood a wastewater treatment plant is located, close to the city centre. The plant is constructed with a capacity of around 630,000 person equivalents. The sewage sludge from the plant is used for the generation of biogas via anaerobic digestion. The generated biogas is used in two combined heat and power (CHP) plants for generating heat and electricity. Each CHP unit has a capacity of 1.2 MWel. It is assumed that these capacities will be available on the long term. Therefore, in the analyses a biogas CHP capacity of 2.5 MW is integrated in all analysed district heating portfolios. It is assumed that the generation costs of the biogas on-site are around 25 EUR/MWh.

Besides the anaerobic digestion also the heat in the water outlet of the plant could be used as a source for a heat pump. Based on measurements of wastewater treatment plant outflow temperatures in other places in Europe It is assumed that the temperature of the outflow will vary between 16 and 24°C over the year. Based on the study of the potential of heat in the outflow of wastewater treatment plants in Frankfurt a potential of available heat for heat pumps of around 35 MWth in the plant in San Sebastián is estimated. For the calculations in the course of this strategy, two system sizes of the heat pumps have been used depending on the portfolio: 8 MWth and 25 MWth.

The seawater could also be used as a source for a large-scale heat pump. However, it is assumed that the desalination of the water in order to use it in heat pumps makes the investment unfeasible compared to the other sources.

As mentioned, San Sebastián is a service-oriented municipality and therefore the number of large industrial facilities in and around the city is very limited. A cement plant is located south around 7 km outside the city centre. However, previous discussions with the plant operators lead to the assumption that no relevant excess heat amounts are available for potential use in a district heating system.

Local biomass from surrounding regions could be also a possibility to supply the heat demand in the city. In 2017 FSS carried out a feasibility study to analyse and characterise the available local biomass resources in detail (Fomento de San Sebastián, 2017). The study found that between 60 and 100 GWh/yr could be available depending on the route of utilisation (chipping; debarking, drying and chipping or producing pellets). In the scenarios, it is assumed that not all of the identified potential is possible to be used for the heat supply in the buildings due to the competition with other potential uses.

In and around the city of San Sebastián it is assumed that the construction of a large scale solar thermal plant is not feasible. The costs of land are very high and make it uneconomical to use land for solar thermal collector fields. At the same time, it is assumed that the installation of solar thermal collectors on the roofs of the buildings can be an interesting option in the city of San Sebastián. In the scenarios of decentral supply for the buildings in the city a potential of around 10 tsd. m² of collector area in the roofs is assumed.

For the scenario calculations we selected different technology combinations for decentral and district heating supply. A description of these technology combinations is given in chapter 6.1.

4.2 Description of existing heating and cooling

The energy balance and total energy consumption in San Sebastián in 2007, taken as the reference in SEAP 2011, was 3.499 GWh, whereof 742 GWh for buildings, 490 GWh for services, industry and equipment/facilities and 2.266 GWh for transport purposes. Mobility is the main energy consumer. Liquid fuels are the most used energy source in the final energy consumption, which accounts for 63%. Electricity and natural gas represent 19% and 16% of the total final energy consumption.

Regarding energy consumption and RES of 2018 in the city, the following figures show the distribution.

- Gas consumption: 777.359.226 kWh
- Gas consumption in sectors (Service, Industry, Households) per inhabitant:
- Domestic: 1.822 kWh / inhabitant
- Industry: 1.037 kWh / inhabitant
- Service: 1.289 kWh / inhabitant

Renewable energy production (in some cases estimated):

- Biogas: 1.800 MWh
- PV: 1.800 MWh
- Geothermal: 2.200MWh
- Solar Thermal: 2.000MWh
- Biomass: 8.800 MWh

Electricity consumption in SS: 699.589.855 kWh

Electricity consumption per inhabitant in SS:

- Domestic: 1.263 kWh/Inhabitant
- Industry: 522 kWh/Inhabitant
- Service: 1.945 kWh/Inhabitant

4.3 Data for economic calculation

The economic calculations for this heating strategy reflect socio-economic criteria: the depreciation time was set to the lifetime of the technologies and an interest rate of 3% was used. This interest rate includes inflation on the one hand and also a supplement for the investment risk on the other hand.

In the following, we describe the relevant data of costs and prices related to the heating system, which are used in the calculation of the scenarios presented in chapter 6.

4.3.1 Data for decentral heat supply technologies

In order to calculate the costs of supplying space heating and hot water in the buildings via decentral supply technologies, the following data are used: investment costs as a function of the device size (larger devices usually have lower costs per power), fixed operation and maintenance (O&M) costs, the thermal efficiency and the lifetime of the devices and the price of the energy carrier used by the device. Table 2 shows these data for the different technologies taken into account in the analysis except for the energy carrier prices. Those are described in chapter 4.3.5.

Table 2: Investment and O&M costs, thermal efficiency and lifetime of decentral heat supply technologies applied in the scenario calculations (Source: Invert/EE-Lab database for Spain (TU Wien, e-think, 2015))

	power [kW_{th}]		invest [EUR/kW_{th}]		O&M fix	thermal	LD [yr]
	from	to	from	to	[EUR/kW_{th}*yr]	efficiency [-]	
Oil boiler	10	200	460.7	186.0	9.9	0.976	20
Natural gas	10	200	290.5	117.3	6.2	0.976	20
Biomass_Automatic	10	200	2055.3	291.6	17.4	0.93	20
Biomass_Manual	10	200	919.8	336.3	13.8	0.93	20
Wood stove	10	200	919.8	336.3	13.8	0.93	20
HP Air-to-Air	10	200	419.7	227.6	21.9	3.41	12
HP Air-to-Water	10	200	445.9	278.5	21.9	3.41	18
HP Brine-to-Water	10	200	2065.7	1430.4	16.5	4.59	20
Solar thermal	3	200	1027.7	653.0	11.3	1	30
Electric heater	10	200	51.9	51.9	1.0	1	30

4.3.2 Data for district heating supply and storage technologies

Table 3 shows the costs, efficiencies and lifetimes of district heating supply and storage technologies applied in the scenario calculations with the district heating supply dispatch module. The data are based on experiences in past projects performed by TU Wien and e-think.

Table 3: Investment and Operation and Maintenance (O&M) costs, thermal and electrical efficiency and lifetime of district heating supply and storage technologies applied in the scenario calculations (Source: own calculations based on experiences in various projects)

	invest [EUR/kW$_{th}$]	O&M fix [EUR/kW$_{th}$*yr]	O&M var [EUR/MWh$_{th}$]	efficiency		lifetime [yr]	Minimum Output Power Factor [0-1]	Cold Start Costs [EUR/Start]
				th	el			
Biomass Boiler	600	18	0	0.85	-	20	0.05	1000
CHP Back Pressure Biogas	2530	76	0	0.45	0.35	15	0.05	1000
Heat Pump Wastewater	750	34	0	2.8 - 4.2	-	20	0.05	1000
Waste Inceneration	1960	54	0	0.8	-	20	0.05	1000

	invest [EUR/MWh]	O&M fix [EUR/yr]	O&M var [EUR/MWh$_{th}$]	hourly heat storage losses [-]	lifetime [yr]	Storage Capacity [MWh]	maximum loading/unloading power [MW]	loading/ unloading efficiency [-]
heat storage	2500	-	-	0.01	25	2800	28	0.97

4.3.3 Costs of district heating network construction

Besides the costs for the supply of heat to the district heating grid, the costs for the distribution of heat via the grid have to be calculated for determining the overall costs of heat supply via district heating. The costs for the heat distribution mainly consist of the investment costs for the network infrastructure. For calculating the investment costs in the network the Hotmaps **"CM - District heating potential: economic assessment"** (Hotmaps Wiki, 2019b) builds on a concept developed by (Persson and Werner, 2011) as well as (Persson et al., 2019). The concept is based on the following relations: 1) a relation of the effective width with the plot ratio, 2) a relation between the effective width, the distributed heat demand and the average pipe diameter, and 3) a relation between the average pipe diameter and the overall investment costs in the network construction. These relations have been derived based on the analysis of a number of existing district heating projects around Europe. A detailed description of the CM for assessing the heat distribution costs and how these relations are used in the module is given in (Fallahnejad et al., 2018).

For the analyses in San Sebastián the relations are used as given in (Persson and Werner, 2011) as well as (Persson et al., 2019). Figure 6 shows the resulting investment costs per meter of trench length (flow and return pipes) for the range of heat demand density relevant in San Sebastián and for different plot ratios e. Plot ratio hereby is defined as the fraction between building gross floor area (GFA) and corresponding land area (LA) in a defined raster element, both measured in [m²]. In the calculations for this strategy a raster element is defined as a land area of 100 x 100 m.

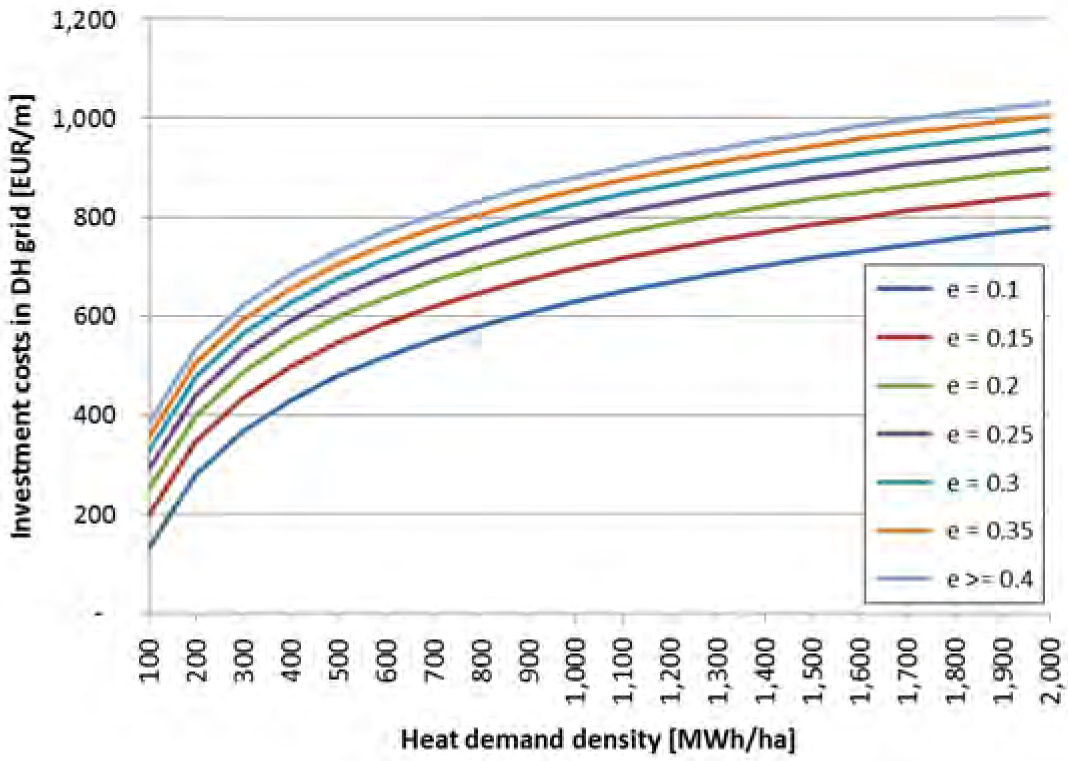


Figure 6: Investment costs in network construction per meter of trench length (flow and return pipes) for different plot ratios e in relation to the heat demand density to be supplied (Source: own calculations based on (Persson et al., 2019))

4.3.4 Costs of renovation measures in buildings

The costs and effects of applying renovation measures in the existing building stock in the city is calculated using the Invert/EE-Lab model. For each typical building currently existing in the city (see chapter 4.1.1 for a description of the current building stock) a set of 9 renovation packages is developed. Each renovation package hereby leads to different relative savings and consists of a combination of the following single measures: insulation of roofs, insulation of exterior walls, insulation of basements and change of windows. While for reaching ambitious savings measures on each part of the building surface are required, packages for reaching less ambitious savings only consist of selected measures. The compilation of the packages is done by identifying the combination of single measures with the lowest investment costs for reaching a certain saving target for a building.

Figure 7 shows the investment costs for renovation measures on the different parts of the building surface depending on the thickness of insulation and the u-value of the windows, respectively. The basis of the values is a detailed analysis of past renovation projects in Germany. The data sample of the German study was high enough to derive cost functions for the different measures showing the correlation between the ambition of the measures and the relative costs. These values have been recalculated to the Spanish situation using the difference in the construction cost index between both countries.

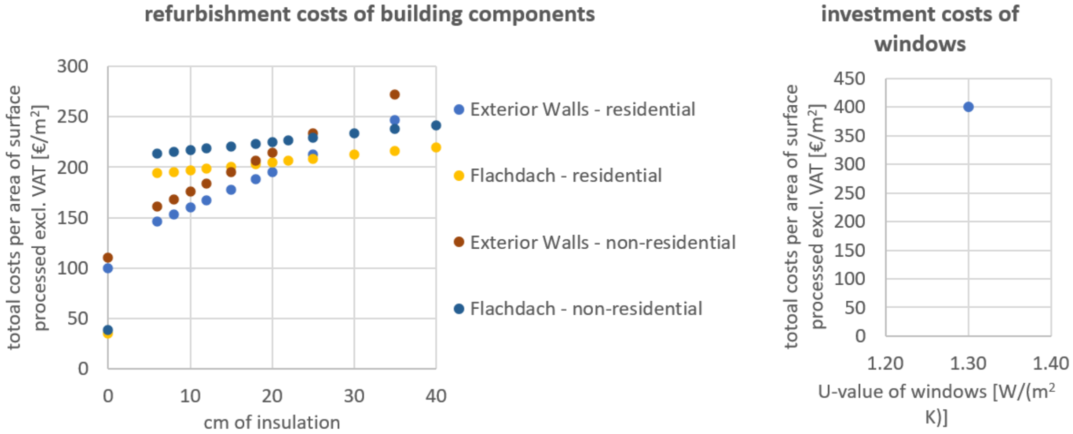


Figure 7: Investment costs for renovating different parts of the building surface depending on the thickness of insulating and u-value of windows respectively (Source: own calculations based on (BMVBS, 2012))

A more detailed description of the approach of deriving renovation costs for the Spanish case and compiling the renovation packages can be found in the article "The costs and potentials for heat savings in buildings: refurbishment costs and heat saving cost curves for 6 countries in Europe" (Hummel et al., 2020).

In order to validate the derived data on costs of renovation measures, these have been compared with data from local sources. To this intent, cost estimates for different renovation measures have been collected from architects situated in the region of San Sebastián. This includes a description of different renovation options for roofs and facades and the related costs. The comparison shows that the data derived based on the approach described above fit well to the data estimates at the local level. For the insulation of flat roofs with 8 cm of insulation material, the local estimates show costs of 80 - 90 EUR/m² excl. VAT including all works. The costs for the insulation hereby account for around 15 EUR/m². This matches exactly with the data derived from the German study. For the insulation of exterior walls with 8 - 10 cm of insulation material the local estimates show costs of around 95 - 105 EUR/m² excl. VAT including all works. Only maintaining the facade would cost 65 EUR/m². Thus, the additional costs for thermal renovation compared to only maintaining the facade account for around 30 - 40 EUR/m², which matched well with the additional costs derived from the German study. All values described from the local estimates as well as from the German study do not include costs for the scaffold in case this is needed. These costs are taken into account in an extra cost position with 35 EUR/m².

The costs and effects on the heat demand of all different renovation packages in all different typical buildings are used for the identification of least-cost combinations of renovation packages in the buildings of the city for reaching certain predefined saving targets. Hereby the additional costs are taken into account, which is the difference between the costs of the renovation measure and the costs of only maintaining the selected part of the building surface. The results of this calculation are presented in chapter 6.1.2.

4.3.5 Prices of energy carriers and CO2 emission allowances

In order to calculate the cost-effectiveness of different alternatives for heating supply and demand reduction, the prices of energy carriers play an important role. For the calculations in the course of this strategy process, we use price data from the Horizon 2020 SET-Nav (SET-Nav, 2020). These data form also the default data on energy carrier prices of the Hotmaps database (Hotmaps Wiki, 2018b).

In the project SET-Nav scenarios of the entire European energy systems for the years 2030 and 2050 have been developed, which are in line with the long-term European climate targets. This included modelling of the heating and electricity systems in Europe as well as the transport grid for heat and electricity. While prices for fossil energy carriers were taken from the IEA World Energy Outlook 2016 (the IEA 450 ppm scenario)(IEA, 2016), the hourly prices for electricity were derived with an electricity market model, Enertile (Fraunhofer ISI, 2020) for 4 different settings regarding political and regulatory framework conditions. The price scenarios were calculated using a cap for the carbon emissions from electricity and district heating generation based on the PRIMES EUCO30 scenario from the European Commission 2016 (734 Mt in 2030, 146 Mt in 2040 and 60 Mt in 2050)[2].

Table 4: Overview of the four different price scenarios (Source: SET-Nav project (Resch et al., 2019))

Scenario name	description
Directed vision	EU/state directed shared vision strong EU policy framework
National champions	utilities & incumbents regulatory capture low transition costs
Diversification	heterogeneous actors coordination (beyond markets) digitalization (diverse heterogeneous actors) regulatory change disrupt incumbents
Localization	local resources resistance to big infrastructure developments experimentation & diversity (many niches) digital winners-take-all

Table 5 and Figure 8 show the average yearly retail prices for electricity, solid biomass and natural gas for end consumers as well as the hourly electricity wholesale prices, both for 2050.

Table 5: Average yearly retail prices for end consumers of relevant energy carriers in the year 2050 in Spain, including taxes, excl. VAT (Source: SET-Nav project, (SET-Nav, 2019))

Energy Carrier	Retail price [EUR/MWh]
Electricity	230.1
Biomass solid	26.3
Natural gas	93.3

[2] A detailed description of the scenarios can be found in (Resch et al., 2019)

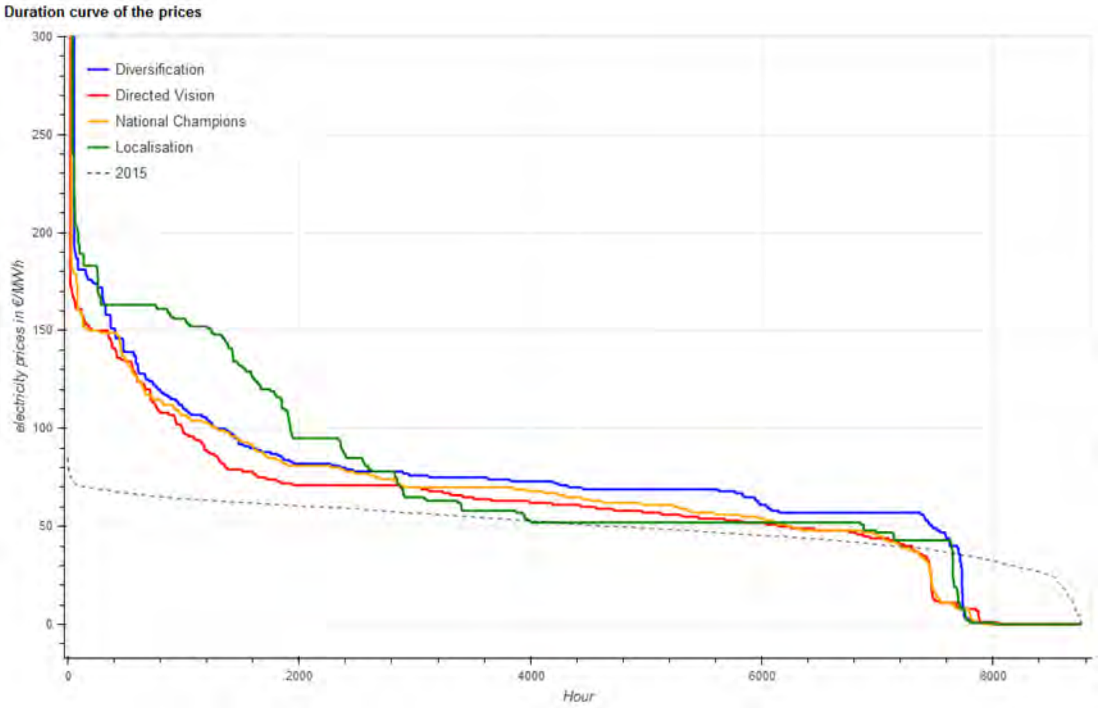


Figure 8: Duration curve of wholesale electricity prices for 4 scenarios for 2050 and historic prices in 2015 for Spain used in the scenario calculations (Source: Enertile (Fraunhofer ISI, 2020), SET-Nav project (Resch et al., 2019))

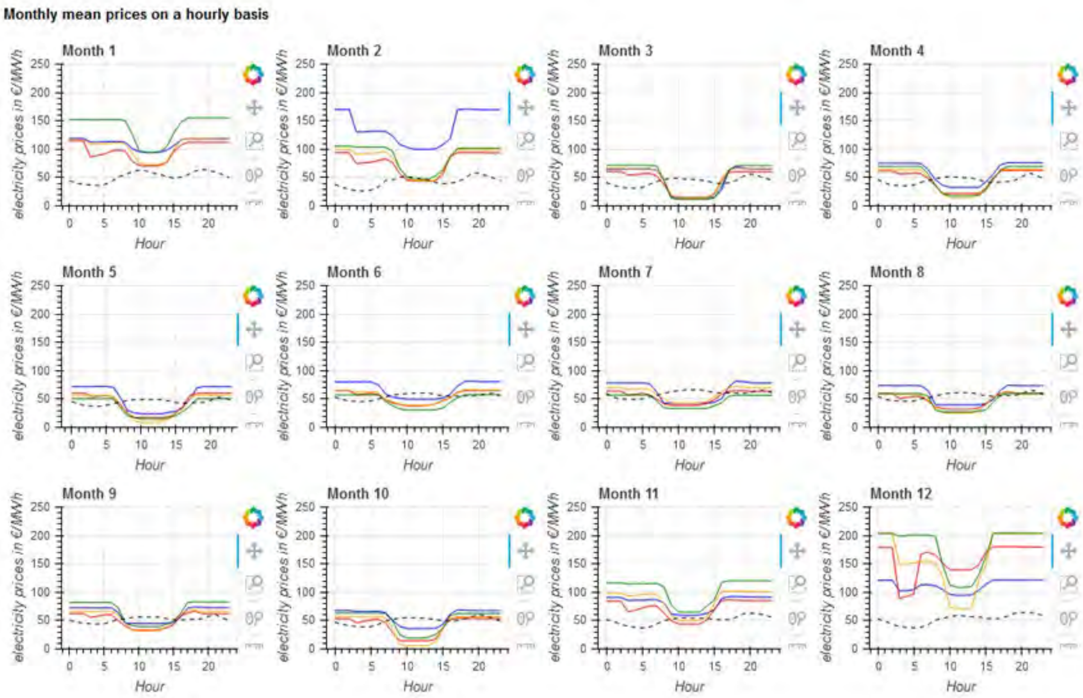


Figure 9: Monthly mean prices on hourly basis of wholesale electricity prices for 4 scenarios for 2050 and historic prices in 2015 for Spain used in the scenario calculations (Source: Enertile (Fraunhofer ISI, 2020), SET-Nav project (Resch et al., 2019))

The electricity wholesale market prices do not include charges for the electricity grid. Therefore, in the calculations, we add 40 EUR/MWh of grid charge on top of the prices.

The following Table 6 shows the mean electricity wholesale prices as well as the CO2 shadow prices[3] in the year 2050 in Spain for the four electricity price scenarios as described before. The CO2 shadow price is used in the calculations for San Sebastián for determining the costs of CO2 from fossil emissions.

Table 6: Mean electricity wholesale prices and CO2 shadow prices in the year 2050 in Spain for the four electricity price scenarios (Source: SET-Nav project (Resch et al., 2019, p. 7))

Scenario	Name	Mean electricity price [EUR/MWh]	CO2 price [EUR/tC02]
Price 1 (P1)	Directed Vision	61.09	183
Price 2 (P2)	National Champions	64.91	139
Price 3 (P3)	Diversification	71.75	199
Price 4 (P4)	Localisation	72.24	296

5 Drivers and Barriers

San Sebastián is committed to sustainable city development. The Municipality and Fomento San Sebastián are actively working on local plans and projects to improve the quality of life of the city in a general sense. Regarding the Heating Planning Strategy, even if this topic has not been of interest so far, the Hotmaps project could change this vision and help San Sebastián to design a Heating Planning Strategy, and so the main Driver would be Fomento San Sebastián and the Municipality itself.

The following paragraph shows the main opportunities and barriers for the Heating Plan:

- Opportunity 1: San Sebastián has not performed heat planning so far; thus, the work done within the Hotmaps project could be the first step to activate this kind of planning and strategy development in the city.
- Opportunity 2: San Sebastián is working actively in plans related to Climate Change, Smart Cities, Energy Efficiency, Urban Sustainable Mobility, etc. There is a political commitment towards a sustainable city, and social awareness is increasing.
- Barrier 1: Heating and cooling have not been a topic of interest in the region and the result of this project could be out of the city priorities.
- Barrier 2: it seems to be difficult to develop or integrate DH systems in existing compact dwellings in San Sebastián.

[3] The shadow prices of CO2 are the result of the optimisation calculation with the Enertile model. For the different framework and technology settings different CO2 prices result from the calculation.

- Barrier 3: High investment costs for the development of DH networks in the city. In addition, the market share of such high investment presents some uncertainties to get a high number of connections to the DH.
- Barrier 4: utility pressure against the development of sustainable DH systems with less share of gas networks.

During the development of the DH intervention in the Txomin-Enea neighbourhood, the first publicly owned DH in the city, Fomento San Sebastián faced several regulatory problems to deploy the network in the urban area. It was not an easy task to clarify and overcome all those problems, and now FSS is in a better position to move forward for future DG developments.

Regarding the drivers within FSS and the Municipality in more detail, some additional issues can be mentioned:

- Fomento San Sebastián and the municipality make renewable energy a priority when developing projects. FSS developed exemplary projects in the city in this way (DH in Txomin-Enea, ENERTIC bioclimatic building, Biomass and geothermal installations, etc.
- Energy and climate goals have been defined in the Municipality in different steps, plans, and strategies.
- Local legislation to promote energy retrofitting in buildings.
- The sustainability and energy efficiency in the Municipality regarding own buildings, installations, services, monitoring, etc. is one of the priorities.
- Involving the local stakeholders and inhabitants turned out to be an important success factor in current projects.

6 Local heating and cooling strategy

6.1 Assessment of scenarios

In order to identify technically and economically sound solutions for future heating systems in San Sebastián, a set of scenarios is calculated and assessed regarding costs and CO_2 emissions. The outcomes then form the quantitative basis for formulating a heating strategy for the city. In the following chapters, the scenarios, as well as the results of the different analysis steps, are described. The method for the development of the scenarios is described in chapter 2 of this document.

6.1.1 Definition of scenarios and sensitivities

For a first analysis, various sensitivities for each of the different parts of the heating demand and supply systems in the city are calculated:

- Six different levels of savings in demand for space heating via virtually applying different renovation packages to different buildings in the city.
- 216 different sensitivities for the expansion of the district heating grids in the city varying the following input parameters: heat demand density maps (developed in the previous step), share of heat demand connected to district heating in the regions where district heating is available, grid cost ceiling of district heating (= the maximum distribution costs in each of the connected regions)
- Six different sensitivities of decentral supply costs in the city varying the following input parameters: heat savings in the buildings according to the saving scenarios developed in the first step
- Four different portfolios of a potential district heating system for the city based on different renewable energy sources, waste incineration and biomass boilers. Different portfolios are compiled for different sizes of potential district heating networks. These are calculated for 4 different electricity and CO2 price scenarios and three different temperature levels in the supply line of the heat distribution grid.

All sensitivities are calculated for the year 2050. The citywide scenarios are then compiled from a selection of those sensitivities.

The following Table 7 gives an overview of the sensitivity calculations in the course of the strategy development, it shows the parameters and range in which these have been varied in the different modules.

Table 7: Overview of sensitivities calculated with the different modules in the course of the strategy process

Main parameters varied	*range of variation of parameter*
Energy demand for space heating and hot water generation	
target of savings in heat demand for space heating	10% - 60% in steps of 10%
Decentral heating supply costs	
savings in heat demand for space heating	10% - 60% in steps of 10%
District heating (DH) distribution costs	
savings in heat demand for space heating	30%, 40%, 50%, 60%
share of heat demand connected to DH in areas with DH grid	50%, 70%, 90%
maximum grid costs [EUR/MWh] in regions connected to DH	9 - 26 in steps of 1 EUR/MWh
District heating (DH) supply costs	
total heat demand supplied by DH	30, 100, 150 and 200 GWh/yr
capacities of installed technologies	4 different portfolia; see respective chapter for more details
electricity wholesale and CO_2 prices	4 different prices scenarios, see chapter 4.3.5
supply line temperatures in the district heating grid	3 different temperature profiles from 55 - 86 °C (median Temperature)

6.1.2 Scenario results

6.1.2.1 Heat demand density maps 2050

A heat demand density map for the city's current situation has been developed based on the data of the building stock in the city and building type-specific demand data from Invert/EE-Lab (see chapter 4.1). Potential changes in the heat demand density in the city have been developed by virtually applying different renovation measures to each of the buildings in the city. These heat-saving measures have been chosen in a way that the overall costs of renovation towards a predefined overall saving target for the city were minimised, i.e. buildings providing cheaper renovations are renovated first and more ambitiously. In the following Figure 10, the heat demand density map of the current situation is shown together with heat demand density maps for three different saving scenarios: 24%, 39% and 46% savings of heat demand in the city.

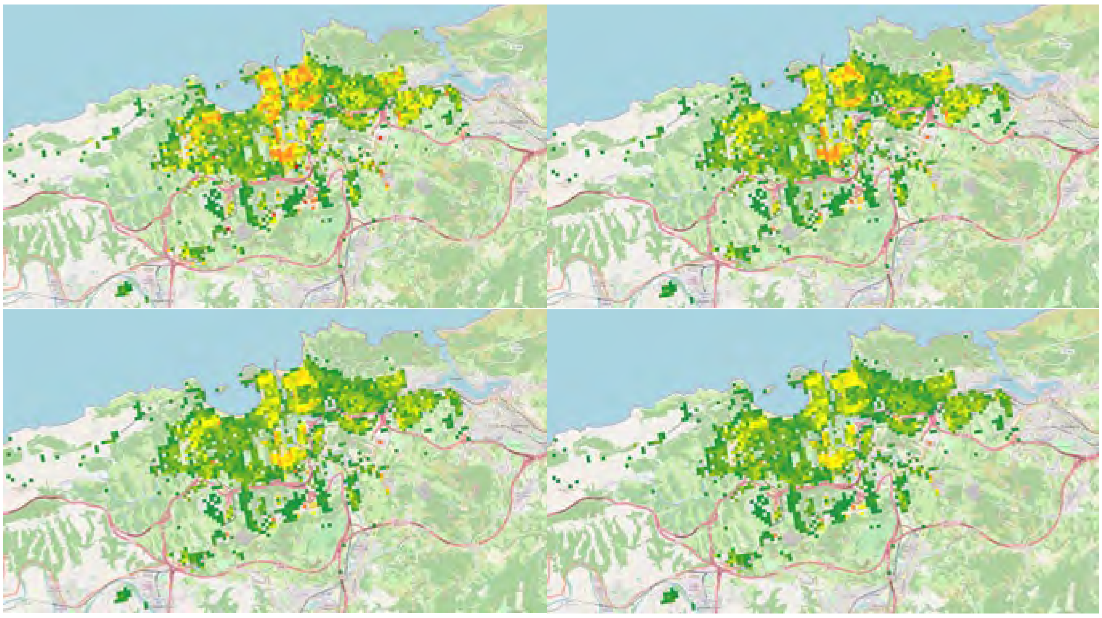


Figure 10: Heat demand density maps of San Sebastián for 2017 (top left), 2050 with 24% savings (top right), 2050 with 39% savings (bottom left) and 2050 with 46% savings (bottom right) (Source: own calculations)

Currently, the useful energy demand for space heating and hot water generation in residential and service buildings in the city of San Sebastián is 585 GWh/yr[4]. The average heat demand density in the city currently is around 374 MWh/ha*yr, the highest heat demand density in the city centre is 5,365 MWh/ha*yr.

As can be seen in the figure, the application of renovation measures in the city would lead to decreased heat demand densities especially in the central parts of the city. In the surroundings of the city, the heat demand density is already low in the current situation. Average (and maximum) heat demand density in the three saving scenarios decreases to 283 (and 5,365) MWh/ha*yr, 223 (and 2,617) MWh/ha*yr and 201 (and 2,016) MWh/ha*yr.

[4] See details on the bottom-up estimation of heat demand and heat demand density in chapter 4.1.1

Figure 11 shows the costs of reaching different levels of heat savings in the buildings of the city of San Sebastián. For different levels of overall savings between 8% and 47% the annualised investment costs per MWh of saving and the total annual investment costs in MEUR/yr are shown. This figure shows that the average costs per savings (yellow line) increase more or less linearly until savings of around 40% of the overall heat demand, which would cost around 92 EUR/MWh. Reaching savings of 47% of the overall heat demand becomes remarkably more expensive at around 135 EUR/MWh. The figure also shows a range of uncertainty in the costs of heat saving measures. This uncertainty results from the methodology used for the calculation of the cost curves: in the calculation of the costs for relative savings in the entire city, it is assumed that all buildings in the city are occupied. Thus, renovation activities in each building of the city in this calculation lead to savings of heat demand. This leads to relatively low costs for reaching specified saving levels (minimum line of uncertainty range).

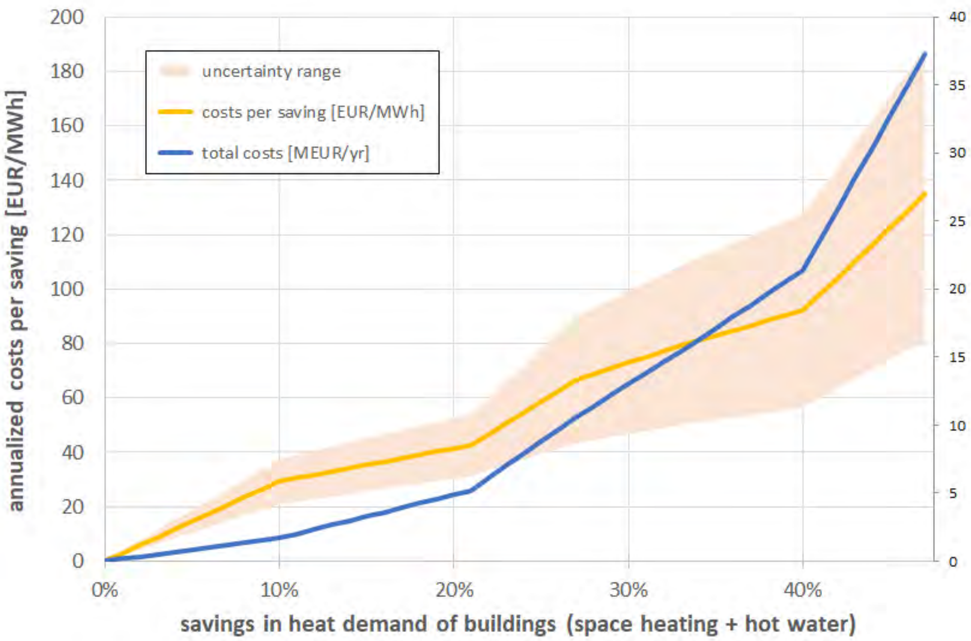


Figure 11: Annualised investment costs per saved heat (left axis) and total annualised investment costs (right axis) for reaching different overall savings of heat demand in building in the city of San Sebastián (Source: own calculations)

In the city of San Sebastián, a remarkable share of buildings' gross floor area is not occupied and therefore it is not heated. Applying the same relative savings per building to all buildings in the city at the same total costs as calculated for the case that all buildings are occupied leads to remarkably higher costs per saving (maximum line of uncertainty range). In reality, it is unlikely that not-occupied buildings would be renovated. Only buildings where savings can be expected would invest in renovation measures. Therefore, the costs per saving in the city of San Sebastián will lie in between the minimum and the maximum range of uncertainty as derived from the calculations. For further analyses, the average costs between the minimum and the maximum line of the uncertainty range has been used.

In order to identify a meaningful level of heat savings in the city not only the costs for the savings are relevant, but also the costs for heat supply and the availability of resources. A comparison of these parameters is done in the scenario assessment section in chapter 6.1. In this comparison, the total annualised heat-saving costs are used to calculate the overall costs occurring in different scenario settings. In the figure, these values are shown in the blue line.

As already described in chapter 4.3.4 and in chapter 6.1.1, different renovation targets are calculated. However, these refer to the total heating demand and still have to be adjusted for the additional hot water production. The following Table 8 shows the relationship between a renovation scenario, the calculated savings and the savings that can be achieved by considering space heating and hot water production.

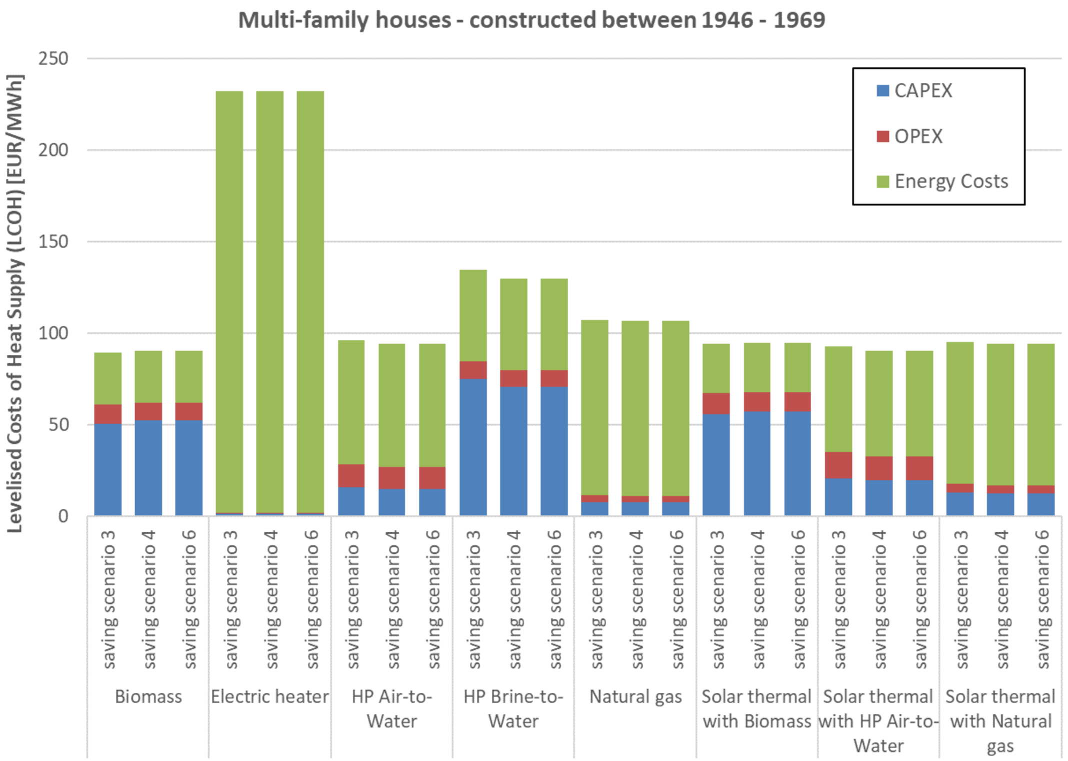
Table 8: Savings in demand for space heating and savings in total heat demand (space heating + domestic hot water) for the calculated renovation-scenarios (Source: own calculations)

scenario name	savings in demand for space heating	saving in total heat demand (space heat + domestic hot water)
renovation scenario 1	11%	10%
renovation scenario 2	22%	21%
renovation scenario 3	31%	27%
renovation scenario 4	40%	33%
renovation scenario 5	49%	40%
renovation scenario 6	60%	47%

In order to reach 33% of savings (at lowest costs), 55% of buildings gross floor area is renovated in the calculations, to reach 40% of savings, 74%, and to reach 47% of savings, 91% of buildings gross floor area is renovated. To reach 33% of savings, nearly the entire non-residential building stock is renovated in the model, while only 83% of the single-family buildings and 42% of multi-family buildings are renovated. In the scenarios with higher savings, the share of residential buildings that are renovated increases and also the ambition of measures in several other buildings increases. Notably, reaching savings of up to 47% requires the implementation of renovation measures at remarkably higher costs compared to the measures necessary in the other scenarios. These expensive measures are ambitious renovations in buildings constructed since the 1980s.

6.1.2.2 Costs of decentral supply

The costs of heat supply (Levelized costs of heat - LCOH) via decentral technologies have been calculated with the **“CM - Decentral heating supply”** (Hotmaps Wiki, 2019c). For each building type and construction period distinguished in the calculation of the current heat demand (see chapter 4.1), heat supply costs in the year 2050 have been calculated. Hereby, costs have been calculated for different levels of refurbishment in these buildings according to the saving scenarios developed in the first step of the analysis (see description of methodology in chapter 6.1.1). The following Figure 12 shows the LCOH for heat supply from different technologies for three saving scenarios (27%, 33% and 47% savings in overall heat demand) for two exemplary building types and construction periods: multi-family houses (MFH) constructed between 1946 and 1969 (top) and office buildings constructed between 1990 and 1999 (bottom).



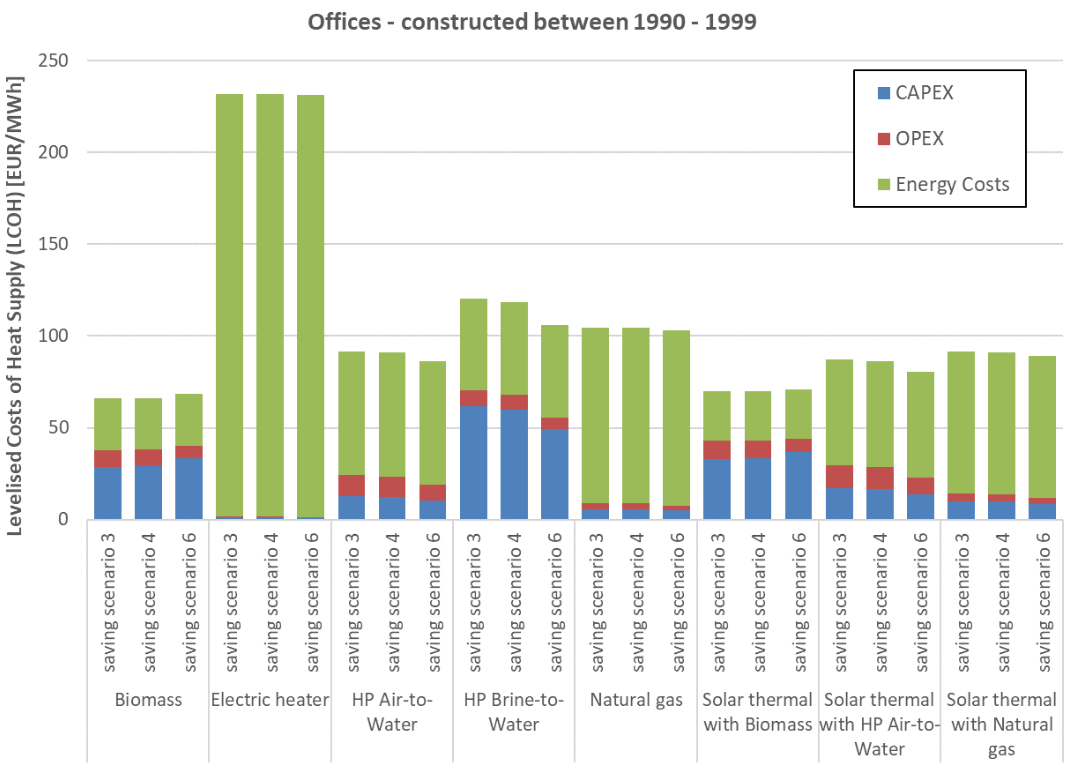


Figure 12: Levelized costs of heat supply from decentral technologies in 2050 for three different scenarios of heat savings in the buildings (27%, 33% and 47% savings in overall heat demand), on the top for multi-family houses constructed between 1946 and 1969, at the bottom for offices built between 1990 and 1999 (Source: own calculations)

Most buildings in the construction period between 1946 and 1969 are economically feasible to renovate in many heat-saving scenarios. Decreasing heat demand in buildings, affects the heat supply costs: smaller device capacities usually lead to higher specific investment costs and many technologies have a certain minimum capacity available on the market. This often leads to increased LCOH with decreased heat demand in the buildings, especially for small buildings or flat-wise heat supply. However, it is also possible that LCOH decrease with decreased heat demand. This is the case when the maximum needed power decreases strongly after renovation. In the figure, this effect can be seen especially for heat pumps in both types of buildings. LCOH for heat supply from decentral technologies in MFH constructed between 1946 and 1969 are calculated to 89 and 232 EUR/MWh, with biomass boilers being the cheapest supply option and electric heaters being the most expensive. The supply with heat pumps leads to LCOH between 94 and 135 EUR/MWh in those buildings. For office buildings constructed between 1990 and 1999 LCOH between 66 and 232 EUR/MWh have been calculated.

The LCOH for each building type, construction period and supply technology are used to calculate the average cost of decentral heat supply in the different heat-saving scenarios. For this, the overall heat demand and related supply costs in all buildings of the city are calculated. The following mix of technologies has been assumed: 50% heat pumps, 25% electric heaters, 10% solar thermal and 15% biomass. This results in weighted average costs of decentral supply in the year 2050 for the different saving scenarios of 133 (no savings), 135 (21% savings) and 134 EUR/MWh (40% savings).

6.1.2.3 Sensitivity of economic district heating expansion

With the **"CM - District heating potential: economic assessment"** (Hotmaps Wiki, 2019b) several scenarios for the expansion of district heating (DH) in the city have been calculated. The module calculates the location, the investment and the heat distribution costs as well as the delivered energy of a potential DH system under different technical and economic framework conditions. The following Figure 13 shows the annualised investment costs into the DH grid over the average grid costs per distributed heat (left side) and the share of DH on the overall heat demand in buildings over the average grid costs per distributed heat (right side). Scenarios have been calculated for various different levels of heat savings in the buildings, different shares of heat demand connected to DH in DH areas and different maximum grid cost ceilings.

The figures show the high sensitivities of the average grid costs per distributed heat [EUR/MWh] to the heat demand density/amount of heat savings in the city (solid vs. dashed vs. dotted lines) and to the share of heat demand that is connected to DH in areas where a DH grid would be built (red vs. green vs. blue lines). Assuming e.g. savings in the heat demand of buildings of 40% (savings 5) and that district heat should be supplied at heat distribution costs of 18 EUR/MWh on average: in case that 50% of the heat demand is connected in areas where a DH grid is constructed would allow a total share of 22% DH in the city, while if 90% of the heat demand in DH areas is connected this would allow for a share of around 84% of total heat demand to be supplied by DH. This shows the remarkable importance of increasing the share of buildings connected to DH in areas where DH networks are constructed for decreasing the costs of DH distribution.

The right side of the figure also shows that the increase of the share of heat demand supplied by DH with increasing average grid costs per delivered heat is not linear: starting from very low average grid costs the curves first have a low gradient, especially for the curves reflecting lower market shares. The gradient of the curves then increases and after a break-over point, the gradient decreases again. When looking up the same curves in the left side of the figure, which shows the total annualised investments in the grid, it is visible that the gradients of the curves do not decrease for high average grid costs as much as is the case on the right side of the figure. The reason is that in the areas with higher heat demand density, a district heating grid is already constructed, and with the same amount of investments only smaller shares of heat demand can be connected. This change in the gradient of the curves on the right side together with potentially feasible average grid costs per delivered heat serves as an indication for economically interesting scenarios of DH expansion in the city.

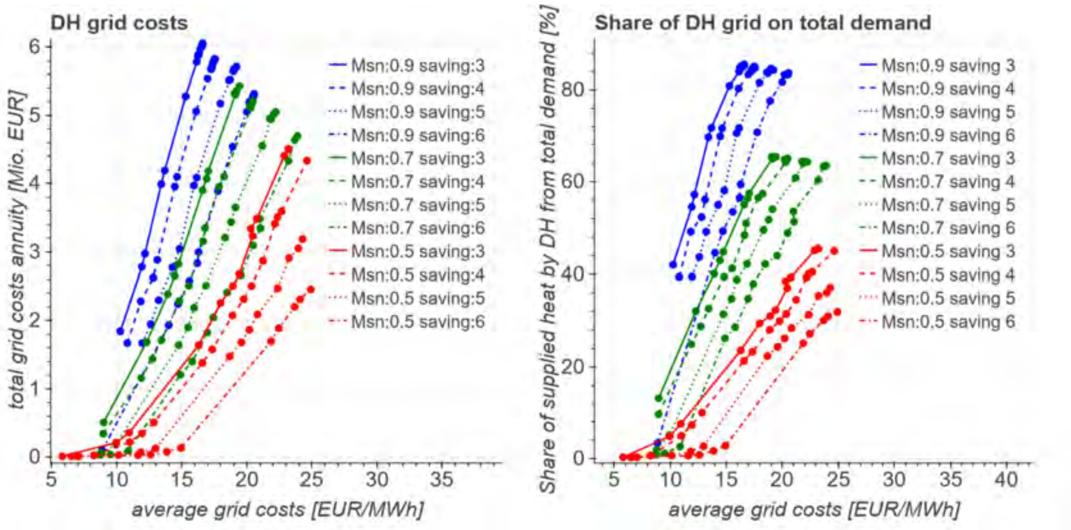


Figure 13: Annualised investment costs into the district heating (DH) grid (y-axis) over the average grid costs per distributed heat (x-axis) (left side) and share of DH on overall heat supply in the city (y-axis) over the average grid costs per distributed heat (x-axis) (right side) for several scenarios with different levels of heat saving[5] in the buildings, different shares of buildings' heat demand connected to DH in DH areas (Msn) and different maximum grid cost ceilings. (Source: own calculations)

6.1.2.4 District heating portfolios and related costs

For the supply of district heat in the city of San Sebastián, a number of different technologies could be used. According to the estimation of potentially available resources, the following technologies have been taken into account in the compilation of district heating (DH) portfolios: a biogas CHP plant in the wastewater treatment plant using biogas generated by anaerobic digestion of the wastewater (currently already in place), a heat pump in the outflow of the wastewater treatment plant, a waste incineration plant outside the city at a distance of around 10 km (construction has recently finished and the plant is generating electricity), a heat storage as well as biomass boilers for covering peak load (small biomass boilers are currently

[5] See chapter 6.1.2.1 for a description of the different heat saving/renovation scenarios and especially Table 8 for the share of heat savings in the related renovation scenarios 3, 4, 5 and 6

already in place in the city). These technologies have been combined with different capacities to different portfolios.

Based on the analysis of the costs of potential DH systems in the city and eventually meaningful amounts of heat supplied by DH three different sizes of heat networks have been modelled: 30 GWh/yr of total heat to be supplied by all devices, 150 GWh/yr and 200 GWh/yr. The following Table 9 shows the compilation of the different technologies for the different sizes of the network.

A small DH system of 30 GWh/yr could be supplied with the existing biogas CHP, an additional heat pump in the outlet of the wastewater treatment plant plus additional capacities of biomass boilers for peak load supply (Portfolio 4). For supplying larger DH systems heat generated in the waste incineration plant might be used (Portfolio 1). Adding the heat pump in the wastewater treatment plant would decrease the need for biomass in the peak load boiler (Portfolio 2). Additionally, adding a heat storage could further decrease the need for biomass for peak load supply (Portfolio 3).

Table 9: Overview of portfolios of district heating (DH) supply calculated for the city of San Sebastián (Source: own assumptions)

Portfolia	Installed capacity [MW]	Yearly Supply [GWh/yr]
Portfolio 1: - Biogas back-pressure CHP - Waste incineration (HOB) - Biomass boiler for peak load	 2.5, 2.6 20, 28 30, 40	150, 200
Portfolio 2: - Biogas back-pressure CHP - Waste incineration (HOB) - Heat Pump in the waste water treatment plant - Biomass boiler for peak load	 2.5, 2.7 20, 28 8, 9.2 22, 30	150, 200
Portfolio 3: - Biogas back-pressure CHP - Waste incineration (HOB) - Heat Pump in the waste water treatment plant - Biomass boiler for peak load - Heat storage	 3, 4.2 20, 28 8, 8 0, 1.8 28, 28	150, 200
Portfolio 4: - Biogas back-pressure CHP - Heat Pump in the waste water treatment plant - Biomass boiler for peak load	 2.5 8 0.1	30

For all portfolios, different sensitivity calculations have been performed. This includes three different temperature profiles of the district heating distribution grid (supply line temperature) and four different price scenarios for the electricity wholesale and the CO2 price. The following Figure 14 shows the Levelized Cost of Heat supply (LCOH) for three different portfolios under different scenario settings.

The figure shows that the future electricity wholesale and CO2 prices have a remarkable influence on the LCOH of DH in the modelled portfolios, especially in portfolios 1, 2 and 3. This is due to the waste incineration plant in these portfolios, as it is assumed that the share of fossil source in the municipal waste will still be relevant in 2050 and at the same time the CO2 price varies remarkably between the different price scenarios (see also chapter 4.3.5). In Portfolio 1 this leads to an increase of the LCOH from 67 EUR/MWh in the lowest CO2 price scenario (P2) to around 82 EUR/MWh in the highest CO2 price scenario (P4). In the results of Portfolio 1 and

3, it can also be observed that the temperature of the DH grid has no effect on the LCOH. This is due to the fact that no or only a small part of the heat is supplied by a heat pump and thus the effect of the temperatures in the grid on the efficiency of heat supply is very small. The figure also shows that these effects are very different for Portfolio 4. Here the CO2 price does not have a relevant influence, but the electricity price is more relevant. In this portfolio higher electricity prices lead to higher revenues in the biogas CHP. The higher costs for electricity for the heat pump is still lower compared to the increased revenues. Therefore, the overall LCOH of the Portfolio decrease with increasing electricity prices. Also, a small influence of the temperature in the district heating grid on the LCOH can be observed as the share of heat supplied by the heat pump is relatively higher than in the other portfolios. Overall, the sensitivity of the LCOH to the different price and temperature scenarios is lower compared to the other portfolios.

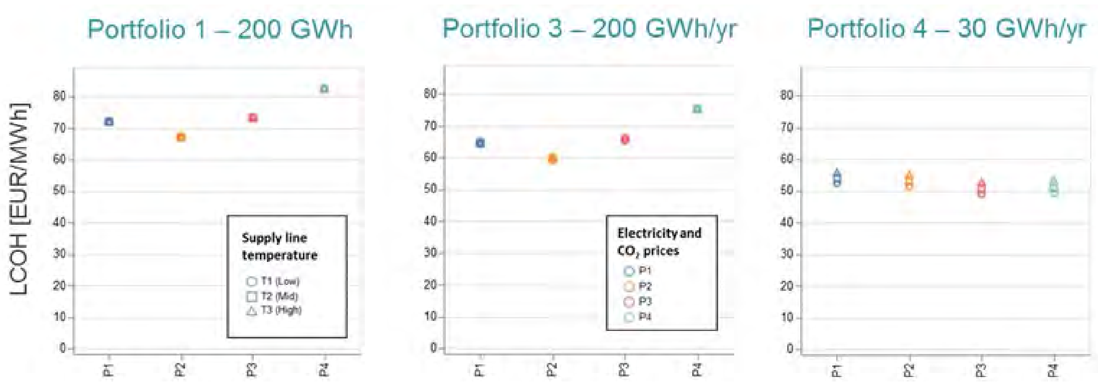
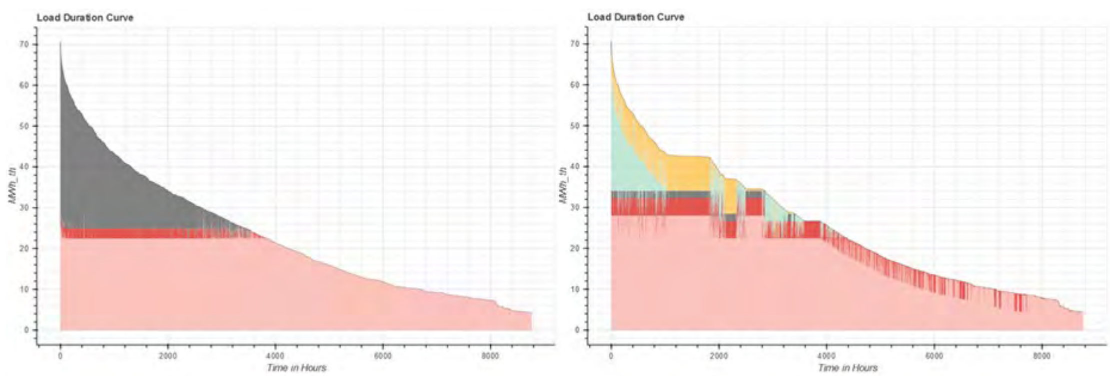


Figure 14: Levelized costs of heat supply to the district heating grid in [EUR/MWh] for three different portfolios, different scenarios for energy and CO2 prices (P1 - P4)[6] as well as supply line temperatures (T1 - T3)[7] (Source: own calculations)

The following Figure 15 shows the load duration curves for Portfolio 1 and Portfolio 3. It shows the split of capacities used in each hour of the year ordered by the total power needed in each hour.



[6] See chapter 4.3.5 for a description of the energy carrier and CO2 prices in the price scenarios P1 to P4.
[7] See the Annex of the document for a description of the assumed supply line temperatures T1 to T3.

Figure 15: Load duration curves for portfolio 1 (left side) and portfolio 3 (right side) - split into the different supply technologies (Source: own calculations)

The figure shows the different technologies that are used in each hour of the year. In Portfolio 1 as well as Portfolio 3 the baseload (lower part of the curve) is supplied by the waste incineration plant. Large parts of the peak load in Portfolio 1 (left side) are supplied by a biomass boiler and only a small share of the heat is supplied by the biogas CHP in the wastewater treatment plant. The use of the biomass boilers, as well as their needed capacities, can be decreased by adding a heat pump in the outlet of the wastewater treatment plant as well as a heat storage (Portfolio 3 - right side). The figure (right side) shows this substitution of the biomass and that only a small amount of the peak power would have to be supplied by biomass in this case.

Although the calculations cover sensitivities for different combinations of technologies, different temperatures in the supply line of the network and different electricity and CO2 prices, other main influencing parameters have not been varied over the scenarios as e.g. the future development of biomass prices and the investment costs of the technologies. This has to be taken into account in the interpretation of the results.

6.1.2.5 Overall city scenarios

Based on the analyses of the sensitivity of costs in the different parts of the heating demand and supply system, a set of scenarios has been selected to compare indicators for the entire city. One main scenario has been selected that seems interesting as a basis for more detailed analyses in the future. Further scenarios have been defined in order to visualise the effects of different changes to the main scenario on the overall citywide indicators. The following Table 10 shows the definition of the main as well as of the different sensitivity scenarios.

Table 10: Overview of scenarios in the different calculation modules combined to overall city scenarios and sensitivities (Source: own assumptions)

	Main scenario	Low savings of heat demand	High savings of heat demand	Low District Heating market share	High District Heating market share	Low District Heating share	Simplified District Heating Portfolio	High Electrictiy and CO2 price
	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5	scenario 6	scenario 7	scenario 8
Savings in heat demand of the buildings	33%	24%	46%	= main	= main	= main	= main	= main
Decentral supply	default technology mix (heat pumps, electrict heaters, solar thermal and biomass)	= main	= main	= main	= main	= main	= main	= main
District heating network	market share in district heating areas (MS) = 70%, yearly district heating demand (YD) = 200 GWh/yr	= main	= main	MS = 50%, YD = 200 GWh/yr	MS = 90%, YD = 200 GWh/yr	MS = 70%, YD = 30 GWh/yr	= main	= main
District heating supply	Portfolio 3, price scenario P3, distribution temperature T2	= main	= main	= main	= main	Portfolio 4, P3, T2	Portfolio 1, P3, T2	Portfolio 3, P4, T2

The following figures show important indicators for the entire city for the different scenarios. These indicators are total annual heating system costs [MEUR/yr], the total annual CO2 emissions [tCO2/yr], the final energy demand [MWh/yr] and the shares of district heating (DH) and heat savings [%].

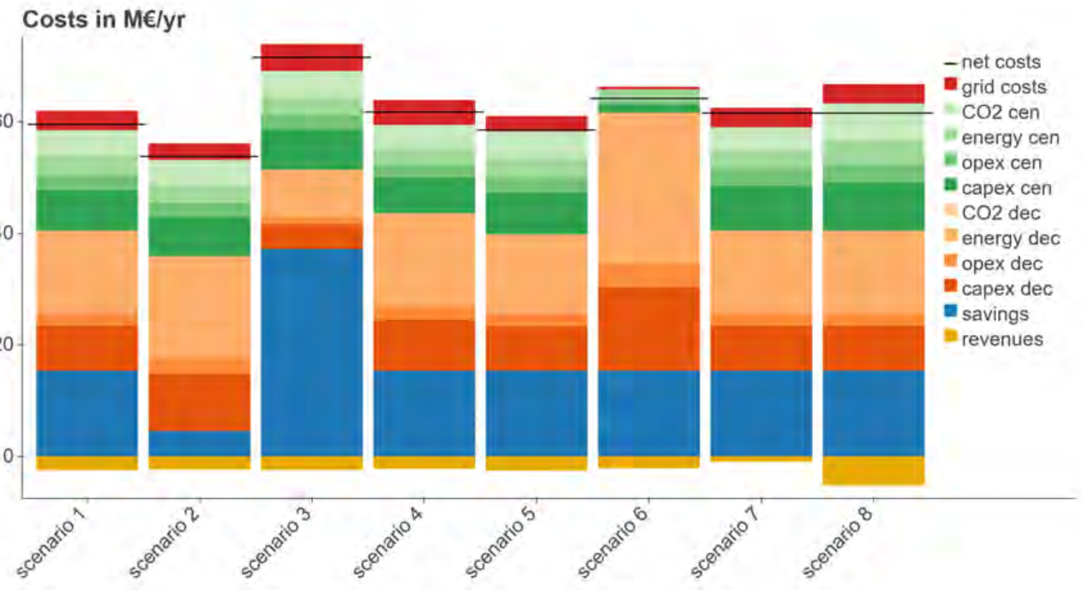


Figure 16: Annual heating system costs for the city of San Sebastián in 2050 for the defined scenarios split into costs for heat savings (savings), decentral supply (dec), district heating supply (cen) and district heating grid (grid) as well as revenues from electricity generation (revenues) (Source: own calculations)

It is visible that scenario 3 has by far the highest annual costs for the overall heating system in the city of San Sebastián. This is due to the very high costs for heat savings for reaching savings of 46% of the heat demand in the buildings of the city compared to the costs of lower savings (see also chapter 6.1.2.1). Also, scenario 6 leads to remarkably higher costs compared to the main scenario. In scenario 6 a low share of district heating in the city is assumed (approx. 8%). The remarkably higher costs of supplying heat from decentral technologies, compared to supplying heat via district heating, lead to higher total costs for this scenario. Scenarios 4 and 5 show the effect of increased or decreased market shares of district heating in areas where district heating is constructed. This effect lies in the range of several MEUR per year. Scenario 8 shows the effect of higher electricity wholesale and CO2 prices on the overall indicators. The figure shows that the overall costs for the heating system in the city do not increase with the increase in the mentioned prices. This is due to the composition of the district heating supply portfolio. While CO2 emissions, as well as electricity demand from heat pumps, cause higher costs in this scenario, the revenues from the sale of electricity from the biogas CHP also increase with higher electricity wholesale prices. This shows that combining CHPs and heat pumps in the portfolio of a district heating system leads to a decreased economic risk of future electricity price developments.

The following Figure 17 shows the fossil CO_2 emissions in the different scenarios considered. This figure shows that all scenarios have been set up in order to avoid nearly all emissions of fossil CO_2. The only source containing fossil CO_2 that is taken into account in the calculations is the municipal waste burnt in the waste incineration plant. Thus, an analysis of which emission factors would be meaningful for waste in the year 2050 and a discussion of the weight of the emission factor compared to resource usage has to be taken in the future.

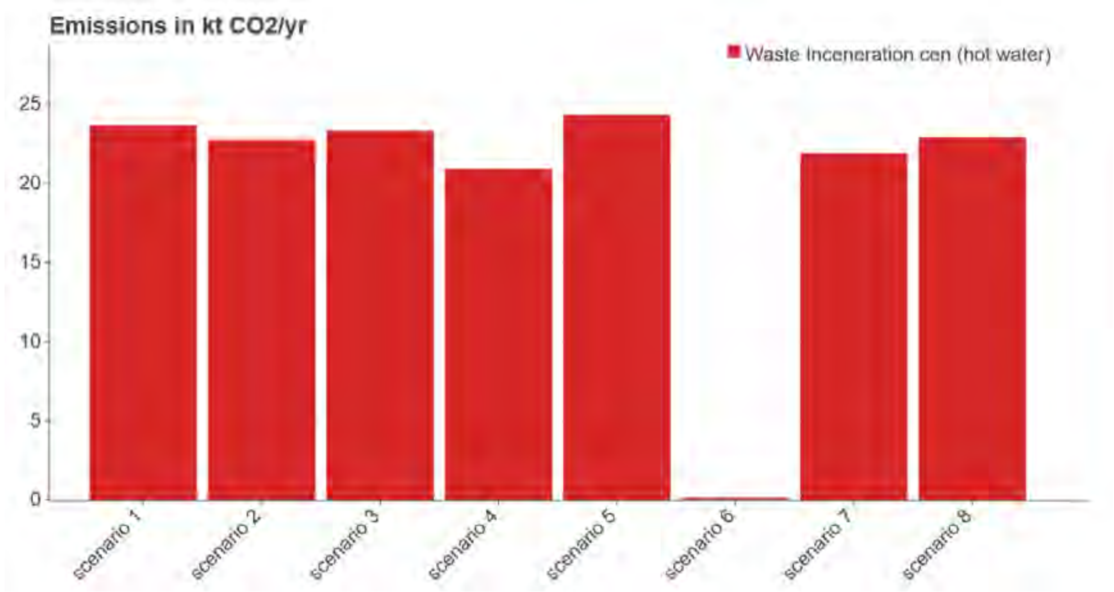


Figure 17: Total annual CO2 emissions for the city of San Sebastián in 2050 for the defined scenarios distinguished between the different supply technologies (Source: own calculations)

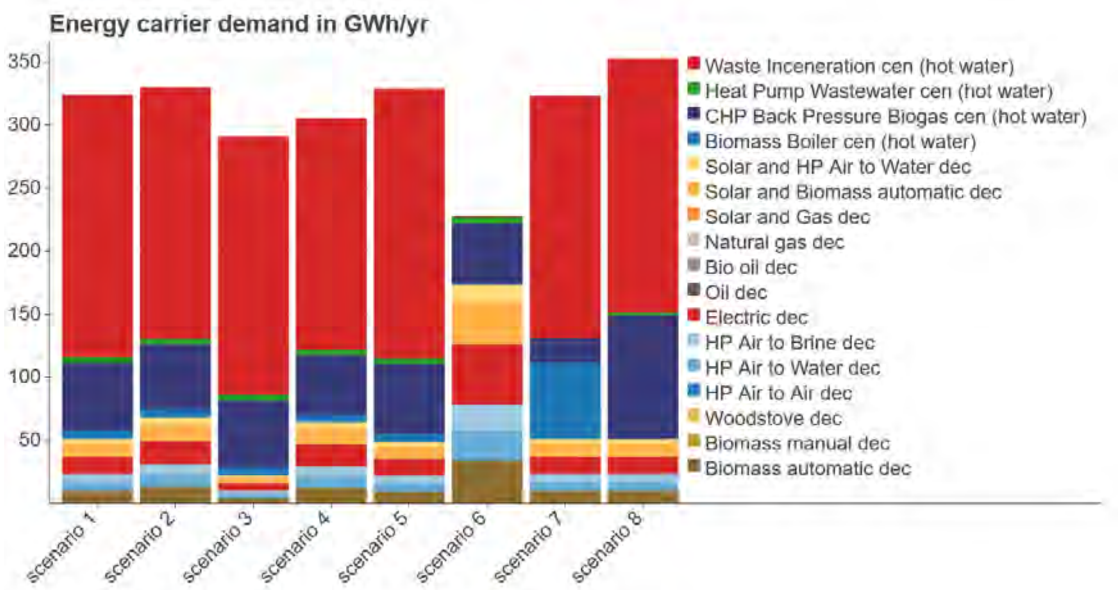


Figure 18: Total energy carrier demand for space heating and hot water generation (energy carriers used in the buildings plus energy carriers used in the district heating supply plants) in the city of San Sebastián in 2050 in the different scenarios distinguished between the different supply technologies (Source: own calculations)

Figure 18 shows the demands for energy carriers in the different calculated scenarios. For decentral heat supply these reflect energy carriers used in the buildings and for district heating supply these reflect the energy carriers used in the supply plants of the district heating systems. Solar thermal energy and ambient heat used in heat pumps is not reflected in the figure. Remarkable differences between the different calculated scenarios can be observed. High shares of the energy carrier demand in the city would be composed of municipal waste and electricity for heat pumps in many scenarios. The increased and decreased energy carrier demand of scenarios 2 and 3 compared to the main scenario result from the different levels of heat savings. Also, lower amounts of energy carriers can generally be found in the scenarios with lower shares of district heating in the city. This is due to the fact that a high share of heat pumps is assumed for decentral heat supply and the ambient heat that is used in the heat pumps is not reflected in the numbers of energy carrier demand.

The following Figure 19 shows the shares of heat savings resulting from the renovation of buildings (on the total heat demand for space heating and hot water generation) and the share of district heating on the overall heat demand from buildings. It shows the broad range of settings in the different scenarios considered.

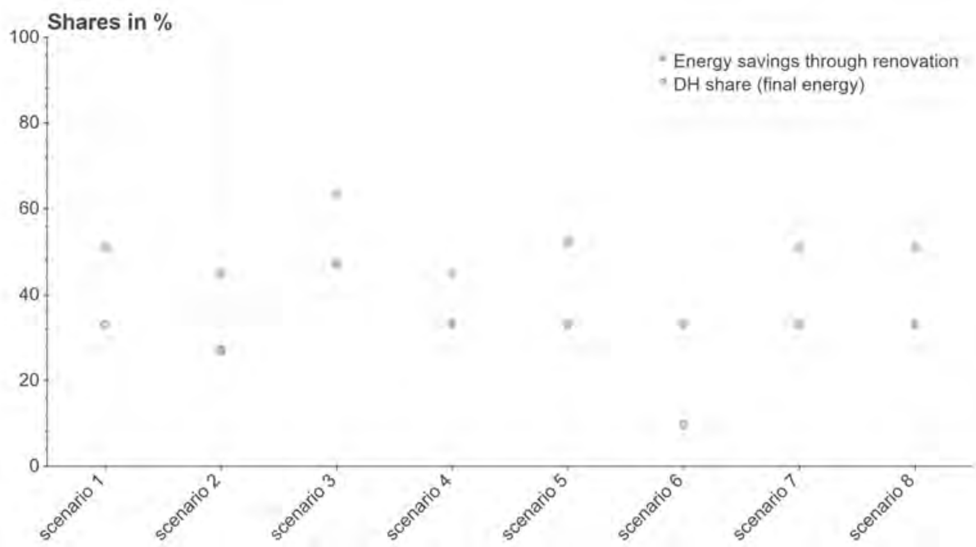


Figure 19: Shares of district heating (DH) and heat savings in the city of San Sebastián in 2050 in the different scenarios (Source: own calculations)

The following figure shows areas of the city where district heating would be developed for two of the calculated scenarios. In both scenarios, the same amount of heat would be supplied via district heating (200 GWh/yr). Also, the market share of district heating in the areas where a district heating system would be developed is the same in both scenarios (70% of the heat demand in those areas would be supplied by the district heating network). The blue areas in the map show the areas with a district heating system for the case that 24% of total heat demand is saved in the city. The green areas in the map show the additional areas where district heating would be constructed in case that 33% of the heat demand in the city is saved in order to reach the same amount of total district heating supply. The lower heat demand density in the city with higher heat savings also leads to increased heat distribution costs, these increase from 14.75 EUR/MWh to 16.78 EUR/MWh. However, compared to the difference between decentral heat supply costs and the costs of heat generation in the district heating grid, this increase in the distribution costs is very low. Therefore, high shares of district heating in San Sebastián seem cost-efficient also for more ambitious heat-saving scenarios.

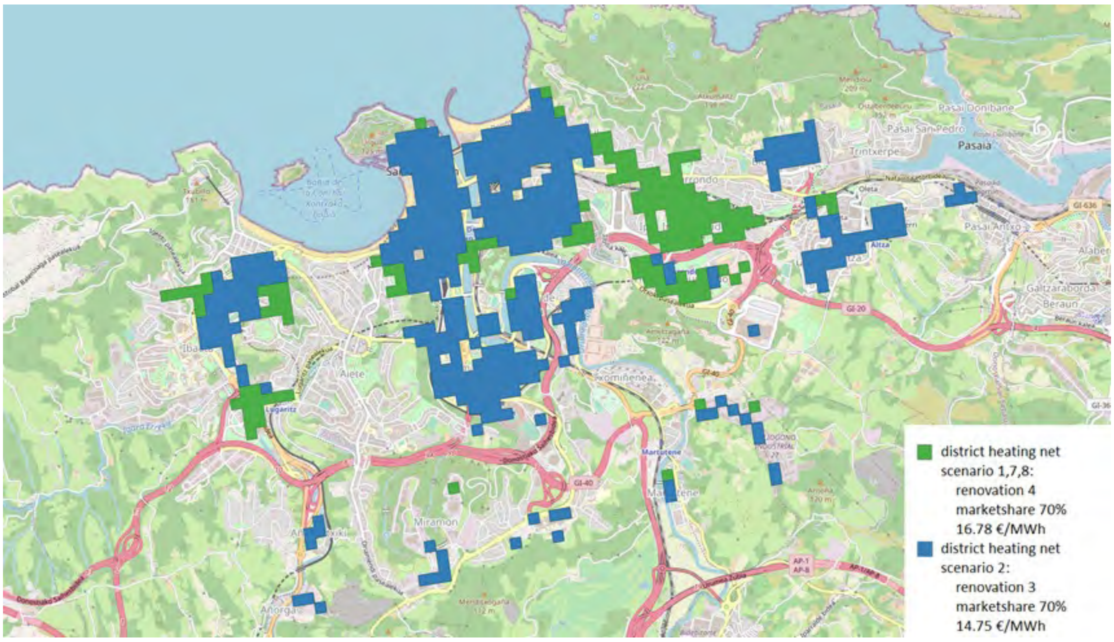


Figure 20: Identified district heating areas in the city of San Sebastián for two district heating expansion scenarios with the same amount of heat delivered by the district heating system, same market share of district heating in district heating areas, but different amount of heat savings in the city (scenario 2 is reflected by the blue areas, scenario 1, 7, 8 is reflected by the blue and the green area) (Source: own calculations)

6.1.3 Conclusions and recommendations from the scenario assessment

Developing this strategy, a high number of calculations has been performed. This included the collection of a remarkable number of input parameters and the variation and combination of various different of those input parameters. The results of the different analyses have been presented in the previous chapters. Based on these calculations the following conclusions and recommendations are derived.

Reaching a low carbon heating system in the city of San Sebastián is based on two important pillars: the saving of heat demand in the buildings and the supply of the remaining heat by energy derived from renewable or excess heat sources. Thus, the availability and the costs of the different options in these two fields are crucial.

The results have shown that the level of heat savings targeted in the city has a high influence on the overall costs of the heating system in the city. Savings of around 25 - 40% of the overall heat demand in the buildings (space heating plus hot water generation) in the city seem to lead to the lowest overall system costs. In order to reach such levels of savings, between 40 and 74% of the entire buildings gross floor area has to be renovated.

For supplying the remaining heat demand a number of different scenarios have been analysed. The results have shown that high shares of heat supply via district heating could be cost-effective in the city of San Sebastián: scenarios with high shares of district heating have led to lower total system costs. A comparison of the weighted average costs calculated for decentral supply and for the supply via district heat (heat generation + heat distribution) shows a gap above 20 EUR/MWh in all calculated scenarios. In the base scenario, this difference is around 40 EUR/MWh.

At the same time, the scenarios have shown that high shares of district heating only make sense when the heat of the waste incineration plant is used. With the heat of the waste incineration plant district heating systems in the size of around 150 - 200 GWh/yr of distributed heat could be cost-effective. When this heat is not available district heating systems in the range of around 30 GWh/yr seem reasonable.

The results of the district heating grid cost analyses show a strong sensitivity of the costs to the share of buildings connected to the grid in areas where district heat is available (market share) and the amount of heat savings in the area. Thus, in case a district heating system is constructed, measures to reach a high share of buildings connected to the grid should be foreseen and prioritized.

The results have shown that the heat in the district heating system can be supplied at similar costs for the different sizes of the district heating system based on the different supply portfolio. Hereby, the resulting costs in all modelled portfolios are affected remarkably by different price assumptions for 2050. However, many important input parameters have to be further discussed like the estimated costs, prices and CO2 factor for the potential use of the waste incineration plant and its transmission line to the city, the availability of biomass and possible future price developments for a peak load boiler, or the costs and availability of heat storage. Furthermore, all scenarios modelled for the district heating systems including a heat pump should be further analysed regarding the meaningfulness of integrating a biomass CHP instead of a biomass boiler and also the waste incineration plant should be modelled as a CHP. This could allow for benefiting from times with low as well as times with high electricity prices over the year and thus hedge against the risk of high electricity price developments. However, it has to be taken into account that the operation of a biomass CHP also involves constraints like high cold start costs and upfront costs that need to be taken into account in the analysis.

Many sensitive input parameters have been varied in sensitivity analyses. However, a remarkable number of input parameters have not been varied in the calculations and are based on estimations and experiences from other cases and countries. Therefore, further analyses have to be undertaken in order to strengthen the conclusions. A summary of which parameters should be included in further feasibility studies is given in chapter 6.2

The calculations in this strategy have been performed with an interest rate of 3% and a depreciation time equal to the lifetime of each technology and component. This reflects socio-economic calculations and lowest costs mean lowest costs for the general public. Based on socio-economically meaningful scenarios business cases have to be developed in which potential investors could find economically interesting investment opportunities.

6.2 Heating and cooling strategy roadmap

Heating network interventions at district and city level are large-scale projects that require significant investments, so their analysis and feasibility must be carried out thoroughly and take into account economic, financial, political and technical factors.

The conclusions of this Strategy Document show several lines of interest to be analysed in-depth, but they should be taken with caution, and analysed in detail and with precise information through technical and economic feasibility studies.

In particular, on the road to a low carbon heating system in San Sebastián two main lines have been identified:

- Feasibility study of the integration of the heat from the waste incineration plant into a potential district heating system and
- More detailed analysis of the heat savings in the buildings of the city.

Near to the city, a waste incineration plant has recently started operation and is generating electricity. A first analysis shows that transporting the excess heat of the plant to the city and using it in a potential district heating system leads to lower costs for the city than more ambitious heat savings and a higher share of decentral heat supply. This option should be further investigated.

The results also show that very ambitious saving targets in the city lead to higher overall system costs compared to lower saving levels together with supply from district heating. Therefore, a detailed analysis of the costs and effects of renovation measures in the different buildings of the city should be performed taking into account also the state of renovation and the occupation of the buildings. This should feed into a renovation strategy for the city.

The next steps in the roadmap of this Strategy Document would be to analyse the identified two lines in the near future, establishing a timeline for 2021/2022 to carry out the feasibility studies. Then, the results of the feasibility studies would be evaluated in the Municipality to define the following actions.

Regarding specific action, items to be taken into account in the roadmap process are:

- Revise the renovation roadmap for the buildings in the city including the following content:
    - Further analysis of heat savings: Analysis of the impact of taking into account the occupation of gross floor area in the cost curve calculations
    - Feasibility studies on predefined renovation activities based on outcomes regarding which buildings to perform which level of ambition
    - more detailed analysis on where which buildings are really realistic to be renovated
    - distinction between buildings that have already been renovated and which have not, including the status of renovation in the buildings database of the city
    - plan for financing / financial assistance in the renovation activities of public and private buildings, definition of renovation targets for different buildings in the

    - city following the overall cost efficiency of renovation in the city (cost-optimal overall heating system searching for the cost optimum between savings and supply)

- Feasibility study of using the (excess) of the waste incineration plant as the main source for district heating in the city of San Sebastián. This should include:

    - analysis of technical implementation at the plant and for the transport pipes to the city centre including a potential routing, related potential of heat to be supplied by the plant including temporal restrictions,
    - economic analysis of technically feasible solutions including investments and O&M costs at plant side and transport pipes, estimation of the price of heat from the plant at the city using different methods for allocating costs between electricity and heat

- More detailed feasibility study of a potential district heating system with more focus on the following aspects and input parameters:

    - more cost details related to the different potential technologies in the system (based on cost sheets of companies active in the area), analysis of sensitivity to different energy price developments and assumptions (prices for energy carriers in the buildings (decentral use), biomass prices, price of municipal waste)

- Development of a step-by-step plan for the transformation of individual supply to supply via district heating in the city. This should include, amongst other, the identification of buildings that already have a central heating system and which don't, the identification of potential large consumers and of public buildings that could be connected first, the necessary policy framework to drive the transformation like e.g. an obligation scheme mixed with subsidies for connecting to DH.

The priorities for this roadmap should be to clarify the potential interest of integrating the waste incineration excess heat into a DH system in the city centre, and to revise a renovation strategy for heat savings in the city.

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8 Annex

In this section we present assumptions on input data used in the calculation of the scenarios that are not described in the other parts of this document.

8.1 A1) Temperature sensitivity of heat pumps

As described in chapter 2.2.2 the modelling of the generation of heat in the district heating systems takes into account the sensitivity of the COP of heat pumps towards changes in the temperatures of the heat source, the flow and the return of the district heating system. This sensitivity is based on the formula and values described in (Totschnig et al., 2017) and (Gumhalter, 2019). The following table shows the values used for the different modelled heat pump systems together with the fade out and shut off temperatures, the source temperatures and the nominal temperatures for flow and return.

Table 11: Specifications of heat pumps as used in the district heating supply dispatch model (Source: (Totschnig et al., 2017) and (Gumhalter, 2019))

	COP source tempe-rature sensitivity (1/°C)	COP flow tempe-rature sensitivity (1/°C)	COP return tempe-rature sensitivity (1/°C)	min shutoff source tempe-rature (°C)	fade out tempe-rature where power reduction starts (°C)	source tempe-rature (°C)	nominal flow tempe-rature (°C)	nominal return tempe-rature (°C)
HP – River Water	0.0578	-0.0247	-0.0136	3	6	10	70	50
HP – Waste water	0.0578	-0.0247	-0.0136			10	70	50
HP – EH Servers	0	-0.0247	-0.0136			30	65	45
HP – Industrial HT EH	0	-0.0247	-0.0136			80	100	70
HP – Industrial LT EH	0	-0.0247	-0.0136			40	65	45
HP – near-surface Geothermal	0	-0.0247	-0.0136			15	65	45

HP ...... Heat Pump
HT ...... High Temperature
LT ...... Low Temperature
EH ...... Excess Heat
COP ...... Coefficient Of Performance

The technology (type and working medium) of the heat pump for each of the sources as defined in the table is chosen based on the temperatures in which the heat pumps should operate. The operating points of each of the heat pumps are defined separately for each of the sources and for each flow and return temperature scenario of the district heating systems (see chapter 8.2). This is done using median values of the yearly flow and return temperature profiles.

8.2 A2) Flow and return temperatures in the district heating system

For the district heating system three different flow and two different return temperature scenarios are calculated to investigate the influence of these temperatures on the COP of the heat pumps and subsequently on further indicators of the heat supply to the district heating system and the entire heating system in the city. The following figures show the modelled flow and return temperatures in function of the ambient temperature in the city.

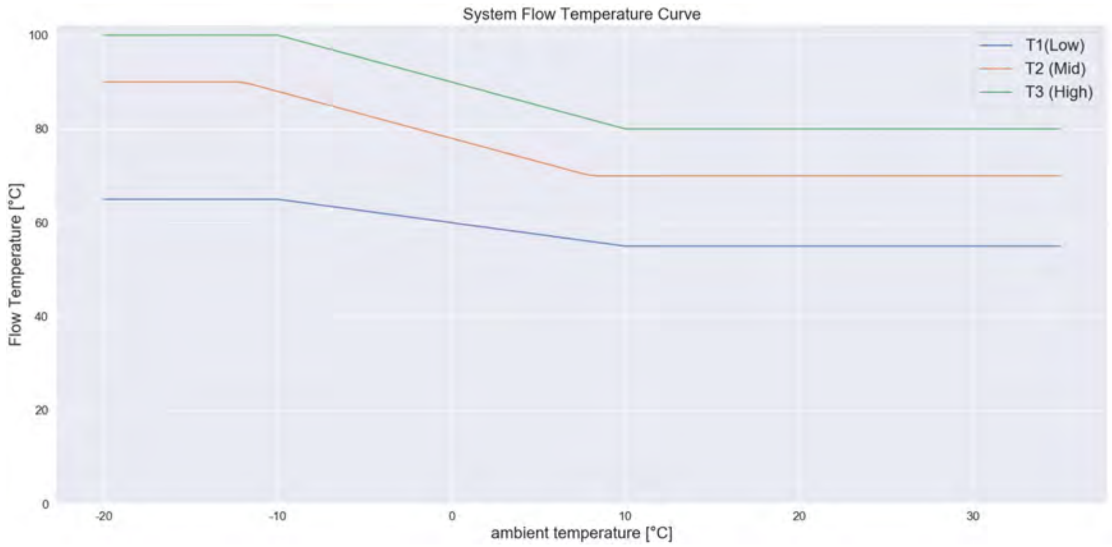

Figure 21: Flow temperature in the district heating systems in function of the ambient temperature used in the dispatch model

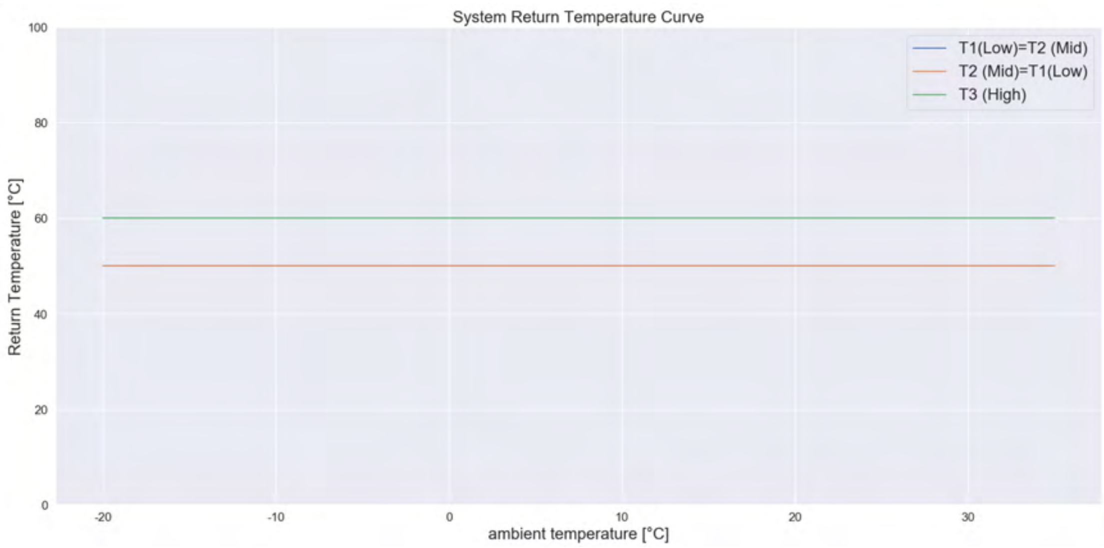

Figure 22: Return temperature in the district heating systems in function of the ambient temperature used in the dispatch model

These relations together with the hourly profile of the ambient temperature (see chapter 8.3) are used to calculate the hourly temperature profiles of the district heating flow and return lines.

8.3 A3) Temperature and solar irradiation profiles

In order to derive the hourly temperature profiles of the district heating flow and return line the ambient temperature for each hour of the year in the city is needed. These data as well as the hourly solar irradiation data have been taken from (EU PVSEC, 2017) for the location of San Sebastian. Furthermore, hourly temperatures of the outlet of the wastewater treatment plant were needed to model the sensitivity of the COP of the heat pumps. These data have been taken from (ECO.S, 2018). The following figures show these values for each hour of the year.

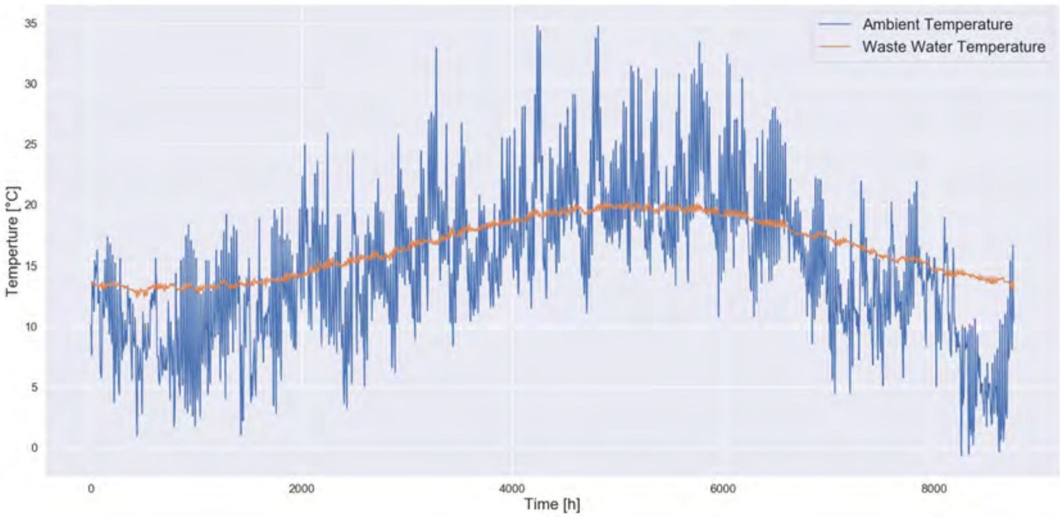

Figure 23: Temperature profiles for ambient air, river water and the outlet of the wastewater treatment plant used in the dispatch model (Source:(GDB, 2020), (ECO.S, 2018), (EU PVSEC, 2017))

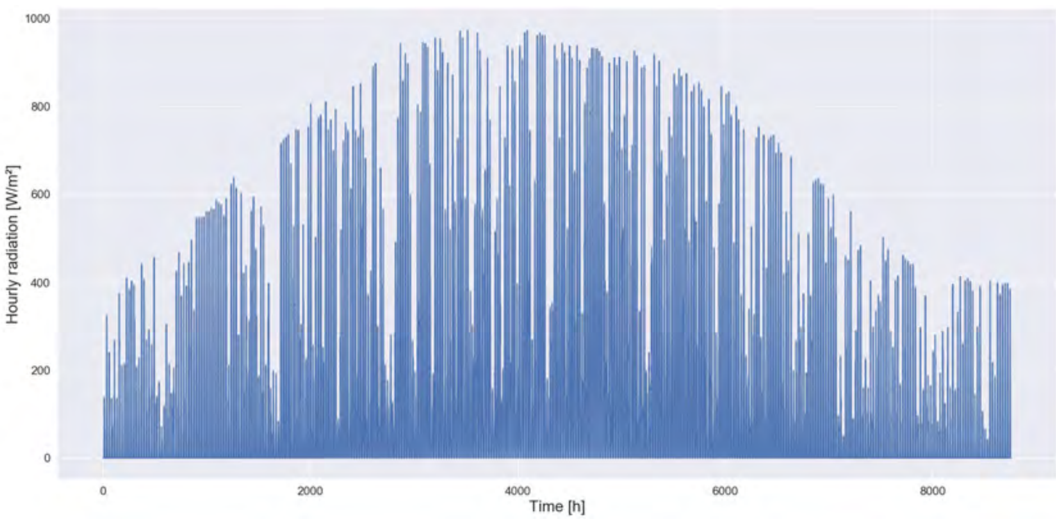

Figure 24: Solar irradiation profile used in the dispatch model (Source: (EU PVSEC, 2017))

8.4 A4) Load profiles of the district heating system

An important input parameter for the calculation of the heat supply to the district heating system is the projected hourly demand profile of the system. For the calculations described in this document the following methodology has been applied: The basis are hourly profiles of space heating demand and hot water demand in the respective NUTS3 region from the Hotmaps database (Fallahnejad, 2019). These profiles are scaled to fit the space heating and hot water demands in the different scenarios using the overall heat demand defined to be supplied to the district heating system in the different scenarios and the split of space heating vs. hot water demand derived in the respective heat saving scenario. With this approach it was possible to account for the change in the characteristics of the load profiles of district heating supply with decreasing share of space heating on the overall load. The following figure show the resulting load duration curves for the overall heat demand (space heating plus hot water) for the calculated sizes of the district heating systems.

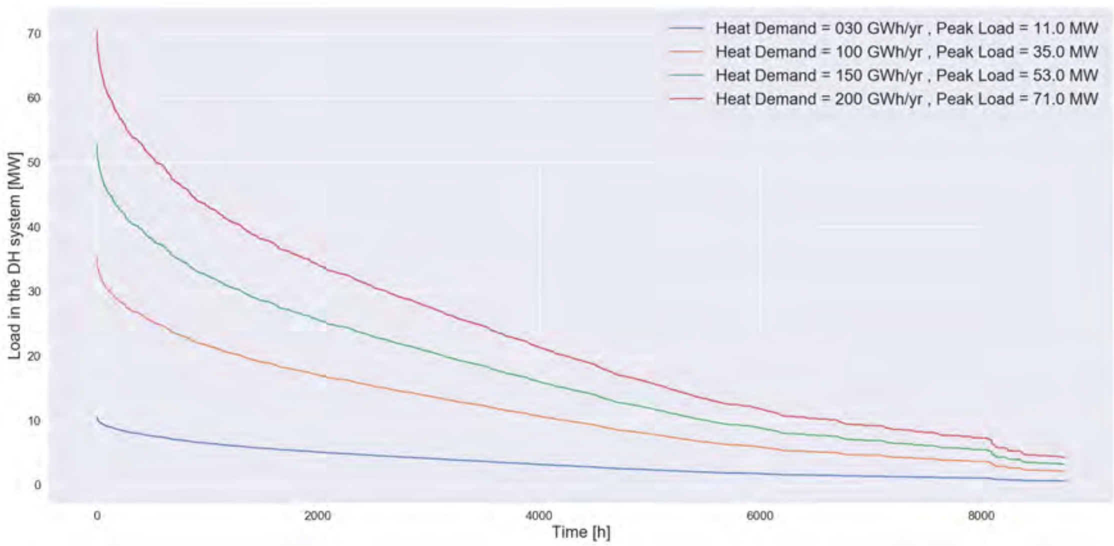

Figure 25: Load duration curves of the district heating system for the different total heat demands supplied by the DH system used in the dispatch model (Source: own calculation based on data from (Fallahnejad, 2019))