Holistic urban energy planning in temporal and spatial resolution for the city of Gleisdorf

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Abstract

Energy transition processes of urban energy systems are key solutions to tackle climate change. In line with the Austrian sustainable targets of decarbonisation and renewable integration by 2050, the present research aims to redesign the heating sector of Gleisdorf to propose a future scenario with reduced CO$_2$ emissions and high renewable penetration.

The research is developed under an extensive methodology combining GIS-based spatial and numerical analysis, application of engineering models and the modelling and simulation of scenarios with the software energyPRO. It is organized under four phases. The first step builds a framework description of the urban and energy status quo of the city. The second phase develops a methodology to predict the future heating demand. The third phase identifies potential sustainable transformation pathways to create scenarios representing the heating sector of the city in 2050. On this basis, the following concepts are studied: (i) a renovation roadmap of the building stock, (ii) a district heating extension plan, (iii) a phase out of fossil fuels and (iv) a solar thermal penetration process. The last phase consists on modelling and simulating the scenarios to match both sides of the system in temporal resolution and create results regarding its technical performance. Finally, the discussion chapter judges the scenarios output according to sustainability indicators, addresses the main research objective and points out the limitations of the study.

The findings demonstrate that Gleisdorf's heating sector holds a great potential for energy savings and CO$_2$ emissions reduction if energy conservation and energy transition measures are put in place. In particular, an **Ambitious** scenario has been regarded as the designed future heating system that can achieve the most efficient energy conversion process. A detailed investigation indicates, compared to current levels, a reduction of final energy demand by 44%, a reduction of primary energy consumed by 60% and a reduction of heat production related CO$_2$eq emissions by 77% by 2050. Last but not least, the thesis has provided insights of how the development of a clear methodology combining different tools is relevant for the results' quality of an urban energy planning process.
Résumé

La transition des systèmes énergétiques urbains nécessite des solutions, clés pour faire face au changement climatique. En ligne avec les objectifs de développement durable autrichiens, de décarbonisation et d'intégration des énergies renouvelables d'ici 2050, la présente recherche vise à restructurer le secteur du chauffage de Gleisdorf. Un scénario futur est proposé, avec une forte part d'énergies renouvelables, afin de réduire les émissions de CO$_2$.

La recherche est développée à l'aide d'une méthodologie avancée combinant les modèles spatiaux et numériques d'analyse des systèmes d'information géographique (SIG), l'application de modèles d'ingénierie et la modélisation et simulation de scénarios avec le logiciel energyPRO. La recherche est organisée en quatre phases. La première étape décrit l'état des lieux urbain et énergétique de la ville. La deuxième phase élabore une méthodologie pour prédire l'état futur de la demande de chauffage. La troisième phase identifie des voies potentielles de transformation durable, pour créer des scénarios représentant le secteur du chauffage de la ville en 2050. Sur cette base, sont étudiés (i) une feuille de route pour la rénovation du parc immobilier, (ii) un plan d'extension du réseau de chauffage urbain, (iii) une élimination progressive des combustibles fossiles et (iv) un processus de pénétration du solaire thermique. La dernière phase consiste à modéliser et simuler des scénarios pour combiner les deux parties du système en résolution temporelle, afin d'obtenir des résultats sur ses performances techniques. Finalement, une discussion juge les résultats des scénarios en fonction des indicateurs du développement durable, répond à l'objectif principal de la recherche et souligne les limites de l'étude.

Les résultats montrent que le secteur du chauffage de Gleisdorf détient un grand potentiel d'économies d'énergie et de réduction des émissions de CO$_2$, à condition de mettre en place les mesures de conservation de l'énergie et de transition énergétique. Dans ce contexte, le scénario Ambitieux est considéré comme le futur système de chauffage qui permet d'accomplir les plus importantes économies d'énergie. Une analyse détaillée indique pour la production de chaleur un potentiel de réduction de la demande en énergie finale de 44%, un potentiel de réduction de la consommation d'énergie primaire de 60% et un potentiel de réduction des émissions de CO$_{2eq}$ de 77%, en 2050, par rapport aux niveaux actuels. Dernier point, mais pas le moindre, cette thèse montre la façon dont le développement d'une méthodologie claire, combinant différents outils, est pertinente pour obtenir des résultats de haute qualité dans une planification des systèmes énergétiques urbain.
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Foremost I would like to thank my thesis advisors Dr. Ingo Leusbrock and DI. Franz Mauthner for allow me this paper to be my own work, but steered me in the right direction whenever they thought I needed it.

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<tbody>
<tr>
<td>AB</td>
<td>Apartment block</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>COP</td>
<td>Coefficient of Performance</td>
</tr>
<tr>
<td>DB</td>
<td>Database</td>
</tr>
<tr>
<td>DH</td>
<td>District heating</td>
</tr>
<tr>
<td>HEB</td>
<td>Heizenergiebedarfgeführt or Final heat demand</td>
</tr>
<tr>
<td>GFA</td>
<td>Gross floor area</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>HDD</td>
<td>Heating degree day</td>
</tr>
<tr>
<td>HEB</td>
<td>Endenergiebedarf Heiz or Final heat demand</td>
</tr>
<tr>
<td>HTEB</td>
<td>Heiztechnikenergiebedarf or Demand for losses of heat production and distribution</td>
</tr>
<tr>
<td>HWB</td>
<td>Heizwärmebedarf or Space heating demand</td>
</tr>
<tr>
<td>kWh</td>
<td>Kilowatt-hour</td>
</tr>
<tr>
<td>MG</td>
<td>Micro-grid</td>
</tr>
<tr>
<td>MFH</td>
<td>Multifamily house</td>
</tr>
<tr>
<td>MW</td>
<td>Megawatt</td>
</tr>
<tr>
<td>MWh</td>
<td>Megawatt-hour</td>
</tr>
<tr>
<td>N-Gas</td>
<td>Natural gas</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td>QGIS</td>
<td>Quantum Geographic Information System</td>
</tr>
<tr>
<td>RE</td>
<td>Renewable Energy</td>
</tr>
<tr>
<td>SDH</td>
<td>Solar district heating</td>
</tr>
<tr>
<td>SFH</td>
<td>Single family house</td>
</tr>
<tr>
<td>TH</td>
<td>Terraced house</td>
</tr>
<tr>
<td>WWB</td>
<td>Warmwasserwärmebedarf or Domestic hot water demand</td>
</tr>
<tr>
<td>ZAMG</td>
<td>Zentralanstalt für Meteorologie und Geodynamik</td>
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PRESENTATION OF THE INTERNSHIP ENVIRONMENT

The MSc thesis presented here was carried out between 1st of February of 2016 to 31st of July of 2016 at AEE – Institute for Sustainable Technologies, or AEE INTEC. AEE INTEC was founded in 1988 as an independent research association and now is regarded as one of the leading institutes in the field of applied research on renewable energy in Austria. The institute is engaged in the exploration of the scientific and technological basis of solar thermal energy, in the development of low or zero-energy buildings and its efficient energy supply systems, as well as in energy efficiency in industry. Its core activities are focused on the sustainable use of energy and resources, and the development of components, systems and strategies that enable the quick and widespread use of renewable energy sources and energy efficient technologies.

Within these scopes, the projects of AEE INTEC range from developing and testing prototypes, initiating, monitoring and analysing of pilot and demonstration plants, development of energy supply concepts for cities and industries, consulting activities, know-how transfer, as well as training and supervising numerous theses. Furthermore, AEE INTEC is integrated in a large network of national and international co-operation (e.g. International Energy Agency). Among others, it is a member of the Association of European Renewable Energy Research Centres (EUREC) and the European Technology Platform for Renewable Heating and Cooling.

The institute is located in the Austrian city of Gleisdorf, 150 km south west of Vienna and 20 km east of the city of Graz. At present 64 persons are working in the institute’ offices, and are organized, excluding administration and management departments, in four main departments: thermal energy technologies and hybrid systems (TEHS), the industrial processes and energy systems department (IPE), the department for sustainable buildings (GEBAUDE) and the data monitoring and testing division (MESSTECHNIK). The TEHS department presents the largest group within AEE and currently has a multidisciplinary team of 34 engineers, researchers and master students.

One of the focuses of the TEHS department lies on the efficient application and integration of renewable energy sources in urban and regional energy systems. Within this topic, the thesis presented here was carried out in relation with an on-going research and development project managed by the TEHS department and under collaboration with many project partners including local governments, technical university departments and research studios. The project is called *EnergyCityConcepts (ECC)* and investigates the development of a methodology and concept for the implementation of sustainable energy systems in cities by the example of Gleisdorf and Salzburg. The project is based on these two concrete model regions to develop and test new methodical approaches under a holistic concept which will link an interdisciplinary urban and regional energy planning approach with modelling and simulation activities. In particular, the work performed here has focused on the small city of Gleisdorf.
1. INTRODUCTION

1.1 Societal context

Mitigating climate change is regarded as the most important challenge humankind has to face in the 21st century [1]. In order to slow down and even stop global warming, urban energy systems need to limit the release of GHG emissions into the atmosphere. In this sense, the solution requires replacing fossil fuels as the main energy source of the global economy.

In 2015, 54% of the world population was living in urban areas. By 2050, urbanization, population growth and migration patterns will raise this value to 66% or 6.4 billion urban dwellers [2]. These urban areas are the consequence of a quickly expansion of the construction sector which frequently has built without a previous urban planning. The resulted urban settlements not only do not have concern on land use or environmental protection but also consist of crowded habitats unable to ensure proper living standards. Moreover, its transportation network is unable to accommodate the demanding traffic as well as the procurement infrastructures for water, gas and electricity are ineffective and insufficient.

The building sector across the world is responsible for 40% of global final energy consumption, 40% of global resources and accounts for 1/3 of global CO₂ emissions [3]. People live in cities, consequently energy is consumed there and commerce is done at the same place. Cities are the heart of our problems but they also harbour the solution. In order to help the world to get to a sustainable place to live by 2050, urban areas must take a leading role towards a sustainable future and undergo a transformation to smart cities.

A smart city can be categorized by 6 aspects: smart economy, mobility, environment, people, living and governance [4]. Yet, one vital aspect connecting these 6 aspects is a city’s energy system since it plays an essential and irreplaceable role in the daily human activity. However, the current situation is not efficient as it could be; built years ago, energy infrastructure most of the time lacks technology and economic efficiency while there is still a huge potential to minimize its environmental impact. High related CO₂ emissions, strong reliance on fossil fuels and low overall efficiency of the energy system point out the need of an energy transition towards a sustainable infrastructure able to provide clean, efficient, affordable and accessible energy for all.

This energy transition includes a replacement of the old centralized systems by a new portfolio with an increased flexibility of production sources and dominated by centrally and decentrally applied renewable energies. In this way, instead of re-investing in outdated conventional infrastructure powered by fossil fuels, governments should aim at producing energy from renewable sources right where the resources are located. Not only would this considerably reduce CO₂ emissions, it would also enable consumers to be self-sufficient in future. Challenges range from social acceptance, economic profitability of investments to further technological research. The latest is needed to still ensure a complete balance of the inherent intermittency of renewable sources. Most of the solutions are already out there, but unfortunately not scaled up to the level that we would like to see.

For instance, in spite of the commonly known solar potential for electricity production, Spain still chooses to restrict the spread of this sustainable technology by setting a “Sun tax”. Although it is said that taxes will contribute to overall system costs and not to compensate utility losses, the overall thinking is that this is put in place in favour of the electricity companies, which might need to bear the costs of grid reinforcements in case high amount of photovoltaic are connected [5]. Regarding the wind sector, the challenge is shared between
the environmental protection sector, who fears noise disturbances during operation, threat to wildlife and visual impact of wind turbines, and the financial part, which discusses in what extent national economic tools such as feed-in-tariffs or green certificates should help bearing the high investment costs of such technology. An example can be found in [6]. Meanwhile, the use of biomass as an energy source also competes with the agricultural sector which in turn bets for using the land to cultivate food instead of energy crops [7]. Moreover, biomass applications range from transportation to electricity or heat production, hence technical potential and economical profitability of the conversion pathways will determine its end use. These are a few examples on already existing sustainable solutions for the energy systems that still harbour some impediments to be widespread adopted during the energy transition process.

This thesis evaluates the potential of an Austrian city to undergo this transition by improving and optimizing its heating supply system. It focuses on the redesign of the urban energy system with the goal of integrating a high ratio of renewables. In particular, the heating sector will be analysed to devise energy transformation opportunities. The final purpose is to develop possible pathways for a complete transition in this sector for the future year of 2050 by eliminating current system weaknesses whilst strengthening its virtues.

1.2. Problem definition

The overall goal of the energy transition is to tackle climate change and reduce the amount of CO₂ released to the atmosphere. For this purpose, the Kyoto protocol or the recently updated (to 2050) EU’s climate and energy policy 20/20/20 commitments were created [8]. Within the latest framework, Austria has worked on his own energy regulation in order to meet the national targets in this field. The country has a target of supplying 34% of final energy consumption from renewable sources by 2020 and 100% by 2050 [9]. The present research focuses on a particular small Austrian town and the transformation of its energy system towards achieving its own sustainability targets. Taking a holistic approach of the problem, the overall goal is to model, analyse and redesign the heating sector of the city in order to propose a future scenario with a high integration of renewables sources.

The chosen town is Gleisdorf, located in the district of Weiz in the province Styria, 28 km east from Graz. Its 6,000 inhabitants live and work in 1,900 buildings spread over a surface of 500 hectares [10].

Gleisdorf municipality has already started its energy transition with the implementation of a district-heating infrastructure in 2012 that is increasingly replacing individual heating systems [10]. In 2011, the city achieved a renewable penetration ratio in its energy system of 26,5% [12]. Looking ahead, the research aims to investigate whether the theoretical target for Gleisdorf to supply the heating demand with 100% renewable sources by 2050 is
feasible. If it is possible, the study will consider potential development pathways in line with an energy transition process to outline the necessary steps to achieve it. However, if the target is unreachable, the research will in turn result with a realistic and achievable future heating system that can be accomplished by 2050.

Within the framework of redesigning energy systems, an approach with three sequential directions is chosen for this research. The starting point is related to energy conservation of the end-consumer side, the building level, where the strategy is to reduce the final energy demand. Scaling up these results to the district level, the second step consists on taking benefits from the possible synergies of a given area. Finally, the last strategy consists on gradually phasing out fossil fuels in favour of an integration of renewable sources in the urban energy system.

This bottom-up approach with a first focus on building level is of high importance due to the current characteristics of the local building stock. It is projected that 50% of the present building stock will still remain in use for the following 30 years [13]. In Europe, 50% of the building stock was built 40 years ago when no or little attention was given to energy performance of buildings directives, the development of efficient technologies was still in an early stage, energy reduction measures were frequently not applied and when the energy sector was dominated by a centralized sector based on fossil fuels [8]. Given this, a high share of the current building stock lacks proper insulating measures as well as energy-efficient technologies, which results in increased energy demands for the current building stock. Therefore, strategies for renovation of the building stock should be of high priority in the sustainable agenda of governments.

Modelling and analysis of urban energy systems have already been discussed by many authors [14] [15] [16] [17] [18]. The applied methods however, differ according to the end-goal of each study [19]. The present research aims to achieve the goal stated above with a not so widespread used methodology. The main idea is to combine spatial information of buildings and their location - as a key distinguishing feature of the study, which will be examined through the integration of Geographic Information Systems (GIS) - in the system analysis with their numerical data (e.g. energy demand and profiles) to generate spatial maps useful for decision making. Combined with GIS, statistical and engineering methods will be used to create and assess the future scenarios of the system [20]. GIS not only allows the mapping of building infrastructure, local resources and energy flows, but also due to its associated numerous attributes it is a valuable tool to combine and evaluate data from different domains (social, economic, energy, transportation, etc.) to identify key urban and energy planning strategies. In the present research, GIS is used as a data visualization tool for a pre-analysis phase. Following, modelling and simulation is undertaken to achieve technical performance and sustainability results. Finally, GIS is used again to represent the final results and its potential benefits. Here, the visualized results could be used as support for a possible later decision making process.

1.3. Objective and research questions

This thesis aims to evaluate different potential pathways for a redesign of an urban energy system in order to create scenarios with high renewable penetration. Although the research only gives results on the case study performed, the methodology adopted aims to serve as guidance for other systems studies with similar characteristics. The study focuses on the heating sector of the city.

The research objective is formulated in the following statement:
To combine GIS spatial analysis tools with engineering, mathematical and statistical methods to assess whether the heating sector of Gleisdorf can be supplied by 100% renewable sources by 2050. Likewise, the research focuses in designing a future urban energy system for the city, which exploits its local resources towards achieving a 100% renewable energy integration and maximizing its self-sufficiency while ensuring a continuous balance between supply and demand in a high temporal resolution.

The following research questions (RQ) and sub-research questions (sRQ) have been formulated in order answer the objective.

**RQ1. Which is the current urban and energy status quo of Gleisdorf?**

a. Which is the distribution of space heat demand and gross floor area (GFA) of the building stock regarding the construction period of the units, regarding the heating system installed and regarding the building use of the constructions?

b. Which is the current renovation state of the buildings?

**RQ2. How can the heat demand of the city be predicted for the investigated period?**

a. Which would be the selected strategies to adopt in order to create energy conservation scenarios within the building level?

b. How much each of the measures represents in terms of energy savings?

**RQ3. Which are interesting scenarios in line with sustainable targets that could represent the energy system of the year 2050?**

a. Which would be a renovation roadmap of the building stock to accomplish by 2050?

b. How the district heating network is going to expand in the future?

c. How much would be the solar thermal penetration in the heating sector of the city?

d. How will central heating systems evolve in the future?

**RQ4. Which of the scenarios considered is more positive evaluated according to sustainability criteria?**

a. Which sustainability indicators are chosen to evaluate the performance of the scenarios?

b. Which are the environmental and technical outputs of the operation of the energy system modelled in each of the scenarios?

**Approach**

RQ1 aims to build a framework description of the case study which can be used as baseline referred to throughout the research process. RQ2 is responsible to predict the future heating demand. RQ3 takes decisions to outline scenarios for the future energy system. RQ4 simulates the models of the scenarios to match both sides of the energy system and create results on the production schedule of a future technology mix. Given the results, a discussion chapter is responsible of judging the scenarios output according to energy performance indicators, address the main research objective and point out the limitations of the study. Step 1 and 2 are done in parallel while step 3 and 4 are dependent on the previous ones.
2. MATERIALS AND METHODS

2.1 Methodological steps

The methodology of the present thesis comprises 4 steps linked to the research questions formulated earlier. Figure 2 shows an overview of how each step of the research study is addressed; therefore, materials, methods and final results are defined. Then, down below an introduction to each step is given.

![Methodology applied](image)

**2.1.1 Step 1**

Data input for this step is based on the obtained GIS DB of the existing building stock of the city, as well as the climate records of the city for the reference year 2015 (see the data collection section provided later). After the processing of the database with correction, update, addition and counterchecking tasks, and a further preliminary analysis, the writer is able not only to draw first conclusions on the urban and energy status quo of Gleisdorf but also to come up with potential future development ideas. The step uses statistical methods to fill in missing information as well as GIS spatial analysis and geo processing tools to calculate physical parameters of the building stock.

It is accomplished in three phases, first the database recognition to familiarize with existing information, second the database correction to rectify inaccurate or wrong entries, and third the database completion where missing buildings are identified as well as lacking attributes are estimated.
2.1.2 Step 2

This step consists on computing the potential energy savings that could be expected by 2050 if an energy transition process takes place. Data input used during calculations comes from the GIS DB revised and completed in Step 1 and from TABULA project, which will be presented shortly. The methodology uses engineering methods based on heat transfer equations applied in the building level; these are specified in the standard EN ISO 13790, which assesses the energy performance of buildings with the calculation of its energy use for space heating and cooling [21]. Moreover, the heating degree method is also used to climate adapt the energy consumption results for future years [22].

2.1.3 Step 3

The step creates scenarios to represent different energy transformation pathways for the future. The methodology consists on detailing four sets of uncertainties regarding the future energy system:

- The renovation rate that will mark the development of the new energy demand
- The new heat supply infrastructure distribution within the city
- The new fuel mix of the system including the additions on solar thermal collectors
- The new solar thermal penetration in the city

This step uses the results of step 2 to derive new heating demands for the year 2050. In turn, with the purpose of redesigning the heating supply infrastructure, GIS spatial analysis tools are used to calculate possible future extension of the energy procurement networks.

2.1.4 Step 4

This step consists on modelling and simulating the energy system defined in each scenario. energyPRO, a modelling software package for combined techno-economic design, analysis and optimisation of a variety of heat related projects is used. The software works balancing demand and supply side of the scenarios and obtaining results of: primary energy consumed, final heat produced by energy source, solar thermal penetration, share of renewables in the system and CO\textsubscript{2eq} emissions produced. In particular, the software calculates the optimum production schedule of each conversion unit modelled in the system. Finally, the performance output of the proposed heating sectors will be evaluated according to sustainability criteria in the discussion chapter.

2.2 Data collection

The present research works with real data of the study area that has been provided by the municipality and local energy providers. In particular, one of the distinguishing features of the investigation is the handling of the heating sector energy demands on an individual building level instead of treating the city as a whole. This characteristic enables to identify potential transformation pathways given in clustered areas which could facilitate future urban and energy planning strategies. The city related data collected which served as basis for the study is presented here:

- Building stock database: provided by Stadtwerke Gleisdorf / Feistritzwerke, it consists on a spatial building stock database where each object is defined by its location as well as construction and energy related parameters. It will be the basis for the calculation of the heating energy demand of the city. The database will be abbreviated to GIS DB within the paper.
Holistic urban energy planning in temporal and spatial resolution for the city of Gleisdorf

- **District heating network**: provided by Stadtwerke Gleisdorf / Feistritzwerke in form of a GIS spatial database and numerical technical information. It specifies the extension of the current district heating network all around the city as well as its heating plants in terms of installed capacity and technical and performance parameters.

- **Weather data**: provided by ZAMG (Zentralanstalt für Meteorologie und Geodynamik), the national weather service of Austria, and for the location of Gleisdorf, ambient temperatures and global solar horizontal radiation are obtained for the year 2015.

The utilisation of established external sources to fill in information gaps has been a constant activity throughout the study. The main external reference used within the project has been used to assume thermal transmittances or construction attributes of typical buildings’ structures. It is presented below.

- **IEE Project TABULA** [23]: supported by the Intelligent Energy Europe, the TABULA project is an international research work performed from 2009 to 2012 about a “Typology Approach for Building Stock Energy Assessment” [24]. The purpose was to develop national building typologies to represent the residential building stock of each territory studied. The typologies consist of a classification scheme grouping buildings according to their size, age and further parameters while creating a set of exemplary buildings representing the building types. Moreover, they include typical heating consumption values for the example buildings and showcase calculations of the possible energy savings under renovation strategies. The database not only will be used for the assumption of construction and thermal resistance values of Gleisdorf’s buildings but also the published methodology to compute energy savings will serve as reference for own calculations. The tool will be abbreviated to TABULA when being referred within the paper.

Also, various sources have been used to assume usual efficiencies and operation parameters of energy conversion units of Chapter 6.

### 2.3 Assumptions

#### 2.3.1 Physical characterization of the building stock

The present project uses the individual buildings of Gleisdorf as key objects for developing future energy planning strategies. Due to the unavailability of physical construction parameters of the building stock, the results of the **TABULA** project [23] are used to fill the information gap. To represent the building typologies of the residential sector, **TABULA** is used to assume typical conditioned reference floor areas, building envelope areas (windows, walls, floor and ceiling) as well as U-values for each of the envelope barriers. Moreover, it also details the typical new U-values in case the building undergoes renovation under Usual or Advanced measures. In step 2, characteristic values from the **TABULA** project [23] are assumed to complete the physical and thermal performance characterization of the residential buildings of the present study.

#### 2.3.2 Climate adaptation

Past research works have commonly accepted that the most significant variable affecting energy demand is the outside temperature [25]. On this basis and considering that variations in temperatures are expected over the years due to global warming [26], a climate adaptation method must be applied when forecasting the space heating demand for a future
investigated year. The method chosen for this task is the heating degree day method [27], which takes into account the number of days in which the outside temperature is below a certain value, 12°C. In these days, the operation of the heating system is required to bring an internal temperature comfort, 20°C, to the building (see Section B.2). Further explanations on the application of the method are given in Chapter 4.

### 2.3.3 Heating demand

The heating demand term referred throughout the paper corresponds to the final annual heat requirements of a building given per m² of GFA. Per each individual object with no distinction on building use, the value is considered to be a combination of the three terms specified in the expression below [28].

\[
HEB = HWB + WWWB + HTEB
\]  

(1)

All through the thesis, the expression “heat consumption” will refer to the heat which is usefully consumed within the building, therefore HWB and WWWB. In turn, the expression “heat demand” will indicate the HEB value which also includes the energy lost during the heating process.

### 2.3.4 Production and distribution heating losses and domestic hot water demand

The final energy demand for the heating sector is computed as the combination between energy needs for space heating (HWB), for domestic hot water (WWWB) as well as the energy lost within the distribution system (HTEB). While values on HWB are either provided for each building in the GIS DB or estimated with a methodology detailed later on, WWWB and HTEB are unavailable. The net energy domestic hot water needs are assumed for every building to be 12.5 kWh per m² of conditioned floor area, a reference value specified in [29].

### 2.3.5 General

The thesis works with annual energy consumption and production values during Chapter 3, 4 and 5 as well as in the spatial mapping of energy related results. These correspond to a year set at 365 days. However, the simulation in Chapter 7 requires the balance of both sides of the system in a high temporal resolution therefore in 8760 hourly steps throughout the year. The methodology to disaggregate the annual values into hourly profiles will be detailed for each energy sector in Chapter 4.

### 2.3.6 Building categories and boundary conditions

According to the information provided in the GIS DB, the existing building stock (with collected data updated in 2015) of Gleisdorf can be classified according to three different characteristics: the period where the building was constructed, its heating system or its building use.

- **Building use:** residential, commercial, industry, communal or mixed (commercial and residential combined uses) sector
- **Heating technology:** coal, oil, gas or biomass boiler, heat pump or electric heating systems
- **Period of construction:** 8 periods ranging from early 1900 to 2020, which are assumed from TABULA categorisation [23]
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The latitude and longitude of Gleisdorf is 47.1068 and 15.7085 respectively [30]. During the course of the project the city is considered to have the boundaries of Figure 3 or Map 1, hence, only the buildings located inside the perimeter are considered in this study.

![Figure 3. Gleisdorf administrative boundary (Map 1)](image)

2.3.7 *Industry sector*

In the current state of development and due to unavailability of data, the thesis does not consider the process heat demand particular of the industries of the city. In this way, the existing data of heat demand for the industry sector only refers to the space heating and hot water needs of the associated offices throughout the year. Further developments and results refinement of the project should focus on integrating the process heat demand from the industry sector in the energy system simulations to ensure that a proper balance between heat production and demand is achieved.

2.4 Tools

2.4.1 *energyPRO*

energyPRO is a flexible energy modelling software package for combined techno-economic design, analysis and optimisation of a variety of heat, CHP, process and cooling related projects [31]. It is developed and maintained by the company EMD International A/S, which also makes the software commercial through its website. The tool works with an input/output approach to model energy systems and optimize its operation using technical, financial and external parameters. It can model systems regardless of renewable or fossil energy sources operating with any mix of conversion units. Finally, energyPRO is suitable to simulate and obtain an integrated technical and financial analysis of both existing and new planned energy projects [31].

The software works with the priority of meeting all the required demands during the investigated period. As a result, energyPRO calculates the optimal production schedule of
the heating plants considering an optimization criterion of minimizing the cost of producing the required heat. To identify the optimal operation strategy, energyPRO avoids the traditional chronological method to obtain the energy productions of each conversion unit using hour by hour calculations and instead, it calculates productions in the most favourable periods for the whole year. In this way, before being accepted, each new production needs to be carefully checked so that it will not disturb the already planned future production [32].

energyPRO will be used in the step 4 of the methodology to model and simulate the scenarios. Chapter 6 presents the modelling parameters introduced in the software whereas Chapter 7 shows and discusses the simulation results in a yearly resolution.

2.4.2 QGIS

Quantum GIS or QGIS is an open source Geographic Information System which is available as a cross-platform free and open source desktop for Linux, Unix, Mac OSX, Windows and Android. It supports most geospatial vector and raster file types and database formats while providing standard GIS functionalities, including many mapping features, data editing, different map projections and GRASS digitizing [33]. The program has been used for the spatial analysis extent of the thesis which is mainly presented in Chapter 3 and 5 as well as referred throughout the work in the maps of Appendix D.
3. BASELINE ASSESSMENT FOR GLEISDORF

The present chapter provides a baseline assessment of Gleisdorf and forms the reference for the later parts. It aims at answering RQ1; hence to assess the current urban and energy status quo of the city through a bottom up approach starting from the building level. The starting point of this section relies on the obtainment of a solid, reliable and complete database with urban and energy information on each building unit of the city. Figure 4 shows the data processing methodology developed for this task. It consists of three different processes where after data corrections and filling data gaps, the initial GIS DB has been transformed to a complete and reliable database which fairly represents the building stock of the city and which will be the basis for the whole project. It should be noticed that although the data was collected in 2012, it has been recently revised and updated. Given this, it is assumed that the initial GIS DB represents the actual building stock of 2015.

Figure 4. Methodology of data processing process of phase 1

3.1 Database recognition

The GIS DB provided by Stadtwerke Gleisdorf / Feistritzwerke contains 1553 objects. These, apart from having a given location on the map, are defined by the following 11 attributes.

Table 1. Attributes of the existing building stock database

<table>
<thead>
<tr>
<th>ATTRIBUTE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJECT ID</td>
<td>ID number for each object spatially located, building or part of it</td>
</tr>
<tr>
<td>Address</td>
<td>The address of the object in the map</td>
</tr>
<tr>
<td>Built area</td>
<td>The surface area on the ground occupied by the object</td>
</tr>
<tr>
<td>Gross floor area</td>
<td>The total floor area of the whole object</td>
</tr>
</tbody>
</table>

- CORRECTION PROCESS
  - Fuel aggregation
  - Year aggregation
  - N°floors, GFA, Built Area consistency
  - Irregular objects

- ESTIMATION PROCESS
  - Type of residential unit
  - State of renovation

QGIS
- TABULA
- Google Maps
- Statistics

INITIAL GIS Building Database

CORRECTED GIS Building Database

COMPLETED GIS Building Database

EXTENDED GIS Building Database

IDENTIFICATION AND ESTIMATION PROCESS
- Geo-localization of missing objects
- Estimation of attributes
- Allocation of H/WB
Although the existing database has been an important starting point, however it cannot be considered complete. After a quick check-up between GIS DB and Google Maps, some buildings not included in the database have been detected. Moreover, errors within the existing entries as well as missing values have been identified. Given that, the thesis’s role includes the extension of this database in the three steps shown in Figure 4. First, a consistency check of all the building entries is made to correct or fill in some absent attributes. Second, an estimation process is performed in order to obtain information on two attributes required for the future methodology of the project. Finally, the missing buildings are spatially located as well as characterized with the estimation of its attributes.

The three different data processing steps are represented in workflows of Figure 5. The next section provides the comprehensive methodology that specifies all the steps, assumptions, statistics and formulas applied.
3.2 Database correction

As introduced in the report, the existing database has errors as well as missing information. The correction process performed is defined in the steps presented below.

3.2.1 Building age categorisation

In this step, the buildings are categorised regarding building age of the objects in seven different constructions periods using the same TABULA definition i.e. <1918, 1919-1944, 1945-1959, 1960-1979, 1980-1999, 2000-2010, > 2020. These periods will be used hereinafter the whole thesis.

3.2.2 Heating system and fuel source consistency

In this step, all types of heating system and fuel sources were categorized into eight different categories: biomass boiler, electric heating system, oil boiler, gas boiler, coal boiler, DH (solar thermal combined with biomass), heat pumps and others. In this way, no distinction in the type of biomass (e.g. pellets and wood chips) or whether the object incorporates solar collectors (e.g. gas solar and biomass solar) is made in the categorisation of the heating system. Table A. 1 in Appendix A shows the initial fuel labels provided in the initial version of the GIS DB and its resulting categorisation. Furthermore, objects where no information on the heating fuel was available have been assumed to be provided by its primary heat source column.

3.2.3 Irregular objects

A preliminary check-up of the existing objects has been performed in order to identify potential irregular objects regarding its building use or heating fuel category. These have been modified after verification with the municipality. Table A. 2 in Appendix A shows the modifications performed.

3.2.4 Correction of enter number of floors

Buildings without information of the number of floors or with a null value have been corrected as follow.

- For residential sector: assign a random value of 1 or 2 number of floors while complying with the existing statistics of the city regarding the distribution of 1 and 2 floors residential buildings.
- For mixed sector: assign a random value of 2 or 3 number of floors while complying with the existing statistics of the city regarding the distribution of 2 and 3 floors mixed sector buildings.
- For industry, commercial and communal sector: number of floors is calculated as $\text{round}(\frac{GFA}{\text{Built Area}})$

3.2.5 Correction of buildings gross floor area

The preliminary check-up also identified buildings with potential erroneous GFAs values. For this step it is assumed that the attributes of number of floors and ground built areas are reliable and trustable data. The methodology to correct the GFA is presented below:

1. Calculate the Real number of floors resulting from $\frac{GFA}{\text{Built Area}}$
2. Wrong GFA objects are identified when $|\text{Real } n^\circ \text{ floors } - \text{ Enter } n^\circ \text{ floors}| > 1.2$. The limiting factor of 1.2 is taken from own assumptions.
3. The new GFA is calculated as $\text{Built Area} \cdot \text{Enter } n^\circ \text{ floors}$
3.3 Database estimation

The database provided by Stadtwerke Gleisdorf / Feistritzwerke was lacking information regarding the residential type as well as the renovation state of the buildings. These two attributes are estimated using the following procedure.

3.3.1 Residential type estimation

This step aims to categorize the residential sector in the same way as in TABULA. For this, one of the following 4 types of residential units must be assigned to the actual building: Single family house (SFH), Multifamily house (MFH), Terraced house (TH) and Apartment block (AB). It should be noticed that terraced houses have been identified on the map using QGIS, if a built area was under 150 m² and objects were adjoining to others. According to built areas and number of floors, based on own assumptions for the threshold values, the remaining categories are distinguished as follows:

\[
\begin{align*}
\text{if Built Area} & < 150 \\
\text{N° floors} & < 3 \quad \text{SFH} \\
\text{N° floors} & \geq 3 \quad \text{MFH}
\end{align*}
\]

\[
\begin{align*}
\text{if Built Area [150-300]} \\
\text{N° floors} & \leq 3 \quad \text{MFH} \\
\text{N° floors} & > 3 \quad \text{AB}
\end{align*}
\]

\[
\begin{align*}
\text{if Built Area} & > 300 \\
\text{N° floors} & < 3 \quad \text{MFH} \\
\text{N° floors} & \geq 3 \quad \text{AB}
\end{align*}
\]

3.3.2 Renovation state estimation

Three types of renovation state are identified within the city: not renovated buildings, low energy buildings already renovated according to Usual measures, and low energy and passive houses already renovated using Advanced measures. The classification of the renovated buildings has only been possible in the residential sector, where TABULA has served as basis for the refurbished scenarios. Given this, all buildings belonging to commercial, industry, communal or mixed sectors are assumed to be in its initial state, therefore not renovated. Due to the inexactitude of the assumption, the incurred error is estimated in the discussion chapter.

The estimation of the renovation state of the residential sector is derived from the typical HWB values of each building category in case the construction is in its initial state, already renovated using Usual measures or Advanced measures. More information on the calculation of these HWB values is given on Chapter 5, which can be performed in parallel.

The methodology consists on comparing the HWB value provided in the GIS DB with the HWB scale values of a building in its same category: \(HWB_{\text{initial state}}\), \(HWB_{\text{usual}}\), \(HWB_{\text{advanced}}\). It should be noticed that these were calculated using weather profiles for Gleisdorf and for the year 2015. In turn, the estimation of the renovation state follows the ensuing rules.

\[
\begin{align*}
\text{HWB}_{\text{GIS}} \geq (HWB_{\text{initial state}} + HWB_{\text{usual}})/2 & \quad \text{Not renovated} \\
\text{HWB}_{\text{GIS}} > HWB_{\text{advanced}}, \text{ and } \text{HWB}_{\text{GIS}} < (HWB_{\text{initial state}} + HWB_{\text{usual}})/2 & \quad \text{Usual renovated} \\
\text{HWB}_{\text{GIS}} \leq HWB_{\text{advanced}} & \quad \text{Advanced renovated}
\end{align*}
\]
Table A. 3 in Appendix A shows the $\text{HWB}_{\text{initial\ state}}$, $\text{HWB}_{\text{usual}}$, and $\text{HWB}_{\text{advanced}}$ values for each residential building category used in the calculation.

3.4 Database extension

In order to obtain a complete building stock database which allows a first representation of the urban status quo of the city, missing buildings have been identified and defined with the attributes of Table 1. The methodology developed for this task is presented below.

3.4.1 Geolocalization of missing buildings

The first step uses spatial analysis tools to identify and estimate the attributes of building use and heating fuel based on the existing GIS DB. Using the geo processing tools of the software QGIS the missing buildings are identified when comparing the existing GIS DB shapefile with one containing the urban land use of the city, which in turns specifies a category for all the polygons representing building objects. The first results were further counterchecked with the information retrieved from Open Street Maps, which has been assumed the most updated data source available.

Map 2 in Appendix D provides the complete figure of the missing buildings identified in the city. Once the polygons are spatially located, the attributes are estimated.

3.4.2 Building use estimation

The building use of the missing buildings is estimated through a crossing data process between Google Maps, Open Street Maps and GIS DB. As a result, the topology of a missing building is deduced according to the surrounding building types. Figure 6 and Figure 7 show how the building use of missing objects has been estimated. In this case, the right-hand figure represents the information taken from the aerial view of Google Maps in a colour-based legend where residential buildings are red, commerces are blue and mixed sector is yellow. Light coloured objects correspond to the already existing buildings which have been used as reference for the estimation.

Map 3 in Appendix D provides the complete figure of building type estimation for the whole city.
3.4.3 Heating system estimation

Regarding the estimation of heating system, this is performed similarly as before and using as well the existing GIS DB. However, the process is restricted with the following assumptions. First, it is taken that the DH network information provided was already accurate and complete in the GIS DB therefore no new buildings have been assumed connected to it. Second, most of the buildings corresponding to larger industrial facilities are powered by N-Gas boilers. Third, buildings powered by gas are clustered due to the presence of a fuel distribution network. The heating fuel of the remaining buildings has been assumed according to the heating fuel of its surrounded buildings. Figure 8 shows an example of the resulting relationship regarding heating system, in this case N-Gas boilers, between the existing and estimated buildings.

![Figure 8. N-Gas existing (light yellow) and estimated (strong yellow) buildings (Map 5)](image)

Map 4 and Map 5 in Appendix D provide the complete figure of heating system estimation for the whole city.

3.4.4 Space heating demand estimation

The following step of the methodology uses data of the Extended (see Figure 4) version of the GIS DB to allocate a HWB value to the estimated objects. In order to perform that final stage, the object is first fully characterized with a renovation state, a residential type if applicable and a period of construction assigned with the methodology and assumptions shown below. The steps required prior to estimate a HWB value are:

1. Assign a number of floors using the same assumptions presented in Section 3.2.4.
2. Calculate the GFA as the product between the ground built area and the number of floors.
3. Allocation of a period of construction is performed randomly but respecting the historical proportion of existing GFA built in a given period. Table 2 shows how the GFA of the city was built over the years for the residential and mixed sectors.
Holistic urban energy planning in temporal and spatial resolution for the city of Gleisdorf

Table 2. Share of total GFA in the city built in a given period for the residential and mixed sectors based on the GIS DB

<table>
<thead>
<tr>
<th>Share of GFA built in a period [%]</th>
<th>Residential</th>
<th>Mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1918</td>
<td>5.65</td>
<td>24.96</td>
</tr>
<tr>
<td>1919-1944</td>
<td>7.62</td>
<td>2.88</td>
</tr>
<tr>
<td>1945-1959</td>
<td>10.09</td>
<td>8.68</td>
</tr>
<tr>
<td>1960-1979</td>
<td>33.59</td>
<td>25.47</td>
</tr>
<tr>
<td>1980-1989</td>
<td>8.98</td>
<td>5.55</td>
</tr>
<tr>
<td>1990-1999</td>
<td>11.21</td>
<td>15.13</td>
</tr>
<tr>
<td>2000-2020</td>
<td>22.78</td>
<td>15.62</td>
</tr>
</tbody>
</table>

4. Assign a residential type (if applicable) using the same assumptions presented in Section 3.3.1.
5. Assign a renovation state randomly but respecting the already existing shares of renovation states in the city.

However, the shortcoming of this process is the unsuitability for objects in the industry/commercial, communal or other sector, where the buildings highly differ among each other and the first step of assuming an average number of floors could result with inaccurate values. As a result, buildings in these listed sectors cannot be defined with the same attributes as the others; therefore will not be covered within this thesis.

Finally, for the residential and mixed sectors a HWB value has been allocated according to the average HWB value of the group of existing buildings with the same characteristics i.e. period of construction, building use, heating fuel, renovation state and residential type. These are calculated as the weighted average HWB of each group in the Extended GIS DB. Weighted average of a given category of buildings is computed as:

$$\text{HWB}_{wa} = \frac{\sum \text{HWB}_i \cdot \text{A}_{\text{gross},i}}{\sum \text{A}_{\text{gross},i}}$$

Table A. 5 and Table A. 6 in Appendix A show the weighted average values of HWB for each of the building types in the city, which have been calculated with the Extended version of the GIS DB. Once this last estimation process is completed, the result consists on the final version of the GIS DB i.e. Completed (see Figure 4) which will be used henceforth throughout the thesis. For an easy manipulation of the database during future calculations, an identification code for each building has been created according to its attributes. This has a format of:

**Period of construction_Heating Fuel_Building Use/Residential Type:Renovation State**

E.g. 5_W_W/MFH:U, refers to a multifamily house from the residential sector built between 1980 and 1989. It uses heat pumps as the heating system and was renovated using Usual measures. The abbreviations of each attribute are listed in Table A. 4 of Appendix A.

The applied methodology has partially completed the building stock database. This leaves the database with a total of 1902 buildings composed by 1553 objects with genuine information (initial), 229 objects whose information has been estimated and 120 objects with
estimations of building use and heating system but without an associated HWB value. This latest group of 120 buildings is composed by all the units in the industry, commercial and communal sector. Although they were geo localized, its attributes however could not be estimated throughout the methodology presented in this chapter. Figure 9 shows the spatial distribution of the presented objects.

The resulting database will serve as the basis for the calculations of the future heat demand in the Chapter 4 as well as for the scenario creation in Chapter 5.
3.5 Urban and energy status quo of the city

An analysis of the completed building stock database has been performed in order to study the distribution of the building stock within the city. The following paragraphs aim to provide an urban and energy status quo of the existing situation in Gleisdorf in terms of space heating energy demand, type of building use and construction period. The results are shown per GFA instead of per individual buildings. It is considered that the first is a more representative variable since a city not only includes building units on the ground but also is extended by building upwards vertically.

Figure 10 shows the distribution of built GFA in Gleisdorf by year of construction, by type of heating system or fuel as well as by building use. It can be observed in Figure 10.a that three quarters of the existing building stock were constructed in the last 50 years. In this period, the graph shows how half of the city was built during two prominent time spans. The first one started in 1960 and during its 20 years of duration, one quarter of the current city extension was constructed. Similarly, the second noted period started in the year 2000, where the city experienced a boom in the construction sector, leading to an increase of the total gross area of 30% within 15 years.

Regarding the heating system and fuel source, the city is controlled by a major trend; half of the total GFA is supplied by an extensive natural gas (N-Gas) network. The second largest group corresponds to the district heating network, which started its operation in 2012 and has increased its costumers ever since. An already detected critical point of the city, and challenge for the future energy system transformation is the high dependency on fossil fuels to cover the heating demand. 16% of the GFA of the city is served with oil boilers while efficient heating technologies such as heat pumps only represent 2%. Consequently, it can be deducted that one of the trends on the future transformation pathways will be focused in addressing this situation, hence, phase out fossil fuels from the system in favour of a higher penetration of renewable sources combined with thermal storage facilities as well as efficient solutions such as heat pumps.

Finally, Figure 10.c shows the residential character of the city, which accounts for 57% of the total GFA. If combined with the mixed sector, which also partially allocates living units, the domestic sector could easily reach three quarters of the territory. How the city is going to grow until 2050 is currently unknown.

Figure 10. a) GFA distribution as a function of construction period. b) GFA distribution according to heating system and fuel source. c) GFA distribution according to building use
While the previous diagrams helped to understand the urban status quo of the city, the next figures aim to provide an overview of the existing situation regarding the heating energy demand. In this case only the needs for space heating are considered. The succeeding three graphs combine the already studied distribution of GFA with the weighted average HWB for each of the building characteristics studied.

Figure 11 shows the average space heat requirements for buildings in each of the construction periods considered. It can be inferred how the evolution of the construction sector, based on a combination of stricter building and construction standards with the usage of better materials and improved insulation solutions lead to a reduction of space heating needs over the years. As a major trend, the older the building, the less efficient is its envelope and the more heating needs are required. It should be noticed that while the reduction in HWB from 1900 to 1999 is almost constant, it is between the last decade of the 1900’s and the start of the 21st century where a major reduction leap in HWB is observed.

Given the statistical results of the city, it is easily deduced that on average all buildings built before 2000 have a higher HWB than the mean value and hence will be probably focus of renovation measures. Moreover, another possible renovation trend would be to select buildings for refurbishment if its associated HWB exceeds a given threshold, could be the average HWB of the city or even adopt stricter thresholds and target a higher proportion of the building stock. These ideas are only result of the pre-analysis of the existing building stock and therefore will be fully revised in Chapter 5.

Finally, given the holistic extent of the work and multidisciplinary discipline of the project, the expected renovation strategy could be further studied from an urban planner perspective to discuss and validate the draft results. After an assessment of the location, neighbouring, aging and construction characteristics of the units, the urban planner would determine in which buildings an actual renovation process could be possible.

![Figure 11. Weighted HWB average of each construction period category vs. GFA built in the city](image)

Figure 12 shows the total space heat demand of each building age group. The contribution of each construction period building group to the total space heat demand can be observed. On this basis, the cluster of buildings constructed between 1980 and 1979 is the one accounting for the highest share of total space heat demand. This is because in this period a huge expansion of the construction sector coincided with poor energy performance.
standards of the building envelope. In contrast, it should be noted that the second largest construction period starting in 2000, although with a similar GFA extension, incurs a much lower quantity of space heat demand. This fact points out the introduction of new restrictive performance standards such as the construction of nearly zero energy buildings.

![Figure 12. Space heating demand per building age](image)

Figure 13 shows the average space heating requirements according to the heating system and fuel source each building. An observation of the graph could be the urgent need to replace fossil fuel boilers (coal, gas and oil) and conventional electric heating systems from the system. Moreover, buildings with electric heating as well as biomass boilers should also update their units with more trendy efficient solutions with a promising future in the heating system market. It should be noticed that HWB values do not take into account the efficiencies of the heating system. A comparison of Figure 11 and Figure 13 points out that the oldest buildings in the city are the ones who use the least advanced heating systems.

![Figure 13. Weighted HWB average of each heating system and fuel source category vs. GFA built in the city](image)
Figure 14 shows the HWB of every building with information in the database sorted by building use. This graph gives an idea of the number of buildings from a given category that are actually above the average HWB of the entire city. Comparing Figure 11 and Figure 14 it can be deduced that the half of the residential units that are above the HWB demand were probably built before 1990.

This pre-analysis of the existing building stock has enabled to detect potential transformation opportunities for the future, which in turn will be fully studied and exploited in further chapters. A summary of the findings in this phase is presented below.

- The natural gas network supplies fuel for heating to 51% of the GFA of the city.
- Gleisdorf’s residential sector covers 57% of the total city and points out the high potential energy savings due to the possible renovation strategies in the upcoming years.
- 40% of the building stock was constructed during the last three decades. The remaining 60% is focus of renovation to comply with energy performance standards.
- The results of the pre-study point out the high potential energy savings in buildings from the residential sector built before 1990.
- Buildings built between 1960 and 1979 will account for the highest energy savings when renovation measures are applied.
- Heating system infrastructures powered by fossil fuels (oil, coal and in an increasing rate gas) and electric heating systems should be eliminated from the heating mix while biomass boilers as well as heat pumps should be replaced by new and up-to-date units to reduce inherent losses.
4. FUTURE HEATING DEMAND PREDICTION

The present chapter is related to RQ2 and focuses on applying a methodology to estimate a future heat demand of the year 2050. The overall final heat demand for Gleisdorf is expected to follow a reduction trend over the years. Considering the three terms constituting the HEB in formula 1, the HTEB as well as HWB terms are expected to decrease whereas the heating demand for domestic hot water is assumed to remain constant in the future.

Here, the reduction of heating demand over the investigated period will be mainly marked by the continuous renovation rate of the building stock expected as a key measure in the sustainable agenda of the city. To a lesser extent, updating the heating supply system and keeping it up to date with best market available technologies will also increase the efficiency of the system and foster a decrease in the production and distribution losses.

In the view of foregoing, the present chapter focuses on estimating the potential heat demand savings in the terms of HWB due to thermal renovation and in HTEB due to an update or replacement of the heat supply infrastructure, in the case where proper energy transformation measures are put in place by 2050. Lastly, with the heat demand savings of each term in the building level, the future heat demand for all the units and the aggregated for the whole city can be calculated.

4.1 Reduction of HTEB

HTEB is understood as the extra heat demand needed to cover the heat losses incurred during the production and distribution process. These are dependent on the heating system and distribution network, and according to reference figures, they range between 10 to 50% of the heat demand for consumption, hence HWB and WWWB. Provided that these values are not available from measured data, the following is assumed for the status quo as well as for future scenarios.

Table 3. HTEB values considered for the status quo and future scenarios

<table>
<thead>
<tr>
<th>Losses HTEB [% of HWB + WWWB]</th>
<th>Status Quo</th>
<th>BAU</th>
<th>Low</th>
<th>Ambitious</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status Quo</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAU</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambitious</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 shows how the future scenarios make an increasing effort in updating the buildings’ heating systems to decrease losses between production and distribution. It is also assumed that during the length of the investigated period, the existing heating system will be undoubtedly changed when it reaches the end of its lifetime, which on average is 20 to 25 years. In this way, it is considered that the HTEB will be reduced for all buildings regardless of a refurbishment process.
4.2 Reduction of HWB

In order to calculate the heat demand savings for space heating due to thermal renovation of the building envelope, the building stock of Gleisdorf must be fully characterized with construction and thermal parameters. Since the latest are not available, TABULA [23] is used to fill in the information gap. Using the latest source as reference, it limits the ensuing methodology to the residential and mixed sector. Thus, without any further assumptions, the heating demand for communal buildings, stores and industries it is assumed that remains unchanged. For the residential units in the database, the future demand will be computed as:

\[ HWB_{future} = HWB_{2015} \cdot \left(1 - \frac{HWB_{\%\text{reduction}}}{100}\right) \]  (3)

While HWB_{2015} values are taken from the Completed GIS DB (see Figure 4), the HWB_{\%\text{reduction}} values are calculated in this chapter. As formula 5 points out, the present methodology relies on calculating the energy savings that a building would experience as a result of a renovation process. To avoid calculating these savings for each building unit, which would depend on their particular U-thermal values and envelope areas, the HWB_{\%\text{reduction}} term will be assumed the same for all buildings built in a given construction period, without distinction on the residential building size i.e. single-family house, multi-family house, apartment block or terraced house.

Given that, the methodology is reduced to calculate the space heat demand savings after a renovation process for only 7 different categories. The results are given per percentage of HWB reduction in respect of the actual values, and are calculated as the average HWB energy savings between the 4 building typologies of a given period. The HWB reduction is calculated as:

\[ \%\ HWB_{\text{reduction}} = \frac{HWB_{2015} - HWB_{2050}}{HWB_{2015}} \]  (4)

There are two main differences between the calculation of HWB_{2015} and HWB_{2050}. The first one concerns the renovation state of the building in 2015 and in 2050. According to it, different materials and insulation solutions are applied to the envelope; thus different values of U-coefficients will be used in the calculation of the heat transfer by transmission for the years 2015 and 2050. The refurbishment measures considered in the calculation are assumed from the TABULA database. They are defined on two levels: an Usual or standard refurbishment according to the guideline nº 6 of the Austrian Institute of Civil Engineering (OIB in German) [28], or an Advanced stage defined according to the requirements of the national climate protection programme klima:aktiv. The most important features of the renovation measures' requirements are presented as follows. For a detailed version of the official regulation, please refer to [28].

Renovation requirements of the national standard

The minimum U-values [W/(m²K)] of the thermal envelope required when a building undergoes a refurbishment process are:

- Ceiling or roof = 0,20
- External walls = 0,35
- Windows = 1,40
Floor or cellar ceiling = 0.40

Moreover, if the building undergoes major renovation, additionally to the minimum U-values above mentioned, the HWB must be limited to the following expression:

\[
HWB_{GFA,\text{ref}} = \max \left( 25 \cdot \left( 1 + \frac{2.5}{l_c} \right) ; 87.5 \frac{kWh}{m^2\cdot a} \right)
\]  

(5)

being \( l_c \) the geometrical quality of the building computed as the fraction between the conditioned volume and the conditioned GFA of the unit. Similarly, OIB 6 also specifies the minimum energy performance requirements for the new construction buildings which are given per maximum HWB acceptable.

\[
HWB_{GFA,\text{new}} = \max \left( 16 \cdot \left( 1 + \frac{3}{l_c} \right) ; 54.4 \frac{kWh}{m^2\cdot a} \right)
\]

(6)

**Renovation requirements of the national programme klima:aktiv**

Although the requirements from the climate protection programme go beyond limitations on the thermal envelope of the building and detail issues of the planning process itself, the application of the advanced refurbishment measures for the present calculations is based only on the assumptions of the U-values specified in the TABULA project, which in turn are stricter than in the standard measures. For further information on the programme requirements, the reader may be addressed to [23].

The second difference between the two HWB terms concerns the climate variations expected 34 years from now. The methodology takes into account this fact by correcting the \( HWB_{2050} \) value with a temperature correction factor based on the heating degree day method which is calculated as follows.

\[
T_{\text{correction}} = \frac{\text{HDD}_{2050}}{\text{HDD}_{2015}}
\]  

(7)

This methodology is already used in [27]. Multiplying the actual heating energy consumption for the reference year by the correction factor, it then gives a measure of what the energy consumption would be in the future year of 2050. The heating degree day value for 2015 is calculated with the formula provided by Eurostat [22]:

\[
\text{HDD} = \sum_{d=1}^{365} (T_{\text{int}} - T_{\text{mean}}) \cdot x_d
\]  

(8)

Being \( T_{\text{int}} \) the internal comfort temperature equal to 20°C, \( T_{\text{mean}} \) the mean daily outside temperature, calculated as the average from the 24 hourly values provided by ZAMG for the year 2015 and \( x_d \) a binary variable which takes 1 when \( T_{\text{mean}} \) is below a \( T_{\text{threshold}} \) equal to 12°C under which the functioning of the building heating system is required. It should be noticed that both \( T_{\text{int}} \) and \( T_{\text{threshold}} \) depend on the climate location. In this case, the values assumed are taken from the TABULA calculator spreadsheet tool [34] for a national Austrian climate.
In turn, for the calculation of HDD\textsubscript{2050}, the statistics published by the European Environment Agency are used [22]. They calculated the evolution trend of HDD in the EU-27 since 1980. The present thesis assumes the same heating degree day evolution for the next 34 years, therefore a reduction on average of 16 HDD per year. Given that HDD\textsubscript{2015} results in 3,093.65 degree days, the HDD\textsubscript{2050} is estimated in 2,533.5 heating degree day.

Finally, it should be noticed that HWB\textsubscript{%reduction} values will respond to one of the four possible different combinations between actual state of renovation, estimated in Section 3.3.2, and future renovation strategy implemented by 2050. These are:

1. A building which is currently not renovated does not undergo a refurbishment process by 2050.
2. A building which is currently not renovated undergoes a refurbishment process by 2050 using Usual measures.
3. A building which is currently not renovated undergoes a refurbishment process by 2050 using Advanced measures.
4. A building which is currently renovated according to Usual measures, updates its building thermal envelope by 2050 using Advanced solutions.

The calculation of the space heating needs HWB\textsubscript{2015} and HWB\textsubscript{2050} of formula 6 is performed for each building category according to the EN ISO 13790 standard and using an hourly method. This means that the heating needs are calculated for each hour and depending on the hourly outside temperature and global horizontal irradiation variation typical of Gleisdorf for the year 2015 and adapted to 2050.

The EN ISO 13790 stipulates that the energy need for space heating is the difference between the thermal losses through the edifice envelope (Q\textsubscript{ht}) and the recovered usable building gains (Q\textsubscript{gains}). The following equations are taken from [34].

\[
HWB = Q_{ht} - \eta_{h,gn} Q_{gains} \quad (9)
\]

The building gains are the sum of the internal gains due to the presence of internal heat sources (Q\textsubscript{int}) and the solar gains due to exposition to solar radiation (Q\textsubscript{sol}). Likewise, the heat transfer losses are the sum of the heat transfer by transmission (Q\textsubscript{tr}) and by ventilation (Q\textsubscript{ve}).

\[
Q_{gains} = Q_{int} + Q_{sol} \quad (10)
\]
\[
Q_{ht} = Q_{tr} + Q_{ve} \quad (11)
\]

Breaking down the expressions above, the individual terms are defined with the following expressions. Solar gains are dependent on the solar radiation as well as the exposed area of windows and its orientation. In turn, internal gains are assumed constant and equal to 3 W/m\textsuperscript{2}.

\[
Q_{sol,h} = (1 - F_p) \cdot F_{sh} \cdot F_W \cdot g_{gl,n} \cdot A_{windows} \cdot I_{sol,h} \quad (12)
\]
\[
Q_{int} = \varphi_{int} \cdot A_{c,ref} \quad (13)
\]
Transmission losses appear through each surface of the building envelope which is not properly insulated; walls, floor, ceiling or rooftop and windows. Each of the surfaces has an associated U-transfer coefficient and a given transmission area taken from the TABULA database [23] for every building category. Considering this, the heat transfer coefficient by transmission is expressed as:

$$H_{tr} = \sum_i U_i \cdot A_{env,i} + \Delta U_{tb} \sum_i A_{env,i}$$  \hspace{1cm} (14)

Consequently, the heat transfer coefficient by ventilation is defined as:

$$H_{ve} = C_{p,air} \cdot (n_{use} + n_{infiltr}) \cdot A_{c,ref} \cdot h_{room}$$  \hspace{1cm} (15)

Combining both terms, the total heat transfer losses are computed as:

$$Q_{ht} = (H_{tr} + H_{ve}) \cdot (T_{int} - T_{hext}) \cdot x_h \cdot F_{red} \cdot T_{red}$$  \hspace{1cm} (16)

Table 4 contains the values and explanation of all the variables and parameters referred throughout the expressions.

**Table 4. Variables and parameters used in the calculation of space heating needs of a building**

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>DESCRIPTION</th>
<th>UNITS</th>
<th>REF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_{h,gn}$</td>
<td>Heat gain utilisation factor [-]</td>
<td>0.94</td>
<td>[35]</td>
</tr>
<tr>
<td>$F_{sh}$</td>
<td>External shading reduction factor [-]</td>
<td>0.6</td>
<td>[35]</td>
</tr>
<tr>
<td>$F_f$</td>
<td>Frame area fraction reduction factor [-]</td>
<td>0.3</td>
<td>[35]</td>
</tr>
<tr>
<td>$F_w$</td>
<td>Non-perpendicular reduction factor [-]</td>
<td>0.9</td>
<td>[35]</td>
</tr>
<tr>
<td>$G_{gl,n}$</td>
<td>Solar energy transmittance</td>
<td>0.65</td>
<td>[35]</td>
</tr>
<tr>
<td>$\Phi_{int}$</td>
<td>Internal heat sources [W/ m$^2$]</td>
<td>3</td>
<td>[35]</td>
</tr>
<tr>
<td>$C_{p,air}$</td>
<td>Heat capacity air [Wh/m$^3$ K]</td>
<td>0.34</td>
<td>[35]</td>
</tr>
<tr>
<td>$n_{use}$</td>
<td>Air change rate by use</td>
<td>0.4</td>
<td>[35]</td>
</tr>
<tr>
<td>$n_{infiltr}$</td>
<td>Air change rate by infiltration</td>
<td>0.2</td>
<td>[35]</td>
</tr>
<tr>
<td>$h_{room}$</td>
<td>Average height of a room [m]</td>
<td>2.5</td>
<td>[35]</td>
</tr>
<tr>
<td>$\Delta U_{tb}$</td>
<td>Thermal bridging surcharge on the U-values (low/medium)</td>
<td>0/0.1</td>
<td>[35]</td>
</tr>
<tr>
<td>$T_{int}$</td>
<td>Internal comfort temperature [°C]</td>
<td>20</td>
<td>[34]</td>
</tr>
<tr>
<td>$x_h$</td>
<td>Binary variable from HDD method [-] (if $T_{ext,h} &lt; T_{threshold}$)</td>
<td>1</td>
<td>[35]</td>
</tr>
<tr>
<td>$T_{threshold}$</td>
<td>Temperature above which heat requirements are needed [°C]</td>
<td>12</td>
<td>[34]</td>
</tr>
<tr>
<td>$F_{red}$</td>
<td>Temperature reduction factor [-]</td>
<td>0.9</td>
<td>[35]</td>
</tr>
</tbody>
</table>

**DEPENDENT VARIABLES**

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>DESCRIPTION</th>
<th>UNITS</th>
<th>REF.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{windows}$</td>
<td>Area of the windows [m$^2$]</td>
<td>-</td>
<td>[23]</td>
</tr>
<tr>
<td>$A_{c,ref}$</td>
<td>Reference conditioned area [m$^2$]</td>
<td>-</td>
<td>[23]</td>
</tr>
<tr>
<td>$U_i$</td>
<td>Heat transfer coefficient of the $i$ element of the envelope [W/m$^2$ K]</td>
<td>-</td>
<td>[23]</td>
</tr>
<tr>
<td>$i$</td>
<td>Index indicating the building element: wall, floor, ceiling, window</td>
<td>-</td>
<td>[23]</td>
</tr>
</tbody>
</table>
The formulas just presented are used to calculate the hourly space heat requirements for each of the 32 typologies specified by TABULA under three different situations: at the present year with current U-values and in the 2050 year if the building undergoes usual or advanced renovation. For the next steps, the thesis works with the yearly aggregated values of HWB for each building category and with the different temperatures consideration.

Figure 15 shows the development of the HWB from the reference year to 2050 if renovation measures are put in place. The computation is done first with the weather profiles adapted to 2050, but also the same is repeated without taking into account the effect of climate change over the years, therefore without a temperature variation between 2015 and 2050 levels.

The previous graph shows the evolution trend of HWB over the years. As expected, stricter renovation measures with better insulation result in less space heating requirements. This is observed in all the constructions periods, regardless of residential type and no matter the temperatures used for the calculation, where Advanced refurbishment HWB values not only are highly reduced compared to actual levels but also are lower than its associated HWB value under Usual renovation.
Another observation is the dependency of the results on climate change consequences. The impact of taking into account the temperature variations in the calculation could be considered as moderate. On average, results considering 2050 temperatures under *Usual* and *Advanced* renovation are 23.4% and 23.9% lower compared to working with reference temperatures, respectively.

Although the results of Figure 15 are quite visual and easy to understand, for the calculation of the future heat demand, percentage reduction values of HWB with respect of 2015 values have been used. Taking the average values per period of construction (not considering the residential type), Table 5 shows the typical percentage of HWB reductions if buildings are renovated from its initial state with *Usual* or *Advanced* measures. Likewise, Table 5 also shows the same in case of a building already renovated with *Usual* measures is updated to an *Advanced* state. The table also differentiates whether 2050 temperatures have been used for the calculation.

<table>
<thead>
<tr>
<th>Period</th>
<th>Not renovated to Usual</th>
<th>Advanced</th>
<th>Usual to Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reference T 2050 T</td>
<td>Reference T 2050 T</td>
<td>Reference T 2050 T</td>
</tr>
<tr>
<td>&lt;1918</td>
<td>68,10 75,54</td>
<td>72,92 79,42</td>
<td>15,48 16,23</td>
</tr>
<tr>
<td>1919-44</td>
<td>66,51 74,38</td>
<td>72,08 78,87</td>
<td>16,42 17,28</td>
</tr>
<tr>
<td>1945-59</td>
<td>61,37 70,26</td>
<td>70,20 77,40</td>
<td>22,00 23,02</td>
</tr>
<tr>
<td>1960-79</td>
<td>65,27 73,30</td>
<td>69,97 77,07</td>
<td>13,30 13,90</td>
</tr>
<tr>
<td>1980-89</td>
<td>43,11 56,18</td>
<td>53,47 64,50</td>
<td>19,87 20,62</td>
</tr>
<tr>
<td>1990-99</td>
<td>30,76 46,60</td>
<td>44,92 57,98</td>
<td>20,32 21,14</td>
</tr>
<tr>
<td>2000-20</td>
<td>19,24 38,46</td>
<td>19,24 38,46</td>
<td>- -</td>
</tr>
</tbody>
</table>

Finally, using the results of Table 5 and for each of the buildings in the residential or mixed sector present in the building stock database, the future demand for the refurbished area will be computed with formula 3. The $\text{HWB}_{\text{Reduction}}$ chosen for each building will depend on the scenario specifications; whether the object is selected for thermal renovation, and in that case which strategy is implemented. If the edifice does not comply with the selection requirements for refurbishment, the $\text{HWB}_{\text{Reduction}}$ would be zero.

This chapter has added an extra value to the Completed GIS DB. At this moment, the database has information on the HWB values of each building if in a future scenario this is renovated according to *Usual* or *Advanced* measures. It will be in the next chapter where the scenarios will determine if a building is finally refurbished or not and which measures will be applied. As a result, the HWB of the unit in 2050 will take one of the following three values.

- The initial HWB value if the building is not renovated throughout the investigated period, but corrected according to the expected temperature in 2050
- The $\text{HWB}_{\text{Usual}}$ calculated in this chapter if the building is renovated using Usual measures
- The $\text{HWB}_{\text{Advanced}}$ calculated in this chapter if the building is renovated using Advanced measures
According to this, all buildings in the commercial, industrial and communal sector will take the first choice since, according to the presented methodology, it has been assumed that they will not be renovated.
5. FUTURE ENERGY SCENARIOS FOR GLEISDORF

The research question approached in the present chapter (see RQ3) investigates potential directions of development of the heating sector of the city. Both demand and supply sides of the sector should be involved in the transformation process. While the end-consumer side must apply strategies related to energy conservation, the heat production and distribution sector should be rather focused in energy transition measures. In order to assess possible future lines of change, assumptions are necessary to create interesting scenarios in line with a sustainable development of the energy system. Three different scenarios are defined:

- **Business as Usual (BAU):** considers a baseline scenario that examines the consequences of continuing with current trends in the development of a future energy system.
- **Low:** considers a scenario where the system undergoes a conservative and slow transformation of the thermal energy sector.
- **Ambitious:** considers a scenario with aggressive renovation measures in all the levels of the thermal energy sector.

Throughout the chapter it is considered that the **Ambitious** scenario puts more effort than **Low** or **BAU** into the transformation process; therefore, the changes are implemented with a quicker response time, with a higher necessary budget for investments and under more severe measures. Finally, the thesis also aims to study the feasibility of a future energy system provided with 100% renewable sources or with CO₂ neutral emissions.

The scenarios aim to represent the heating sector of Gleisdorf in 2050. With this purpose, decisions must be taken in order to define four different blocks of uncertainties that will highly influence the transformation process. These are represented in Figure 16; the scheme not only specifies the steps comprising the methodology and its required order of implementation, but also the methods and tools used in each task. The first block is related to the future renovation strategies to be adopted and that will mark the new heating needs of the city. The second analyses the DH extension opportunities within the city. The third studies the development of the heating production units of buildings with a central heating system while the last block concerns the solar thermal penetration in the individual building level.

The definition of the scenarios will lead to the following chapter where these will be simulated with the modelling software energyPRO. Once the simulation is completed and results are obtained, the scenarios will then be judged according to its sustainability extent. Sustainability will be positive assessed when the scenario a) reduces the energy dependence of the city from external resources and imports, b) increases the efficiency of the whole energy system, introduces community owned energy systems, c) increases the proportion of renewable sources as well as d) has reduced CO₂ emissions related to the operation of the system. The sections below specify the methodology developed for the creation of the scenarios.
5.1 Renovation roadmap: New heating energy demand for the city

The new heating energy demand of the city is calculated as the aggregation of the individual future heating demands of every building in the city. This section only considers the calculation of the new HWB demand for the city, which will be influenced by the refurbishment process of the existing building stock. It is important to recall, however, that HWB values will only change for the buildings in the mixed and residential sector which will undergo renovation, whereas the demand from the industry, commerce and communal sectors will remain invariable. The different assumptions regarding the building renovation scheme for each of the scenarios are marked by two points.

1. **Selection of buildings focus of renovation:** The buildings whose HWB is above a certain threshold value are considered to be focus of renovation in the scenarios. The threshold HWB value is taken from own assumptions to be equal to 50 kWh/(m²·a).

2. **Selection of renovation measures:** The second task of the scenarios consists on adjudicating a renovation scheme among the *Usual or Advanced* measures defined in Section B. 1. This settlement has been differentiated according to the period of construction as well as the current state of renovation of the unit.

The different renovation states of a building in 2015 or 2050 are defined as follows:

- **Not renovated:** the building has not been refurbished by 2050 when referring to scenarios or by 2015 when referring to the actual state.
- *Usual*: the building has already been refurbished under *Usual* measures when referring to the actual state, or it will be refurbished under *Usual* measures by 2050 when referring to scenarios.

- *Advanced*: the building has already been refurbished using *Advanced* measures when referring to the actual state, or it will be refurbished under *Advanced* measures by 2050 when referring to scenarios.

On this basis, Table 6 resumes the renovation roadmap chosen for each scenario in terms of type of refurbishment measures (according to construction period and actual state of renovation), yearly renovation rate and total number of buildings to refurbish by 2050.

Table 6. Assumptions on the future renovation state of the building stock in order to define the new heat demand for the *Low* and *Ambitious* scenarios. Results on the number of buildings needed to accomplish renovation by 2050 and the expected yearly renovation rate

<table>
<thead>
<tr>
<th>Residential sector</th>
<th>Period</th>
<th>BAU</th>
<th>Low</th>
<th>Ambitious</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;1918</td>
<td>Usual</td>
<td>Usual</td>
<td>Advanced</td>
</tr>
<tr>
<td></td>
<td>1919-1944</td>
<td>Usual</td>
<td>Usual</td>
<td>Advanced</td>
</tr>
<tr>
<td></td>
<td>1945-1959</td>
<td>Usual</td>
<td>Usual</td>
<td>Advanced</td>
</tr>
<tr>
<td></td>
<td>1960-1979</td>
<td>Usual</td>
<td>Usual</td>
<td>Advanced</td>
</tr>
<tr>
<td></td>
<td>1980-1989</td>
<td>Not renovated</td>
<td>Usual</td>
<td>Advanced</td>
</tr>
<tr>
<td></td>
<td>1990-1999</td>
<td>Not renovated</td>
<td>Usual</td>
<td>Advanced</td>
</tr>
<tr>
<td></td>
<td>2000-2020</td>
<td>Not renovated</td>
<td>Usual</td>
<td>Advanced</td>
</tr>
<tr>
<td>Actual</td>
<td>&lt;1918</td>
<td>Usual</td>
<td>Usual</td>
<td>Advanced</td>
</tr>
<tr>
<td></td>
<td>1919-1944</td>
<td>Usual</td>
<td>Usual</td>
<td>Advanced</td>
</tr>
<tr>
<td></td>
<td>1945-1959</td>
<td>Usual</td>
<td>Usual</td>
<td>Advanced</td>
</tr>
<tr>
<td></td>
<td>1960-1979</td>
<td>Usual</td>
<td>Usual</td>
<td>Advanced</td>
</tr>
<tr>
<td></td>
<td>1980-1989</td>
<td>Usual</td>
<td>Usual</td>
<td>Advanced</td>
</tr>
<tr>
<td></td>
<td>1990-1999</td>
<td>Usual</td>
<td>Usual</td>
<td>Advanced</td>
</tr>
<tr>
<td></td>
<td>2000-2020</td>
<td>Usual</td>
<td>Usual</td>
<td>Advanced</td>
</tr>
<tr>
<td>Advanced</td>
<td></td>
<td>Advanced</td>
<td>Advanced</td>
<td>Advanced</td>
</tr>
<tr>
<td>Number of buildings</td>
<td>761</td>
<td>1037</td>
<td>1358</td>
<td></td>
</tr>
<tr>
<td>RENOVATION RATE [%]</td>
<td>1,21</td>
<td>1,65</td>
<td>2,16</td>
<td></td>
</tr>
<tr>
<td>Typical reference in Austria</td>
<td>1-1,5</td>
<td>~1,5</td>
<td>2-2,5</td>
<td></td>
</tr>
</tbody>
</table>

* The building has not changed its initial renovation state by 2050.

As can be seen in Table 6, BAU and *Low* scenarios only consider *Usual* renovation measures while, on the other hand the *Ambitious* scenario will only apply *Advanced* measures, therefore more effort should be made to transform it to the best version of modern standards.

Another point worth to mention concerns the increasing yearly renovation rate set up according to the transformation process severity of the scenarios. Taking a linear renovation rate over the years and prioritizing older buildings, the renovation rates per year and starting in 2017 in the residential and mixed sector range from 1,21 to 2,16%. It should be noticed that the obtained renovation rates were set according to typical figures in Austria, so the scenarios considered could be considered as much realistic as possible.
Figure 17 aims to present the renovation roadmap implemented through the scenarios. On one hand, it shows the distribution of space heat demand according to if the building is renovated in 2050 (Usual or Advanced) or not. On the other hand, it presents the number of buildings that belong to each group. It should be noticed that only residential and mixed sectors have been differentiated since are the only ones where the roadmap is applicable. From Figure 17 the following points are observed:

- Space heat demand distribution in the residential and mixed sector is switched between renovated and not renovated building groups throughout the investigated period. In the reference year of 2015, most of the space heat demand (81%-100%) in those sectors belongs to not renovated buildings, in the future scenarios of 2050, the majority of the HWB demand (90%-91%) comes from the renovated buildings.
- On the overall picture, the roles are still not changed at the end of 2050. Not renovated buildings still represent the highest share of the total HWB demand (62%-52%). This is due to the assumption that all the other sectors i.e. communal, commercial and industry, will not experience a thermal renovation process by 2050.

It should be noticed that buildings in the residential or mixed sectors included in the not renovated groups are units which have not fulfilled the selection requirements of the renovation scheme presented in page 32. In this way, for example in the Ambitious scenario, the 101 and 14 buildings not renovated from the residential and mixed sectors, respectively, are units with a HWB value below 50 kWh/(m²·a). Map 26, 27 and 28 show the distribution of the building stock within the city according to its renovation state for the BAU, Low and Ambitious scenario, while Map 11 does it for the status quo.

![Figure 17. Distribution of space heat demand per building sector and according to the renovation state in the status quo and for each scenario. Values in parenthesis represent number of buildings in each group.](image-url)
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Figure 17 does not show the reduction in space heat demand due to the renovation measures of *Usual* or *Advanced*, however, this is further discussed in the following paragraphs and represented in Figure 18.

Given Table 6, the new value of HWB for each building is calculated with formula 3 in using the HWB\_\%reduction values of Table 5. Finally, the total heat demand in the scenarios will be composed by the three terms specified in formula 1: HWB has been already discussed, WWWB is considered constant over the years as introduced in the Section 2.2.4 and HTEB values are assumed in Table 3. The aggregation of the three terms for each building leads to the final city’s heat demand values of Figure 18. The reduction of CO\(_2\) emissions from the whole energy transformation process will be discussed later on in Chapter 7.

Given Table 6, the new value of HWB for each building is calculated with formula 3 in using the HWB\_\%reduction values of Table 5. Finally, the total heat demand in the scenarios will be composed by the three terms specified in formula 1: HWB has been already discussed, WWWB is considered constant over the years as introduced in the Section 2.2.4 and HTEB values are assumed in Table 3. The aggregation of the three terms for each building leads to the final city’s heat demand values of Figure 18. The reduction of CO\(_2\) emissions from the whole energy transformation process will be discussed later on in Chapter 7.

![Figure 18. Final heat demand HEB calculated for each scenario](image)

Values represented in Figure 18 are calculated using the HWB values that consider the temperature variation between 2015 and 2050 levels. Figure 18 shows the effectiveness of the energy conservation strategies in the building level represented in the scenarios. Regarding the reduction on final heat demand over the investigated period, on average, these results are obtained:

- 53% of the total reduction is due to renovation of the building stock
- 25% of the total reduction is due to the consideration of increased temperatures over the years
- 22% of the total reduction is due to the reduction in losses

In turn, the increasing reduction according to the severity of the scenarios is due to the growing yearly renovation rate considered, the implementation of *Advanced* refurbishment measures in the *Ambitious* scenario as well as the assumption in the development of the HTEB term from 20% to 10% of the final heat demand for consumption. It can be seen from the graph that the initial final heat demand is reduced by 31.81%, 39.28% and 44.18% in the BAU, Low and Ambitious scenarios, respectively.

Figure 19 shows the reduction of the HWB values mainly due to the applied renovation roadmap to the residential and mixed sector building stock. The effectiveness of the measure can be seen for example in the residential sector, where the average value of HWB has been reduced between 51.64% to 59.50% of the initial HWB value according to the scenario characteristics. *Map 35, 36, 37 and 38* in the Appendix D represent the new HWB values after renovation in the BAU, Low and Ambitious scenarios, respectively.
Figure 19. Development of HWB values over the scenarios for the residential and mixed sectors

Hereinafter, the thesis uses the final heat demand values of Figure 18 as the basis for the calculation of the next section, where the DH extension opportunities will be studied.

5.2 District heating extension potential

Currently buildings can either take profit of community based networks and receive heat from DH network or receive gas from the N-Gas network, or on the other hand, produce their own heat with an individual boiler and a central heating system particular of the building. However, in 2050, the heat requirements within the city will be supplied in a different way than nowadays.

Two major trends are expected to mark the future heating supply infrastructure of the city. While the DH network will expand and connect new costumers, the N-Gas pipeline network is assumed to be present in 2050 but perhaps with a fuel replacement by biogas. Leaving aside this topic to the discussion chapter, this section focuses on the future DH sector of 2050. Its development over the next years will be marked by two tendencies.

1. An expected rise in costumers’ connections will force the network to be expanded to areas with not only a sufficient heat density demand potential but also complying with technical constraints such as availability of heat producing resources or proper distances from the existing network.
2. An expected increase of the solar thermal fraction in the DH network.

This section aims to propose three possible extension plans, corresponding to BAU, Low and Ambitious scenarios. Moreover, the section also discusses the future fuel used in the network’s heating plants and its contribution in the total heat produced.

5.2.1 District heating network extension plans

The section starts with a presentation of the status quo of the current DH network. Then, it focuses on developing future extension plans by determining which buildings could be part of the DH network by 2050. These in turn either will abandon their connection to the N-Gas network, or will replace its central heating boiler by a community supplied heat.
The current DH network started its operation in 2012 and due to continuous expansion projects over the years, at present it consists of one main line and an isolated independent line constructed outside the city centre. The development of the network has led to an actual line distribution as shown in Figure 20. The figure shows both the main network extension, called Bestand, as well as the isolated line, referred to as North. It should be noticed that in the GIS DB some buildings are also defined as district heating even though they are not connected to either of the networks of Figure 20. The reason is that these units are supplied by small and decentralized micro-grids which also use biomass and solar thermal to produce heat. Throughout the ensuing figures of this chapter, the buildings labelled as district heating in the GIS DB will be clustered in two categories:

1. Main DH network (DHN), or Bestand.
2. Isolated network, or North, plus the decentralized micro-grids (MG) spread around the city.

Figure 20 also shows the DH extension plan that has already been approved by the municipality. This includes the connection of additional buildings as well as a line extension process. This information was part of the data collection process (see Section 2.2). Then, regardless of the results from the DH extension opportunities analysis for the Low and Ambitious scenario, these set of buildings will be always considered to be connected in the future DH sector. Having understood the actual situation of the DH sector, the next paragraphs aim to propose DH extension plans for the BAU, Low and Ambitious scenarios.

Regarding the BAU transformation process, the scenario only considers for the new connections the future DH extension plan already approved by the municipality. Figure 21 shows in blue the existing network and its connected buildings and in red the already planned new additions as well as the new line construction.
Regarding the DH extension opportunities for the Low and Ambitious scenarios, the following methodology has been applied.

1. Calculate the heat density distribution within the city for the investigated year 2050.
2. Select the regions with a techno-economic potential for a DH expansion project.
3. Identify the buildings in DH extension potential areas and cluster them in priority regions.

The input data in each case corresponds to the final heat demand of each building calculated previously in Section 5.1 of the present chapter. A detailed explanation of this three-step methodology is presented below; however, the same can be applied for the Ambitious situation.

The first step consists on analysing the heat density distribution within the city corresponding to the year 2050. Using the geo processing tools of the software QGIS, the heat density values are calculated as the aggregated final heat demand of a cluster of buildings located in a square area of 50 per 50 meters. It should be noticed that the 120 buildings in red from Figure 9 were omitted from the calculation since a HWB value was lacking in their database and therefore its final heat demand could not be obtained. Figure 22 shows the reproduced heat maps representing how the heat density distribution is predicted to change from 2015 (status quo) to 2050 for each of the scenarios. For a better understanding of the development of the heat density values, the legend uses the same scale for all the maps.
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a) Status Quo (Map 12)

b) BAU Scenario (Map 13)

c) Low Scenario (Map 14)

d) Ambitious Scenario (Map 15)

Figure 22. Heat density distribution within the city
As a result of the applied increasing yearly renovation rate according to the scenario, the heat density within the city has been reduced as expected over the investigated period. Three main changes can be observed among the different maps of Figure 22.

1. The northern areas of the city will see a major reduction in heat density requirements as the maps change to a greener colour in those cells.
2. The same trend is observed in the eastern part of the city where not only high demanding red cells disappear over the scenarios, but also the majority of yellow cells change to a greener colour.
3. The city centre will also see a drastic change in its heat density requirements level. Although it will still represent the region with the highest demand, its level will be highly reduced as the map points out the transition from reddish to yellowish colours.

It should be noticed that the maximum heat density values, located in the north-west area of the city, are not considerably reduced since they correspond to the commercial sector. As explained before in the assumptions, commercial buildings are not focus of renovation in this project, therefore they cannot experience high savings in thermal losses due to an improvement of its thermal envelope. In turn, its slight reduction in final heat demand is mainly due to the consideration of an increase in temperatures by 2050, which in turn causes the HWB to be reduced, but also because of the assumed decrease in the HTEB term.

In general, the city will experience a decrease of the heat density requirements due to the refurbishment of old and not efficient buildings from the residential sector. Given that, the situation in 2050 will be marked by a more homogeneous heat distribution without remarkable hot spots.

The second step (see page 38) consists on identifying those areas where the DH network can be extended. The construction of such an infrastructure is only feasible if the targeted region has a high enough heat density requirements, or in other words, if a whole community of buildings can take profit of it. In this basis, the heat density maps created here will serve to select the areas with a techno-economical potential to harbour a DH network. In order to determine those suitable areas, two heat density thresholds have been selected; these are taken as reference from a side-project based on another Austrian location with similar urban and energy characteristics [36].

To identify areas with a technical potential, a threshold of 32 kWh/(m²-a) [36] has been chosen. However, due to the holistic extent of the work, the economic viability of the solutions takes also an important part in the results. Thus, to include the economics that such cluster of buildings would need to bear with, a higher threshold of 45 kWh/(m²-a) would identify areas with a techno-economical potential [36]. Regions with a heat density above these values are the ones with a clustering of buildings that share a technical potential or techno-economical potential to develop future networks.

Figure 23 shows, for the Low scenario, the filtered areas which have a technical or techno-economical potential for a DH project. It can be inferred how the more restrictive the selection threshold is, the less areas become suitable for a DH project. With the purpose of creating the most realistic scenarios as possible, and to avoid overextending the network, the most limiting threshold, 45 kWh/(m²-a), which considers both technical and economic characteristics of the areas has been selected to identify the regions where the DH network could be extended.
a) Technical potential (>32 kWh/(m²a)) (Map 16)  
b) Techno-economical potential (>45 kWh/(m²a)) (Map 17)

Figure 23. Regions with technical or techno-economical potential for DH projects

The third step of the methodology (see page 38) consists on identifying the buildings located in the marked areas of Figure 23. Figure 24 shows, for the Low scenario, the candidates to be connected to a DH network in 2050 if a techno-economical selection criterion is considered.
Afterwards, these have been studied in relation to the existing DH network in order to identify three different types of focus projects: line extension, priority areas, and micro-grids. The next three paragraphs define the three types of project. Figure 25 presents the DH opportunities for the Low scenario resulting from analysing the distribution of the buildings in Figure 24. Each of the building clusters is analysed as a district heating project that could be implemented by 2050.
A first step based on Figure 24 could be the evaluation of a possible line extension: Here, one can aim to connect the buildings that are close to the current DH network by extending the lines on average less than 100 meters, with exceptions of some punctual cases. This is represented in Figure 26, where the yellow covered areas gather the buildings located less than 100 m away from the existing DH network and the black circles point out building exceptions. The selected buildings for this line extension opportunity are represented in red in Figure 25. It is possible to see that a high majority of them are already located next to the network, but currently not connected. The line extension project would also include the set of buildings which are already defined in the approved DH extension plan (in planning in Figure 20).
Next, a priority area is understood as a region where not only a cluster of buildings with similar urban or energetic characteristics exists, but also its spatial distribution suggests the possible suitability of a line construction. In general, its heat density is distributed evenly and largely extended over a given area, usually following the pattern of the already existing road infrastructure. As represented in Figure 25, five different priority areas have been identified.

1. **City centre**: represented in yellow, it consists mostly in mixed sector buildings where the ground floor is dedicated to business sector while the other levels are occupied by residential units.

2. **Residential/Commercial**: represented in purple, it is located in the west side of the city and it consists of a mixture between residential and commercial buildings.

3. **Commercial/Industrial**: represented in green, it is located in the northern part of the city. It clusters large buildings dedicated to commercial centres or industries.

The remaining two other priority areas are considerably less expanded as they include a small number of buildings.

4. **East**: represented in light blue, it clusters 25 apartment blocks with the majority not renovated so far.

5. **North**: represented in pink, it consists of 9 building units from different sectors. They do not share the same characteristics but due to its location close to the North network, they could be connected to it through a line extension.

Moreover, smaller clusters of buildings with a reduced number of customers have been defined as possible *micro-grids* projects. These are represented in brown. While the east
located block clusters a set of terraced houses belonging to a same construction project, the north one consists of a school and a few apartment blocks. Due to the isolated location of the east cluster of buildings, these could be supplied by a small decentralized micro-grid. Meanwhile, the second block could either be supplied by a line extension of another large project or by another micro-grid. Finally, the buildings represented in grey and labelled as Not Suitable are buildings located in the periphery of the city, far away from the main network infrastructures, therefore it has been assumed that they will not be included in the future DH sector of 2050.

This was the spatial analysis using GIS tools of the DH extension opportunities for the Low scenario. The results for the Ambitious scenarios are similar but with a reduced number of candidate buildings to be connected to the future DH network. This is a result of the greater yearly renovation rate (see Table 6) assumed by the year 2050 and its Advanced refurbishment measures, which in turn reduce the heat density within the city compared to the Low scenario. As a consequence, the number of potential areas that exceed the techno-economical threshold is reduced and therefore the candidate buildings located in them. This behaviour is represented in Figure 27 where the two areas marked in black show how a same building in the Low scenario is proposed to be connected to the future DH, while in the Ambitious situation, is left apart from the extension projects. Finally, Maps 23, 24 and 25 in Appendix D show a detailed version of the resulting maps regarding the DH extension opportunities in the BAU, Low and Ambitious scenarios.

The Low and Ambitious scenarios assume as DH projects to be implemented by 2050 the seven different building clusters represented in Figure 25: five priority areas, one line extension and one micro-grid project in two different regions. The only difference between both scenarios relies on which buildings are included in each project, as shown in Figure 27, as well as on the final heat demand of each unit.
Figure 27. Differences between the DH Extension opportunities in the Low and Ambitious scenarios

Figure 28 gives the values of final heat demand corresponding to the different DH regions, i.e. North, main network, and a large group of buildings referred to Extension, which gathers the seven different potential projects to be implemented by 2050. It shows the same evidences previously discussed. Regarding the combined final heat demand from the Extension projects, it is now clear that the Ambitious scenario has a lower final heat demand since not only there are less candidate buildings to be connected, but also the units have a reduced final heat demand compared to the Low scenario.

![Figure 27: Differences between the DH Extension opportunities in the Low and Ambitious scenarios](image1)

<table>
<thead>
<tr>
<th></th>
<th>Status Quo</th>
<th>BAU</th>
<th>Low</th>
<th>Ambitious</th>
</tr>
</thead>
<tbody>
<tr>
<td>North+MG</td>
<td>8.526,38</td>
<td>5.103,68</td>
<td>4.819,87</td>
<td>4.445,54</td>
</tr>
<tr>
<td>Main DHN</td>
<td>6.935,38</td>
<td>5.650,72</td>
<td>5.405,41</td>
<td>5.216,90</td>
</tr>
<tr>
<td>Extensions</td>
<td>-</td>
<td>4.240,50</td>
<td>30.220,71</td>
<td>27.579,80</td>
</tr>
</tbody>
</table>

Final heat demand [MWh]

![Figure 28: Final heat demand of the district heating sector classified by DH regions and scenarios](image2)

The DH spatial extension plans outlined in this section have a great potential of CO₂ and monetary savings due to the group of buildings that will abandon the N-Gas distribution.
network in favour of a connection to new DH lines. In particular, 67%, 73% and 74% of the final heat demand represented in the red blocks of figure 16 comes from buildings previously supplied by N-Gas boilers in 2015, for the BAU, Low and Ambitious scenario, respectively. Supplying this HEB values with the DH network will cause the N-Gas fuel and CO$_{2eq}$ savings shown in Table 7. For the calculation, the PCI value of N-Gas is taken as 10.83 kWh/Nm$^3$ [37] while the emission factor used is 237 gCO$_{2eq}$/kWh [10].

Table 7. Savings in N-Gas consumption and related CO$_{2eq}$ emissions as a result of the DH extension plan

<table>
<thead>
<tr>
<th>Demand coming from N-Gas boilers to be supplied by DH in 2050 (kWh)</th>
<th>BAU</th>
<th>Low</th>
<th>Ambitious</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of buildings</td>
<td>27</td>
<td>204</td>
<td>197</td>
</tr>
<tr>
<td>Primary energy required N-Gas (kWh)</td>
<td>3.273</td>
<td>24.091</td>
<td>22.250</td>
</tr>
<tr>
<td>Savings in fuel consumption N-Gas (Nm$^3$)</td>
<td>302</td>
<td>2.225</td>
<td>2.055</td>
</tr>
<tr>
<td>Savings in CO$_{2eq}$ emissions (ton)</td>
<td>776</td>
<td>5.710</td>
<td>5.273</td>
</tr>
</tbody>
</table>

It should be noticed that the savings presented in Table 7 only make reference to the greatest heat supply change incurred by the DH extension plan i.e. the abandonment of the N-Gas network by 27, 204 and 197 buildings in the BAU, Low and Ambitious scenario. To acquire an overall picture of the total CO$_{2eq}$ and fuel savings from the N-Gas replacement, the possible additional consumption of N-Gas to supply part of the DH demand should be taken into consideration. This will not outweigh the savings already accomplished, but these will definitely be reduced. Finally, a similar study can be performed to obtain the fuel costs and emissions savings from buildings currently supplied by oil or coal boilers that will be connected to the DH network in 2050. This paragraph aimed to individually evaluate the environmental benefits of the DH extension plans; however, an overall assessment of the CO$_{2eq}$ and related monetary savings of the whole energy transformation process is presented in Chapter 7.

It will be in the next two sections where the technology and energy sources to produce the heat distributed in the network will be defined. The scenarios will be focused in increasing the share of renewables in the fuel mix as well as in increasing efficiency of the existing producing units. With these energy transition trends in mind, the case studies will analyse the maximum capacities expected from the future Extension projects and will determine the new capacities to be installed by energy source.

### 5.2.2 Solar thermal fraction in the district heating network

A critical point to answer is the solar penetration ratio in the DH network and therefore the reliance on the intermittency and intensity variation of the solar radiation. Together with the fuel selection of the base load plants, the solar penetration ratio will judge the renewable extent of the future solution.

The purpose of the scenarios is to introduce realistic and spatially feasible shares of new solar thermal collectors so that the future DH network could be understood as a solar DH infrastructure. The methodology approached in this section is detailed as follows.

1. Define the required values of solar fraction i.e. share of the aggregated final heat demand from the DH sector to be provided by solar thermal technology.
2. Calculate the required collector area to provide such levels of demand. The results will vary according to the solar thermal yield to be considered in each scenario, which in turn will rate the efficiency performance of the collectors.
3. Spatially locate on the city map a territory suitable for the required dimensions where a ground mounted solar thermal plant could be implemented.

As pointed out in step 3, the development of the solar thermal sector in the DH network will be focused in ground mounted solar thermal plants rather than small scale individual rooftop solutions. Table 8 shows the assumptions on solar fraction and solar yield for the steps 1 and 2. Solar fractions values for the Low and Ambitious scenarios were set up in line with the SDH guidelines in [38]. Both Low and Ambitious scenarios aim to raise the solar fraction to an average value between 10% to 20%. The solar fraction for the BAU scenario was assumed equal to the current solar share, between 2-3% according to [39]. Regarding the solar yields of the collectors, it should be pointed out that these highly depend on the supply and return water temperature of the collector.

Table 8. Solar fractions and solar yields of collectors assumed for each scenario

<table>
<thead>
<tr>
<th>Solar fraction* (SF) [%]</th>
<th>Status quo</th>
<th>BAU</th>
<th>Low</th>
<th>Ambitious</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar yield* (SY) [kWh/m(^2)a]</td>
<td>300</td>
<td>320</td>
<td>320</td>
<td>320</td>
</tr>
</tbody>
</table>

*(F.Mauthner, personal communication, June 2016)

Considering a typical collector aperture area of 90%, the required collector areas to provide the detailed solar fractions were calculated as:

\[ A_{\text{collector}} = \frac{HEB \cdot SF}{SY \cdot 0.9} \]  

(17)

Table 9 shows the aggregated HEB demand values for each DH region considered in the scenarios, as well as the required collector areas to comply with the solar thermal fractions of Table 8. The assumed solar yields are only illustrative for the calculations of the preliminary study; hence the final solar thermal share provided by the new collector areas will be corrected and validated with the simulations of the ensuing chapter.

Table 9. HEB and collector areas to be installed by DH region and scenario

<table>
<thead>
<tr>
<th></th>
<th>BAU</th>
<th></th>
<th>Low</th>
<th></th>
<th>Ambitious</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HEB [MWh]</td>
<td>Collector area [m(^2)]</td>
<td>HEB [MWh]</td>
<td>Collector area [m(^2)]</td>
<td>HEB [MWh]</td>
</tr>
<tr>
<td>Main DHN</td>
<td>5.651</td>
<td>1.046</td>
<td>5.405</td>
<td>1.877</td>
<td>5.217</td>
</tr>
<tr>
<td>North and MG</td>
<td>5.104</td>
<td>945</td>
<td>4.820</td>
<td>1.674</td>
<td>4.446</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2.777</td>
<td></td>
<td>14.090</td>
<td></td>
<td>25.863</td>
</tr>
</tbody>
</table>

The Ambitious scenario results in the highest required value of collectors’ area, almost 26.000 m\(^2\). Taking into account the ratio between m\(^2\) ground/m\(^2\) collectors, around 3.5 times the collector area [40], the required land will reach 91.000 m\(^2\). Figure 29 shows the location and dimensions of potential sites where the collectors could be located. It also includes the extension of the Ambitious DH sector. It should be noticed that Figure 29 aims to serve as a
Holistic urban energy planning in temporal and spatial resolution for the city of Gleisdorf

preliminary study to point out the availability of free areas for such an instalment. However, the selection criterion has only focused in non-constructed regions, therefore a further comprehensive study considering land use, ownership, feasibility of implementation, etc. should be performed in future steps of the project.

As comparison, if one would aim to have a 100% coverage with solar thermal in the DH network, considering the ambitious scenario this would require a land extension of 452.606 m².

Once the DH solar fraction as well as the required collector area to be installed have been defined for the scenario, the next section will detail the fuel mix of the future heating plants of the network and the merit order of each technology.

Figure 29. Possible locations of DH solar thermal plants (Map 32)
5.2.3 District heating network new capacity power plants

The main DH network is currently served with four heating plants which combine biomass and N-Gas boilers with solar thermal collectors. Table 10 shows the capacity installed in each plant and its type of technology.

Table 10. Capacity installed and technology type of each heating plant in the existing DH network [10]

<table>
<thead>
<tr>
<th></th>
<th>Gartengasse</th>
<th>Kloster</th>
<th>GeoWohnen</th>
<th>Neue Mittelschule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>1700 kW</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>N-Gas</td>
<td>-</td>
<td>1030 kW</td>
<td>-</td>
<td>2015 kW</td>
</tr>
<tr>
<td>Solar</td>
<td>191 kW/300 m²</td>
<td>-</td>
<td>181,9 kW/285,6 m²</td>
<td>316 kW/496 m²</td>
</tr>
</tbody>
</table>

New capacity plants are required to supply the total of the heat demand coming from the Extension project. To outline future scenarios, it is assumed that the DH network will be served by biomass boilers, solar thermal collectors and N-Gas boilers.

While biomass boilers using wood chips will be responsible to balance the base load throughout the year, the remaining demand corresponding to peak load will be supplied by N-Gas boilers. This is assumed in this way due to the technical constraints of both types of technologies. Biomass boilers are well suitable to operate at a constant rate during continuous periods of time. However, these are not proper solutions to balance peak loads which require fast start-up and shut-down times as well as to work at low capacity rates. It is in this type of operation where N-Gas boilers will be used. However, in order to limit the dependency on fossil fuels and avoid emissions, the production of heat using N-Gas boilers will be restricted to a percentage of the final heat produced. In this way, BAU accepts a N-Gas fraction around 15%, the Low scenario a value up to 10% while the Ambitious situation requires decreasing the N-Gas use below 8% of the final heat produced for the DH sector.

These values are only illustrative requirements to define the scenarios of 2050, however, the real distribution of heat produced from each source will be dependent on the solar thermal output, which will always be the first in the merit order of the units. It should also be noticed that according to the severity of the scenario, N-Gas could be replaced by a renewable N-Gas such as biogas.

Finally, the size of the DH capacity plants in the status quo and scenarios is presented in Table 10. The obtainment of those values is explained in Section 6.1.3 of the modelling chapter. It should be noticed that Table 10 refers only to the total considered capacity installed for each situation. To get the new capacity additions for each type of heating system, the difference between status quo and scenarios values must be taken.

Here ends the second step of the methodology to create the scenarios (see Figure 16) which thoroughly studies the DH extension opportunities for the future heating sector of Gleisdorf. Three different extensions plans have been defined in terms of spatial location of the custommers to be connected, solar thermal fractions and required new collector areas as well as in terms of the fuel use limitations in the heating producing plants of the future networks. Map 23, 24 and 25 represent the future DH extension planed over the city whereas Table 9 provides the required dimensions of the future solar thermal plants of the DH network.
5.3 Development of the central heating buildings

The scenarios need also to determine the development of the heat producing units in buildings with central heating systems (see Figure 16). It is highly expected that buildings currently served with fossil fuel boilers or electric heating systems will update its technology supply by a cleaner and more efficient one. Considering the results from [41] as a trend indicator, the scenarios are ruled by the assumption that fossil fuel boilers will be fully replaced either by electrical-run applications such as heat-pumps or by biomass boilers by 2050.

Here the scenarios of Low and Ambitious split into two variations according to the fuel used to replace the inefficient individual supply systems. The first one considers biomass boilers as a heat producing technology, while the second one uses instead heat pumps and eliminate biomass in the energy mix due to the incurred low heat value of the fuel, which increases the primary energy needed and therefore reduces the overall energy efficiency of the system.

Finally, the BAU scenario assumes that none of the buildings with central heating system will change its type of heat supply technology to a more efficient solution unless the building was previously selected to join the future DH network. Table 11 shows how the change in heating system has been assumed in the scenarios.

<table>
<thead>
<tr>
<th>Initial heating system</th>
<th>BAU</th>
<th>Low and Ambitious</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Variant 1</td>
<td>Variant 2</td>
</tr>
<tr>
<td>Oil Boiler</td>
<td>Biomass Boiler</td>
<td>Heat Pump</td>
</tr>
<tr>
<td>Coal Boiler</td>
<td>Biomass Boiler</td>
<td>Heat Pump</td>
</tr>
<tr>
<td>Biomass Boiler</td>
<td>Biomass Boiler</td>
<td>Heat Pump</td>
</tr>
<tr>
<td>N-Gas Boiler</td>
<td>N-Gas Boiler</td>
<td>N-Gas Boiler</td>
</tr>
<tr>
<td>Heat Pump</td>
<td>Heat Pump</td>
<td>Heat Pump</td>
</tr>
<tr>
<td>Others</td>
<td>Biomass Boiler</td>
<td>Heat Pump</td>
</tr>
<tr>
<td>Electric Heating System</td>
<td>Biomass Boiler</td>
<td>Heat Pump</td>
</tr>
</tbody>
</table>

5.4 Decentralized solar thermal penetration

This is the last step of the methodology to define the scenarios (see Figure 16). Its purpose is to define which buildings will install rooftop solar thermal collectors, and in this case how much area. Whether a building will install solar thermal in its rooftop will depend on its transformation process over the years: in particular, marked by a change of its heat supply system or a thermal renovation of its envelope. Given that, the following assumptions regarding the building groups that will install solar thermal collectors by 2050 have been taken.

- **BAU**: only buildings which have undergone a refurbishment and a change of heating system.
- **Low**: only buildings which have undergone a thermal renovation, regardless if they have changed its heating supply system.
- **Ambitious**: any building that has undergone a transformation process.

Change of heating system is understood as if a building has been selected to be included in a DH network project or if it has changed its central heating system according to
Likewise, the thermal renovation indicator is taken for each building according to Table 6. The previous assumptions select the buildings with a new solar thermal installation by 2050. The second task consists on specifying the area to be installed. For this, the following methodology is applied:

1. Define a solar fraction that the installation will provide from the total HEB.
2. Define solar thermal yields of the installation in kWh/m² of collector.
3. Obtain the collector area required in order to provide the above solar fraction.
4. Calculate the suitable rooftop area and transform it to suitable collector area.
5. The final collector area to be installed is the minimum value between 3) and 4).

It should be noticed that if the building already includes collectors, the corresponding area is reduced from the obtained 5) value. An extended explanation of the methodology outlined before is presented in Appendix B, which also includes the approach and incurred assumptions used to estimate the rooftop areas of the buildings in the city. The assumptions of point 1) and 2) are taken from reference benchmark figures for solar thermal applications in urban environments [42] and provided in Table 12.

<table>
<thead>
<tr>
<th>Solar fraction [%]</th>
<th>BAU</th>
<th>Low</th>
<th>Ambitious</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar yield [kWh/(m² collector a)]</td>
<td>380</td>
<td>450</td>
<td>450</td>
</tr>
</tbody>
</table>

*(F. Mauthner, personal communication, June 2016)

Table 13 shows the required collector areas to be installed buildings with central heating disclosed by type of heating system. These are calculated with formula 17.

<table>
<thead>
<tr>
<th>Heating system of the building</th>
<th>BAU</th>
<th>Low</th>
<th>Ambitious</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass Boiler</td>
<td>4.226</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>N-Gas Boiler</td>
<td>4.518</td>
<td>7.117</td>
<td></td>
</tr>
<tr>
<td>Heat Pump</td>
<td>107</td>
<td>8.805</td>
<td></td>
</tr>
</tbody>
</table>

5.5 Summary of the scenarios

This section aims to recapitulate how the three different scenarios have been defined. Bullet points recalling the main assumptions and outcomes are provided for each uncertainty block of Figure 16.

Renovation roadmap

- BAU and Low scenarios assume Usual renovation measures while the Ambitious scenario uses Advanced schemes.
- The yearly renovation rate is increased from 1.21% to 2.16% over the scenarios.
**DH extension potential**

- For the **Low** and **Ambitious** scenario, the DH sector will be extended with seven different projects: five priority areas, a line extension and a micro-grid project.
- The **Low** and **Ambitious** extension plans are almost the same, only being differentiated by the candidate buildings to be connected and the associated final HEB, which is 9.14% lower in the **Ambitious** situation.
- The DH solar fraction over the scenarios changes from 5% to 10% and 20% in BAU, **Low** and **Ambitious** respectively.
- N-Gas boilers use in the DH network is limited to produce between 15% and 8% of the final HEB.

**Development of the central heating systems**

- Fossil fuel boilers and electric heating systems will be replaced by biomass boilers or heat pumps according to the scenario.

**Solar thermal penetration in buildings’ rooftops**

- New solar thermal collectors installed in buildings rooftops are assumed to provide between 10% and 50% of the final HEB according to the scenario.

Finally, Figure 30 shows the distribution of city’s heat demand by heating system installed in each building. It is observed how at the end of the transformation process, in 2050, for the **Low** and **Ambitious** scenario only DH network, N-Gas network as well as heat pumps and biomass boilers are remaining.

![Figure 30. Final heat demand by heating system in each scenario](image-url)
6. MODELLING OF THE SCENARIOS

The chapter introduces a general outlook about how the models have been developed in the software. Six different models are created for the ensuing simulations: five referring to the future systems in 2050, and a status quo model representing the current heating sector in the year 2015. Each model is organized under an input/output approach, which in turn relies on defining the supply side with installed capacities of heating units and fuels, as well as representing the consumer side with aggregated annual demands in combination with its temporal distribution. The tool will be responsible then to analyse the system and balance both sides in an hourly resolution during one-year time span and according to the available heat producing technologies. The output result is the optimal production schedule of each energy conversion unit in the system.

6.1 Models development

This section specifies the input parameters required to run the software and obtain the production schedule calculated by the tool. From end-consumer side to primary energy supply, energyPRO requires the definition of: aggregated annual demands and its temporal distribution, storage elements, if required, capacities and efficiencies of energy conversion units and fuels within the system. Moreover, some of the mentioned elements depend on external variables such as ambient temperature or global solar radiation, as well as have an associated environmental impact when being used in the system. The weather profiles introduced in the simulations are the ones presented in Section 2.2 for the year 2015, whilst emission factors for a future sustainability evaluation of the solutions are provided here.

6.1.1 Profiles and aggregated annual demands

Due to the characteristics of the software, the final heat demand for the city needs to be represented in the model by a combination of different HEB according to the heating fuel of the system. In this way, three different supply groups have been identified.

- **District heating network**: its final heat demand value has been differentiated between the DH regions of Figure 20: Main DHN, North and MG and Extension. The three DH regions have been represented in different sites since its boilers are not interconnected e.g. a boiler in the North network cannot participate in supplying the demand of the main DH network.
- **Natural gas network**: its associated HEB represents all buildings connected to the N-Gas network.
- **Central heating systems**: it gathers all buildings with a centralized heating system. This group has been further disclosed by type of technology.

Table 14 shows the HEB values of each heating supply group introduced in the software for the status quo as well as for the scenarios.
Table 14. Values of HEB by heating supply group introduced in energyPRO

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>District Heating Network</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensions</td>
<td>-</td>
<td>4.241</td>
<td>30.354</td>
<td>27.580</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main DHN</td>
<td>6.935</td>
<td>5.651</td>
<td>5.405</td>
<td>5.217</td>
<td></td>
<td></td>
</tr>
<tr>
<td>North+MG</td>
<td>8.526</td>
<td>5.104</td>
<td>4.820</td>
<td>4.446</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-Gas Network</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-Gas Boiler</td>
<td>66.038</td>
<td>42.314</td>
<td>19.968</td>
<td>18.596</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Central Heating Systems

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass Boiler</td>
<td>6.814</td>
<td>3.981</td>
<td>12.142</td>
<td>-</td>
<td>-</td>
<td>10.963</td>
</tr>
<tr>
<td>Electric Heating System</td>
<td>5.992</td>
<td>2.547</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Coal Boiler</td>
<td>692</td>
<td>330</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Oil Boiler</td>
<td>21.100</td>
<td>11.535</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Heat Pump</td>
<td>1.084</td>
<td>765</td>
<td>695</td>
<td>12.837</td>
<td>11.621</td>
<td>658</td>
</tr>
</tbody>
</table>

Although not detailed in Table 14, each of the HEB distinctions has also been differentiated between heat requirements for consumption, therefore WWWB + HWB, and losses, therefore HTEB, according to the assumptions of Table 3. For example, in the case of the DH extension group in the Low situation, its total heat demand of 30.354 MWh is divided as follows.

Given that in the Low scenario: $HTEB = 0.15 \cdot (WWWB + HWB)$

and

$$HEB = (WWWB + HWB) \cdot 1.15 = 30.354 \text{ MWh}$$

Then:

$$Heat \ demand \ for \ consumption = WWWB + HWB = \frac{HEB}{1.15} = 26.395 \text{ MWh}$$

$$Heat \ losses = HTEB = 0.15 \cdot (WWWB + HWB) = 3.959 \text{ MWh}$$

In order to disaggregate the HEB values into hourly profiles, a method provided by energyPRO has been used. The assumptions on the calculation of the hourly profiles for the planning period are:

- The dependant fraction on external conditions corresponds to the share of HWB in respect of HEB. For each heating supply source, this ratio has been calculated as the average value between all buildings in the same group.
- The demand depends linear on hourly ambient temperatures of Gleisdorf, with a reference temperature of 20 °C [34].

According to the final HEB value, the software develops a formula to calculate the hourly heating needs in the form of:

$$A \cdot \text{Max}(20 - T_h; 0) + B$$

(18)
where A and B are fitting parameters to match the generated hourly values with the measured data for the year (HEB values of Table 14). These are given in MW/°C and MW, respectively. $T_{ih}$ refers to the hourly ambient temperatures of Gleisdorf. Figure 31 shows an example of the hourly profiles generated by energyPRO for the heat demand for consumption (HWB+WWWB) of the buildings with oil central heating system, in the BAU scenario. It should be noticed that the lower fraction of the demand delimited by the rectangle between 0 to 0.2 MW and the entire time span, corresponds to the base load which is equal to the WWWB term constant over the year. In this case, the fraction corresponds to 19.7% of the whole area below the red curve, or to 1.894 MWh (being 9.612.5 MWh the total heat demand for consumption and 19.7% the ratio between WWWB/(HWB+WWWB)).

![Figure 31. Hourly profile generated by energyPRO for the heat demand for consumption of the buildings with oil central heating system in the BAU scenario](image)

6.1.2 Fuels

The models use five different fuels and imported electricity for the operation.

- **Biomass**, in form of *wood chips*: used in the DH biomass boilers.
- **Biomass**, in form of *wood pellets*: used in the individual boilers of the central heating buildings.
- **Natural gas**: used in the individual boilers of the central heating buildings. It is supplied by an extensive network spread around the city.
- **Coal**: used in the individual boilers of the central heating buildings in the status quo but not considered in the scenarios.
- **Oil**: used in the individual boilers of the central heating buildings in the status quo but not considered in the scenarios.

The heat value of each fuel is assumed to be 1 MWh of heat produced per each MWh of fuel combusted. In this way, the heat of combustion values relating mass or volume units with energy units have not been taken into account.

- **Imported electricity**: used to run electric heating systems and heat pumps. No further details regarding the variable prices in a spot market have been assumed. Instead, a fixed market tariff has been considered for the actual and future situation.
### 6.1.3 Energy conversion units

This section specifies the technical characteristics of all the energy conversion units in the heating sector, as well as its installed capacity and fuel. The following types of units have been defined:

- **Biomass and N-Gas boilers**: for the DH network or for buildings with central heating.
- **Coal and oil boilers, electric heating and heat pumps**: for buildings with central heating.
- **Solar thermal collectors**: for the DH network or for buildings with central heating.

For each of these conversion units, efficiencies, capacities and technical parameters of operation have been defined. Excluding the capacities installed in the main DH network (see Table 10), the other existing or future capacities in the system are unknown. In order to define them in the software, these have been assumed equal to a slightly higher value than the hourly maximum demand for each heating supply group. These values are obtained from the generated hourly profiles of final heat demand. Table 15 shows the installed capacity of all conversion units of the system. In turn, solar thermal collector areas to be installed as medium-large scale plants for the DH network or in rooftops of central heating buildings were already defined in Table 9 and Table 13, respectively.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>District Heating Network</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass Boilers (Pellets)</td>
<td>4,3</td>
<td>4,5</td>
<td>12</td>
<td></td>
<td></td>
<td>10,85</td>
</tr>
<tr>
<td>N-Gas Boilers</td>
<td>4,55</td>
<td>5,25</td>
<td>8,55</td>
<td></td>
<td></td>
<td>8,7</td>
</tr>
<tr>
<td><strong>N-Gas Network</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-Gas Boiler</td>
<td>20</td>
<td>12</td>
<td>5,4</td>
<td></td>
<td></td>
<td>5,0</td>
</tr>
<tr>
<td><strong>Central Heating Systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass Boilers</td>
<td>2,0</td>
<td>1,1</td>
<td>3,5</td>
<td>-</td>
<td>-</td>
<td>3,1</td>
</tr>
<tr>
<td>Electric Heating Systems</td>
<td>21,9</td>
<td>0,7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Coal Boilers</td>
<td>0,2</td>
<td>0,2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Oil Boilers</td>
<td>6,4</td>
<td>3,3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Heat Pumps</td>
<td>0,4</td>
<td>0,3</td>
<td>0,3</td>
<td>3,6</td>
<td>3,4</td>
<td>0,2</td>
</tr>
</tbody>
</table>

* Corresponds to the total installed capacity between the three DH regions.

Efficiencies, partial load characteristics and other performance parameters of the conversion units are defined below. Table 16 shows the efficiencies considered for each energy conversion unit in the scenarios. It can be inferred how the replacement of units by best available market technologies with higher performance values has been assumed over the scenarios. This is the case for N-Gas boilers, air source and ground source heat pumps and biomass boilers.
Table 16. Efficiencies of the energy conversion units for each of the scenarios

<table>
<thead>
<tr>
<th>Efficiencies* [%]</th>
<th>Status Quo</th>
<th>BAU</th>
<th>Low</th>
<th>Ambitious</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-Gas boilers</td>
<td>87</td>
<td>87</td>
<td>92</td>
<td>92</td>
</tr>
<tr>
<td>Air source heat pumps (COP)</td>
<td>3,5</td>
<td>3,5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Ground source heat pumps (COP)</td>
<td>4,2</td>
<td>4,2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Biomass boilers: Wood chips or Wood pellets</td>
<td>85</td>
<td>90</td>
<td>90</td>
<td>92</td>
</tr>
<tr>
<td>Oil boilers</td>
<td>85</td>
<td>85</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Coal boilers</td>
<td>72</td>
<td>72</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Electric heating systems</td>
<td>90</td>
<td>90</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*(F. Mauthner, personal communication, June 2016)

During the whole simulations phase, only a single type of collector has been used regardless of the scenario considered. The selected unit consists on a flat plat collector with the following efficiency coefficients. This is taken from the system model of [39]:

\[
\begin{align*}
\eta_0 &= 0.79 \\
\alpha_1 &= 3.97 \text{ W/(m}^2\text{°C)} \\
\alpha_2 &= 0.014 \text{ W/(m}^2\text{°C)}^2
\end{align*}
\]

The incidence angle modifier is defined with a \( K_\theta \) value at 50 degree of 0.94. Its inclination is assumed to be 36 degrees while its orientation (deviation from south) 0 degrees. Its performance depends on the hourly profile of ambient temperatures and aggregated radiation on horizontal plane for the year 2015 and the city of Gleisdorf. Finally, Table 17 shows the temperatures assumed for the models, on the demand side of the heat exchanger after a temperature drop over the heat exchanger of 5 °C. Given that, the numbers introduced in the software are 5°C higher. It should be noticed the difference in supply and return temperatures according to the heat system the collector is connected to. Moreover, the losses in pipes in collector field in percentage of production are assumed to be 10%.

Table 17. Temperatures from and to the collector on the demand side of the heat exchanger for each of the scenarios

<table>
<thead>
<tr>
<th>From collector/To collector Temperatures* [°C]</th>
<th>Status Quo</th>
<th>BAU</th>
<th>Low</th>
<th>Ambitious</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Pump</td>
<td>65/40</td>
<td>65/40</td>
<td>60/30</td>
<td>60/30</td>
</tr>
<tr>
<td>Pellets</td>
<td>65/40</td>
<td>65/40</td>
<td>60/30</td>
<td>60/30</td>
</tr>
<tr>
<td>DH</td>
<td>90/60</td>
<td>90/60</td>
<td>80/50</td>
<td>80/50</td>
</tr>
<tr>
<td>N-Gas</td>
<td>65/40</td>
<td>65/40</td>
<td>60/30</td>
<td>60/30</td>
</tr>
</tbody>
</table>

*(F. Mauthner, personal communication, June 2016)

Information taken from [39] [10] regarding the heating plants of the main DH network has enabled to create a simplified model of the main line (represented in blue in Map 22) with authentic technical parameters of biomass boilers, N-Gas boilers, solar thermal collectors, and thermal storage units. The installed capacity of each type of boiler is also available and was given in Table 10. The entire list of the units’ technical specifications such as minimum
and maximum capacities, efficiencies at rated load, start up and shutdown times, orientation of the collectors, etc. is provided in Appendix C.

The heating plants of the remaining DH regions, North, micro grids and Extension are taken under own assumptions. It is accepted that these are composed by biomass boilers, N-Gas boilers and solar thermal collectors. Unlike the biomass boilers of central heating systems, which use wood pellets as fuel, the ones installed in the DH network are powered by wood chips. The same efficiency values are taken, however, a minimum operating time of 48 hours in the status quo and BAU scenario, and of 32 hours in the Low and Ambitious situations is defined. Moreover, the biomass boilers of the DH network are assumed to have a minimum required capacity to operate of 20% of the full load capacity. These two specifications will limit the operation of these boilers and make them unavailable to supply low loads during summer (the remaining demand not met by solar thermal collectors) as well as peak loads. The rest of the units connected to DH, N-Gas boilers and solar thermal collectors take the same assumptions previously defined.

6.1.4 Storage units
The models include a small-scale hot water storage unit together with each solar thermal collector installation. The dimensioning of the storage units has not been further studied therefore the assumption was made that for each square meter of solar collector, 80 litres of tank storage are required (F.Mauthner, personal communication, June 2016). This is a typical figure to dimension thermal storages for single family houses and small commercial applications, which usually can provide storage for a period of a few days to a week [43].

6.1.5 Emissions
In order to evaluate the environmental effects of the proposed systems, the emissions factors of the fuels used are required. The research has limited the emissions scope only to carbon dioxide equivalent. These are given per MWh of fuel combusted, while the imported electricity for heat generation emission factor is given per MWh of electricity consumed.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>CO₂eq emissions [Kg/MWh]</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass Wood Chips</td>
<td>58.3848 Kg/MWh&lt;sub&gt;Wood chips&lt;/sub&gt;</td>
<td>[10]</td>
</tr>
<tr>
<td>Biomass Wood Pellets</td>
<td>70.0920 Kg/MWh&lt;sub&gt;Pellets&lt;/sub&gt;</td>
<td>[10]</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>237.0 Kg/MWh&lt;sub&gt;NGas&lt;/sub&gt;</td>
<td>[10]</td>
</tr>
<tr>
<td>Oil</td>
<td>308.0 Kg/MWh&lt;sub&gt;Oil&lt;/sub&gt;</td>
<td>[44]</td>
</tr>
<tr>
<td>Coal</td>
<td>383.0 Kg/MWh&lt;sub&gt;Coal&lt;/sub&gt;</td>
<td>[44]</td>
</tr>
<tr>
<td>Imported electricity</td>
<td>310.0 Kg/MWh&lt;sub&gt;el&lt;/sub&gt;</td>
<td>[44]</td>
</tr>
</tbody>
</table>

The present chapter has detailed all the parameters used to represent the heating sectors of the scenarios in the modelling software. The succeeding episode will present the results of the simulations. Figure 32 and Figure 33 provide an example of how the Low scenario with biomass boilers has been modelled in energyPRO. Seven different sites were defined in order to represent the system. Three sites for the DH sector (North+MG, Main DHN and Extensions), one for the N-Gas network, one for biomass boilers, and two for the already existing heat pump systems which will not change by 2050. Two sites were required for this last group in order to represent the assumption that half of the installed heating pumps are ground-source heat pumps while the other half consists on air-source heat pumps.
Figure 32. Model of the heating sector in the Low scenario with biomass boilers in energyPRO
Figure 33. Model of the DH expansion project in the Low scenario in energyPRO
7. SIMULATION AND SPATIAL RESULTS

After running the simulation for the status quo and the five scenarios, the results are analysed. Then a comparison of the transformation process proposed by each scenario is presented. The five modelled systems differ mainly by final energy demand per energy source, primary energy consumption per energy source, produced CO₂ equivalent emissions and share of renewables.

When analysing the results of the study, it should be remarked that the entire energy system simulation was carried out without considering the economical extent of the solutions. A future comprehensive economic investigation of the proposed systems would provide further insights to come up with a holistic evaluation of the transformation process outlined in the scenarios.

7.1 Indicators

Using the results obtained in the simulations, this section presents a set of indicators that will be used to evaluate the sustainability extent of the proposed future heating systems of the city in 2050.

7.1.1 Final energy demand

Figure 34 presents how the final heating demand of the entire city, without distinction of DH sector, N-Gas network or central heating systems, is supplied in terms of heat production units. The figure shows the results in MWh as well as in how much each type of unit contributes in percentage to the total heat produced. It should be noticed that the simulations’ results are in line with the expectations when creating the scenarios. From the up side graph it is clear to observe the following trends.

1. The decrease in final heat demand from the status quo to BAU, Low or Ambitious scenarios as pointed out in Figure 18 and already discussed in Section 5.1.
2. The increased usage of biomass boilers powered by wood chips in the DH network as a result of the DH expansion projects in BAU, Low or Ambitious. The increase usage of N-Gas in the DH network is not reflected in the graphs since it is totally offset by the group of buildings initially connected to the N-Gas network moving to a DH line as a result of the expansion projects.
3. The elimination of fossil fuel boilers and electric heating systems in the 2050 scenarios of Low and Ambitious.
4. In the Low or Ambitious scenarios, the rise in biomass boilers powered by wood pellets or heat pumps in order to substitute the inefficient central heating units.

In turn, the down side graph allows to see the overall solar thermal penetration in the city. While currently solar thermal collectors are only responsible for 1.4% of the total heat production, the combination of assumptions in Chapter 5 makes this value to rise to approximately 12% in the Low scenario and to above 20% in the Ambitious scenario. These values not only represent the heat produced in individual solar rooftop collectors spread around the city but also they include the energy produced in the large solar plants providing heat to the DH network.
To study how the different assumptions regarding the new solar thermal installations by 2050 have resulted in each heating supply group, Table 19 provides the solar thermal penetration values for the DH network as well as for the buildings with central heating. If the reader compares the assumptions of solar fractions in Table 8 and Table 12 regarding the expected solar factors in each supply group, with the values of Table 19 obtained after the simulation of the models, some differences arise.

Figure 34. Final heat demand of the city by heat producing unit in each scenario
Table 19. Solar fractions obtained in energyPRO by heating supply group in each scenario

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>District Heating</td>
<td>2,6</td>
<td>3,8</td>
<td>9,7</td>
<td>9,7</td>
<td>17,0</td>
<td>17,0</td>
</tr>
<tr>
<td>Central Heating Buildings</td>
<td>1,3</td>
<td>2,2</td>
<td>15,7</td>
<td>15,6</td>
<td>23,9</td>
<td>23,7</td>
</tr>
</tbody>
</table>

The 10% and 20% solar fractions expected in the DH network are not achieved in the simulations. This mismatch in the results is due to an overestimation of the solar yields of the collectors used to calculate the required collectors’ area. In particular, the hypothesis does not work properly in DH systems because of its high supply and return temperatures of the water circulating through the system. This is inferred in this way since the same assumptions have resulted well when considering rooftop collectors in buildings with central heating systems, which in turn work with lower circulating temperatures (Table 17). A lower network temperature would increase this share and could be achieved by improved or low temperature heating systems in the connected buildings as well as by optimized substations. This approach could be incorporated in the renovation plans.

When analysing the solar thermal fractions obtained in the central heating buildings group, it is important to distinguish between the overall solar penetration in the combination of all buildings with a central heating system, and the solar fraction expected for an individual building installing collectors. The assumed values of 20%, 35% and 50% (see Table 12) obviously do not occur when comparing the values in the table above. This is explained going back to Section 5.4, which clearly points out that not all buildings will install solar thermal collectors by 2050.

7.2.2 Primary energy consumption

Figure 35 presents the results regarding the primary energy consumed to balance the overall final heat demand of the city. The graphs distinct the fuel consumed by type of source and show the results in MWh as well as in percentage of the total primary energy consumed. As before, the simulations results are in line with the expectations created with the scenarios and explained in the list of Section 7.2.1.

The main difference between Figure 34 and Figure 35 is the vanishing of the heat produced with solar thermal collectors. This is not accounted in the fuel consumption since it is produced from renewable solar energy. Furthermore, comparing again both figures it is possible to observe the high coefficient of performance (COP) of the heat pumps used in the Low and Ambitious scenario; although they are responsible to provide between 14,2% to 11,9% of the total heat demand, they barely consume imported electricity as observed in the down side graph of Figure 35. This behaviour was expected since the coefficient of performance of these units was set to a value between 4 and 5 in Table 16.
Holistic urban energy planning in temporal and spatial resolution for the city of Gleisdorf

Figure 35. Primary energy consumed in the city by energy source in each scenario

If the overall heating energy efficiency of the system is understood as the ratio between heat produced by fuel consumed, Table 20 provides the ability of the proposed heating systems to fulfil the city’s demand using the less resources as possible.

Table 20. Results of energy efficiency of the heating sector in each scenario

<table>
<thead>
<tr>
<th></th>
<th>Energy efficiency of the heating sector [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status Quo</td>
<td>88,5</td>
</tr>
</tbody>
</table>
It is observed that the scenarios that use heat pumps result with higher system’s efficiencies. Among them, the one with the highest share of solar thermal fraction is concluded to have the best efficiency value; hence the *Ambitious* scenario with heat pumps.

### 7.2.3 Renewable energy fraction (%RE)

The renewable energy fraction of the heating sector is understood as the proportion of the total energy delivered to the demand that was originated from renewable sources.

\[
\%RE = \frac{\text{Final Energy originated from Renewables}}{\text{Total Final Energy}}
\]  

(19)

In the calculation, all fuels except N-Gas, oil and coal, are considered as renewable sources. Moreover, for the year 2015, 67% of the imported electricity used for heat production is considered to be originated from renewable sources [45]. For the year 2050, this same fraction is taken under own assumptions to be 80% and 90% for the *Low* and *Ambitious* scenario. Table 21 presents the results.

**Table 21. Results of renewable fraction of the heating sector in each scenario**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>22,0</td>
<td>26,2</td>
<td>71,3</td>
<td>68,6</td>
<td>72,8</td>
<td>73,8</td>
</tr>
</tbody>
</table>

The increasing %RE compared to the current levels is mainly due to the extension of the DH network, which mainly uses biomass and solar thermal collectors to supply the heat. On one hand, the change from 22% to 26,2% in the BAU scenario is only caused by the construction of the already planned projects in the DH network. On the other hand, the further rise of %RE in the *Low* and *Ambitious* situation not only is caused by the larger DH extension projects, but also is a result of the replacement of the fossil fuel boilers in the system.

It should also be noticed that the non-renewable fraction is only caused by the combustion of N-Gas in the DH system as well as the presence of the N-Gas network in the city. Although 100% levels of %RE are unreachable, the highest renewable fraction achieved in the simulations corresponds to 73,8% in the *Ambitious* scenario with biomass boilers. Further on in the discussion chapter, potential solutions to obtain a 100% renewable fraction will be proposed.

### 7.2.4 CO$_2$eq emissions

Figure 36 presents the cumulative yearly CO$_2$ equivalent emissions produced when operating the entire heating sector of the city. It can be inferred the reduction of CO$_2$eq emissions after the transformation process is finalized in 2050. The reduced use of N-Gas over the investigated period as well as the phase out of fossil fuels out of the system has triggered the successful partially decarbonisation of the heating sector. As pointed out in the graph, the heating sector has reduced its heating related emissions by 72% in the *Low* scenarios and by almost 77% in the *Ambitious* situations, compared to current levels.
Regarding the BAU scenario, the emissions would be reduced mainly because of the decrease in final heat demand due to the renovation of the building stock and to a lesser extent because of the extension DH projects. However, the resulting amount of emissions produced is still considerably high and cannot be accepted in 2050 levels. As before, potential solutions to achieve a CO$_2$ neutral heating sector will be discussed in the ensuing chapter.

![Graph showing CO$_2$eq emissions](image)

**Figure 36. CO$_2$eq emissions produced from the operation of the heating sector**

Considering an emission price of 100 €/ton in the year 2050 [41], and compared to a BAU scenario, the different variants of the Low and Ambitious scenarios would achieve the following monetary savings regarding the reduced CO$_2$eq emissions produced within the heating sector. These are calculated as the difference between the values in the BAU and in each of the scenarios.

<table>
<thead>
<tr>
<th>Monetary savings (€) related to reduced CO$_2$ emissions of a Low or Ambitious scenario compared to a BAU scenario in 2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low: Biomass</strong></td>
</tr>
<tr>
<td>1,035,900</td>
</tr>
</tbody>
</table>

The present research has only focused on two years of the investigated period from 2015 to 2050. In order to obtain an overall picture of the cumulative monetary savings accomplished year by year during the whole transformation process, a detailed steeply study for intermediate periods is required e.g. the same study for 2020, 2030 and 2040. In this way, the combined monetary savings from the reduced CO$_2$eq emissions cannot be estimated yet since how the transformation process i.e. final heat demand, DH extension plan, solar thermal integration, etc. is going to change from 2015 to 2050 is yet unknown. A roadmap
specifying all the steps to perform year by year is required for a further extension of the research presented here.

### 7.2 Summary of the results

The following four pages use the core concept of the thesis to provide the best illustrative findings. While the numerical results obtained in the simulations are fundamental to understand the overall balance within the heating sector studied, however, they do not address the spatial extent of the thesis. In order to represent the different scenarios on the map, QGIS is used again to create maps that, going deep into the building level, provide an understanding of how the heating sector will be composed in 2050. Three different maps are created to represent the main aspects defining the scenarios: distribution of future heating systems, renovation state of buildings and solar thermal penetration in the city.

On this basis, a fact sheet combining graphs, maps and numerical results is created for each scenario with the purpose to explain how the heating sector of Gleisdorf is now constituted and how it will look like in 2050.
Holistic urban energy planning in temporal and spatial resolution for the city of Gleisdorf

Heating system distribution (Map 8)

Renovation state (Map 11)

Solar thermal collector areas in central heating buildings

- Final heat demand: 120.859 MWh/year
- CO₂eq emissions: 31.194 ton/year
- System efficiency: 88.46%
- Solar fraction DH: 2.55%
- Solar fraction heating sector: 1.45%
- Share of renewables: 21.95%

STATUS QUO
Heating system distribution (*Map 29*)

Renovation state (*Map 26*)

Solar thermal collector areas in central heating buildings (*Map 39*)

**Final heat demand:** 78,788 MWh/year
**$\text{CO}_2\text{eq}$ emissions:** 19,085 ton/year
**System efficiency:** 89.45%
**Solar fraction DH:** 3.85%
**Solar fraction heating sector:** 2.51%
**Share of renewables:** 26.23%

**Heat production [%]**
- N-Gas Boiler: 57.2%
- Oil Boiler: 16.2%
- Biomass Boiler: Wood Chips: 14.8%
- Biomass Boiler: Wood Pellets: 4.8%
- Electric Heating System: 2.5%
- Solar Thermal: 3.3%
- Heat Pump: 16.8%

**Primary energy consumption [%]**
- N-Gas: 58.8%
- Oil: 16.7%
- Biomass: Wood Chips: 15.5%
- Biomass: Wood Pellets: 5.0%
- Imported Electricity: 3.5%
- Coal: 0.0%
Holistic urban energy planning in temporal and spatial resolution for the city of Gleisdorf

Heating system distribution (Map 30)

Renovation state (Map 27)

Solar thermal collector areas in central heating buildings (Map 33)

Heat production [%]

Primary energy consumption [%]

Final heat demand: 73,835 MWh/year
CO₂eq emissions: 8,726 ton/year
System efficiency: 114,1%
Solar fraction DH: 9,7%
Solar fraction heating sector: 12,3%
Share of renewables: 71,3%

LOW SCENARIO (Biomass)
Heating system distribution (Map 31) | Renovation state (Map 28) | Solar thermal collector areas in central heating buildings (Map 34)

Final heat demand: 68,459 MWh/year
CO₂eq emissions: 7,245 ton/year
System efficiency: 128.8%
Solar fraction DH: 17%
Solar fraction heating sector: 20%
Share of renewables: 72.8%

**AMBITIOUS SCENARIO (Heat Pump)**

- Heat production [%]:
  - N-Gas Boiler: 26.0%
  - Biomass Boiler: Wood Chips: 11.9%
  - Biomass Boiler: Wood Pellets: 20.1%
  - Solar Thermal: 42.0%
  - Heat Pump: 20.1%

- Primary energy consumption [%]:
  - N-Gas: 36.4%
  - Biomass: Wood Chips: 3.4%
  - Biomass: Wood Pellets: 36.4%
  - Imported Electricity: 60.2%
8. DISCUSSION

In this chapter the findings are explained and interpreted in order to discuss the objective of this research. A critical evaluation of the study is also given to understand and point out the limitations of the research. Finally, the approach taken is justified in the view of the outcome of the obtained results and the existing knowledge about the subject.

8.1 Comparison of the scenarios

In this section, the scenarios are compared in terms of the indicators presented in the results chapters. Sustainability criteria will be ruling the benchmark assessment and will judge which scenario can provide a better clean, affordable and efficient solution for the future heating sector of the city.

- The scenario that achieves the higher reduction of final heat demand, a 44% compared to the reference year, is any of the variants of the Ambitious situations.
- The scenario that consumes less primary energy for the production of the final heat demand corresponds to the Ambitious with heat pumps situation.
- The scenario that achieves the lowest CO$_{2eq}$ emissions and the highest reduction, almost 77% compared to the reference year, is the Ambitious with heat pumps situation.
- The scenario with the highest %RE i.e. 73,8%, corresponds to the Ambitious with biomass situation.
- The scenario that achieves the highest solar thermal penetration ratio, both in the DH network as well as in the central heating buildings, is the Ambitious with heat pumps situation. This corresponds to 20,1% of the total heat produced for the city.
- The scenario which operates most efficiently the heating sector of the city, with an efficiency value of 129%, is the Ambitious with heat pumps situation.

It is clear then that the heating sector of Gleisdorf for the year 2050 that yields the best performance is represented by the Ambitious with heat pump scenario. After applying energy conservation and energy transition measures to trigger the transformation process, among the proposed systems, this is the solution that contaminates less and makes the best use of the available resources. Table 23 shows how each of the remaining scenarios rank in all the sustainability indicators mentioned before. Please take 1 as the maximum ranking and 5 the worst position.

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Final heat demand</td>
<td>Minimum</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Primary energy consumption</td>
<td>Minimum</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>CO$_{2eq}$ emissions</td>
<td>Minimum</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>%RE fraction</td>
<td>Maximum</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>% Solar fraction</td>
<td>Maximum</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>Maximum</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
From Table 23 it is possible to infer two different trends. The first one indicates the better performance of heat pumps compared to biomass boilers regardless of the Low or Ambitious scenario. The second trend situates the Low scenario always behind the Ambitious scenario in any of the sustainability indicators considered. It should be noticed however, that if future developments of the project take into account the investments costs incurred during the transformation process, the Low situation would probably become more economically profitable than the Ambitious scenario. This is explained by the different renovation maps assumed in Section 5.1. Not only the Ambitious scenario has agreed on a greater yearly renovation rate, therefore it requires a higher budget for building refurbishment tasks, but also the selected renovation scheme, Advanced, is more expensive than the Usual solutions.

Combining both findings, it should be pointed out that in the case the Low scenario is chosen for the transformation process, the situation which uses biomass boilers in the central heating buildings would incur the best performance.

In order to present the success of the results, the following findings are presented.

- According to the proposed building renovation roadmap, Gleisdorf could save by 2050, 35.1 GWh and 38.0 GWh in the Low and Ambitious scenario, respectively. This corresponds to a 42% and 46% reduction from the 2015 heat demand for space heating.
- According to the assumed improvements on the heating supply systems, Gleisdorf could save by 2050, 10.6 GWh and 14.0 GWh in the Low and Ambitious scenario, respectively. This corresponds to a 52% and 70% reduction from the 2015 heat demand due to losses between production and distribution side.
- Considering both energy saving measures, Gleisdorf’s total final heat demand of 2015 has been reduced in 47.5 GWh and 53.4 GWh or by 39% and 44% in the Low and Ambitious scenario, respectively.
- Compared to a BAU scenario, Gleisdorf’s heating sector could reduce CO\textsubscript{2eq} emissions in 10.400 ton and 11.800 ton or by 54.5% and 62%, in the Low and Ambitious scenario, respectively. Likewise, the overall CO\textsubscript{2eq} emissions reduction achieved in the proposed systems is of 22.500 ton and 23.900 ton or by 72% and 77%, in the Low and Ambitious scenario, respectively and compared to the current year.

8.2 100% renewable and CO\textsubscript{2} neutral targets

Given the results so far it is clear that Gleisdorf’s heating sector could not be supplied by 100% renewable sources by 2050 or could not be CO\textsubscript{2} neutral by 2050. Both targets are interrelated since the main obstacle is the presence of the N-Gas network in the city and the use of N-Gas fuelled boilers for the peak load of the DH network. To a lesser extent, although it is a renewable energy source, the use of biomass also contributes to the CO\textsubscript{2eq} emissions of the system. Here two possible solutions are proposed. The first one aims to achieve the presented targets while the second is rather focused towards increasing the efficiency of the system while reducing the amount of N-Gas consumed.

The first solution proposes replacing the supply of N-gas by a fuel with similar characteristics that could be distributed through the already existing pipeline infrastructure. Previous studies on decarbonisation pathways of energy systems have pointed out that current N-Gas networks will be mostly abandoned by 2050 [46]. However, there is potential to reutilise the existing pipeline infrastructure to continue supplying energy to the still connected buildings. Gas decarbonisation options where the main fuel is replaced range
from bio-methane, hydrogen injection to the N-Gas or adaptation of the network to deliver hydrogen.

Bio-methane is either produced upgrading biogas from anaerobic digestion to up to 99% of methane composition, or cleaning a syngas from gasification of biomass [47]. Both options result in a gas which is 100% renewable and is carbon-neutral. Although the combustion of bio-methane releases biogenic carbon dioxide, this is not additional to the natural carbon cycle since the carbon content comes from plant matter that fixed this carbon from atmospheric CO\(_2\). Moreover, from a lifecycle perspective, the emissions savings from displacing conventional natural gas production far outweigh bio-methane’s production emissions [48]. If a future heating system considers supplying bio-methane through the existing grid infrastructure, a number of the indicators previously mentioned would be affected. Not only the %RE of the heating sector would rise to 100% and the CO\(_{2eq}\) emissions would be slightly reduced, but also from a lifecycle perspective, the use of this fuel would be CO\(_2\) neutral. The following issue to discuss would concern the production of the required biogas or syngas, and in turn the self-sufficiency extent of the heating sector. While biogas could be produced via an anaerobic digestion process where the feedstock ranges from a variety of organic matter types, a syngas would require a gasification plant of biomass.

Another option would be to inject hydrogen into the distribution natural gas network. The level of hydrogen that could be safely added depends on the characteristics of the existing natural gas system and on the design of the end-user appliances [46]. This solution would reduce the carbon content of N-Gas and therefore low the CO\(_2\) emissions when being combusted. At the same time, the renewable fraction of the heating system would rise close to 100% if hydrogen is produced from renewable electricity through a Power-to-Gas technology, or from fossil fuel resources with carbon capture and storage [49]. These are two potential fuel alternatives of N-Gas that can achieve great progress towards the 100% renewable and CO\(_2\) neutral targets.

The second solution suggested consists on replacing the N-Gas boilers by absorption gas heat pumps. H. Hans Martin et al. draws the same conclusion regarding the type of heating systems that will prevail in 2050 [41]. The use of absorption gas heat pumps is beneficial in respect of the condensing N-Gas boilers since they have higher efficiencies or gas utilization efficiency. Unlike a N-Gas boiler, with efficiencies of 92% considered in the simulations, absorption gas heat pump can transfer to the medium to be heated between 130% and 150% of the input energy [50]. As a result, the use of the mentioned units would reduce the amount of N-Gas consumed as well as its incurred CO\(_{2eq}\) emissions.

8.3 Effect of wrong estimations in the methodology

This section aims to provide an evaluation of the more critical assumptions taken through the thesis.

8.3.1 Estimation of building number of floors

The procedure to estimate the number of floors presented in Section 3.2.4 relies on the calculated statistics of the existing building stock in the city. It ensures that the resulting statistics with the new assumed values comply with the previously distribution of number of floors according to the building use of the units. In this way, the methodology does not affect the average value but however, it might incur errors since the allocation is made randomly. In
order to obtain a refined database and reduce the arisen inaccuracies as possible, two different approaches are proposed here.

The first corresponds to a more conventional method consisting on physically checking the attribute of number of floors using pictures or real time observations. Considering that Google Maps is not available on Austrian soil, the approach would require a physical visit to each missing building to identify its number of floors. The second approach is based on analysing the terrain characteristics with GIS tools. It requires obtaining a high resolution i.e. 1 meter per 1 meter, digital surface model (DSM) and digital elevation model (DEM) of the studied territory. The methodology follows as:

1. Calculate the normalized digital surface model (nDSM) as the difference between DSM and DEM, and obtain the height of all the protruding elements on the ground.
2. Use the existing building database to identify which of those heights correspond to a building unit. Then, the height of all buildings is obtained.
3. Perform statistics on the calculated heights corresponding to a same building unit to obtain the average height value. Heights might differ because of pitched roofs.
4. Assume a typical floor height and calculate the resulting number of floors for each building.

This approach was tested with digital terrain models with resolution of 10 per 10 meters. Nevertheless, due to the low resolution of the input data, the results were not as accurate as expected; therefore, the actual methodology was considered the best way to follow and it prevailed in the thesis.

8.3.2 Estimation of current renovation state of the buildings

The current renovation state of the buildings was estimated only for the residential units. The reason is because TABULA, the tool used for that, only includes this category of buildings. In an attempt to estimate the renovation state of the residential sector, a methodology based on current practice and expert opinion was developed. The methodology was based on Austrian conditions (typical Austrian comfort temperatures [34] and current weather profiles of Gleisdorf) and validated with other references.

An important issue here concerns the renovation state of buildings in the commercial, industry or communal sector. These were assumed not renovated regardless of its current HWB value in the GIS DB. It is expected that this assumption incurs some errors leading to an over estimation of the heating demand of given buildings. A second analysis of the database focused on those sectors has noticed that among the 440 buildings estimated as not renovated in current levels; only 49 and 13 units could be already renovated under Usual or Advanced measures, respectively. This new computation is taken as follows:

- If HWB < 50 Renovation state is Advanced
- If HWB ≥ 50 and HWB < 100 Renovation state is Usual
- If HWB ≥ 100 Building is not renovated

Although the incurred error is not critical, it is suggested that future developments of the project put more effort in investigating the renovation state of these sectors.

8.3.3 Future renovation in the commercial, communal and industry sector

Similarly as before, buildings in commercial, industry and communal sector are assumed to remain unchanged during the transformation process. This is because no information regarding future development trends in those sectors was found. Moreover, the author
Holistic urban energy planning in temporal and spatial resolution for the city of Gleisdorf considers that these buildings should be studied individually instead of assuming a specific trend for all units in the sector. Being critical with the study, the assumption taken would be partially erroneous for some buildings (explained below), which will probably undergo a renovation process by 2050. As a consequence, the results of heat density within the city could have been overrated.

In particular, an analysis of the database has pointed out that if renovation was considered in those sectors, the final heat demand for the BAU, Low and Ambitious scenarios would be reduced by 8.689 MWh or on average would be 16% lower compared to the current calculations. This new computation is based on a decrease of 50% of HWB values for all the buildings in the commercial or communal sector that have a current HWB above the average of the city, hence 120 kWh/(m²a). Due to the indicative character of the studied error, it is recommended then for future developments of the thesis to put more effort in investigating the particular evolution trends of each building in these sectors.

8.3.4 Prediction of future temperatures

The prediction of temperatures in 2050 has also been a critical issue in the project. It was required to climate adapt the actual ambient temperature profiles according to climate change effects expected in the future. For that, the heating degree day method (HDD) was applied, however also based on assumptions regarding the calculation of HDD for the 2050 year.

A solution to refine the future temperature profile and achieve improved results of future space heating requirements due to thermal losses would be to use hourly profiles for the year 2050 retrieved from the Meteonorm software. It should be noticed that these could not be obtained at the time of the realisation of the thesis.

8.3.5 Temperature assumptions in the HWB calculations

Hourly space heat requirements are calculated depending on the internal comfort temperature, assumed to be 20 °C, and the threshold temperature under which the functioning of the building heating system is required, assumed to be 12°C. As explained before, these were taken from [34] and assumed constant over the investigated period. However, different assumptions on these temperatures would lead to different results. For example, Eurostat considers 18°C as internal comfort temperature. In this case, if this was the most accurate value, the results of space heat demand obtained here would be overestimated since the heat requirements to raise the comfort temperature two extra degrees would be accounted.

8.3.6 Process heat demand from industries

An inclusion of process heat demand from the industry sector would change the heat density distribution within the city. Maps from Figure 22 would incorporate red hot spots right where the different industries are located. It should be noticed that this fact would not alter the heat density of other areas of the city but just the adjoining raster areas.

However, the DH extension opportunities would be focus of revision. Not only because a new type of heat demand should be provided in a network-based infrastructure, but also because the addition of these costumers could be useful to incorporate process waste heat streams into the network.

8.3.7 Generation of hourly profiles

The temporal resolution of the planning project is fundamental to be able to balance available resources and demands at any time. Regarding the demand side, hourly profiles generated by the simulation software have been used. This approach is justified since no
hourly time series of the heating sector were available, however, down below is suggested the best way to follow if resources were accessible.

As has been commented during the report, the heating sector of the city can be understood under three big heating supply groups. Two corresponding to heat supplied by a common network infrastructure, DH and N-Gas pipelines, and the third consists on the remaining buildings which produce their own heat with a central heating system. While the hourly profiles of this last group can be difficult to obtain, the two other time series data should be collected for the future developments of the project through collaboration with the responsible parties of supplying the heat or fuel through the networks. These must have extensive records on the hourly demands from the whole community. Using real profiles in the simulations will make the results of required new capacity to install and production schedules more trustable for the energy planning process.

8.4 Urban energy planning with GIS and numerical analysis approach

The introduction of GIS tools into the research provides a new and innovative aspect and shows high added value to current urban energy planning approaches. In this context, the utilization of the software QGIS has widened the analysis of the energy system and allowed the interpretation of results in a spatial context. This fact has raised the complexity of the thesis and has become the differential factor of the presented work when compared to a traditional energy planning project focused on balancing supply and demand side in temporal resolution.

Chapter 5 is the perfect example of how the thesis provides insight of the benefits resulting from combining GIS tools with numerical analysis. This is found in the two first steps of the methodology of scenario creation: the DH extension opportunities could not have been studied without the previously assumption of future renovation states of the building stock and its corresponding prediction of space heating demand. In this way, the numerical results of final heat demand were the basis for the calculation of the heat density distribution within the city. In turn, without the application of a GIS-based spatial analysis, the DH extension opportunities would not have made sense. It is clear to see that both tasks are interrelated.

Another of the key benefits of using GIS tools relies on its inherent power to illustrate results and draw conclusions from that. From today's perspective and under the context of an energy transition process, a building retrofit project is more likely to happen when the unit can be improved from different aspects (e.g. to reduce thermal losses, to update of central heating system or to be connected to a DH network). Then, GIS maps are able to identify those buildings which have a common interest to undergo a transformation process because of its inefficient thermal envelope, therefore focus of renovation, and because of its location in a DH potential extension area, therefore are future candidates to be included in the DH network.

The representation of results in any research is critical to ease the understanding of the reader. On these lines, GIS tools serve to engage the public in the presented work in a way that results can easily be perceived and a higher interest is created. Moreover, illustrative results could be useful when applied to a decision making process.

Finally, an aspect that could be improved in further developments of the project is presented here. A combination of GIS tools with the current numerical analysis could be used to better define the solar thermal penetration in the city. While numerical methods are already applied to come up with the required solar collector areas to install, GIS tools should be incorporated to find out its optimum location. In this way, the thesis could use solar
radiation maps of the city to identify the areas with the highest solar potential. Regarding solar plants for the DH network, ground-areas should be identified, whereas when referring to individual buildings installations, the best regions of the rooftops should be selected.
9. CONCLUSIONS

This thesis has demonstrated the suitability of the presented methodology to assess the current and future heating demand of a city and to develop an urban energy planning process based on this information. In particular, the study has addressed the original research question of how to develop a potential heating system supplied by 100% renewable sources and evaluate its actual feasibility. By applying this methodology, a potential redesign of the current heating sector of Gleisdorf through sustainable transformation pathways in line with the future energy transition focuses of 2050 was presented, hence allowing decarbonisation and renewable integration.

Quantitative results comparing the proposed systems have pointed out that the Ambitious scenario with heat pumps is the potential future heating system that can achieve the most efficient energy conversion process. A detailed investigation of the scenario indicates, compared to current levels, its ability to reduce final energy demand by 44% as a result of an ambitious energy renovation process of the building stock and retrofit of heating systems, its ability to reduce the primary energy consumed by 60% due to a high proportion of heat pumps for building heating as well as a significant penetration of solar thermal technology, as well as its capability to reduce heat production related CO$_{2}$eq emissions by 77%.

The comparison of the explored schemes shows that Low scenarios usually lead to least desirable energy performances compared to Ambitious scenarios when the economic extent of the transformation process is omitted. At the same time, scenarios considering heat pumps in the central heating buildings result with better values of primary energy consumption, overall system efficiency and CO$_{2}$eq emissions, while scenarios using instead biomass boilers derive better results in terms of renewable fractions.

It becomes clear that Gleisdorf’s heating sector holds a great potential for energy savings and CO$_{2}$ emissions reduction if energy conservation and energy transition measures are put in place. From the presented analysis it can be derived that the success of such an urban energy planning process relies on two different aspects. First, the methodology needs to evaluate all the potential transformation opportunities from the end-consumer side, i.e. building level, passing through the distribution sector, and finalising on the production side. The second fundamental component of the methodology relies on the resolution used within the analysis. On this basis, the higher the resolution analysis is in all mentioned levels, the more qualified knowledge can be retrieved and the more realistic and accurate planned systems can be obtained.

The key aspect of the presented methodology consists on the combination of different tools to approach each of the comprising phases. From spreadsheet-based processes, GIS-based spatial and numerical analysis, application of engineering models to the modelling and simulation of the scenarios with energyPRO, the thesis is supported with a multitude of tools which are used according to its suitability for each task. In this way, the thesis aims to provide insights of how the development of a clear methodology combining different tools is relevant for the quality of the energy planning results. Along these lines and referring to one of the initial purposes of the study, the presented methodology is expected to serve as basis of knowledge to other research works as well as to have a wider applicability to similar urban energy planning projects.

Last but not least, the study desires to highlight the importance of accessible data for such an extensive process with interrelated sections. As it has been mentioned throughout the paper, the thesis has been forced to rely on assumptions in order to fill the unavailability of information. Although these have been contrasted and justified, since the current project
refers to real data, the incorporation of suppositions to the thesis undermines the reliability and limits the applicability of the results (and not the methodology) to indicators of a test study.
10. VALORIZATION CHAPTER

The thesis presented here shows great starting points for projects aiming to move towards urban and regional systems that can provide affordable, efficient and sustainable energy for its communities. Although the study approaches energy efficiency and energy conversion measures, the most important value captured from the proposed solution is related to the term of supplying sustainable energy, which in turn concerns the overall end goal of tackling climate change. In particular, the research has demonstrated the ability of the future heating system of Gleisdorf in 2050 to reduce current levels of CO$_{2eq}$ emissions by 77%. Further measures to increase this fraction have been highlighted as well.

The value described here is created through human effort collaboration i.e. cooperation between all the implicated partners (administration, supply services, costumers, etc.), while applying technological and scientific knowledge provided by the professionals in charge to develop the project. In terms of the involved players in the project, all of them capture value through mutual beneficial activities. While all players would capture value through the common good of a less contaminated atmosphere and a more thoughtful use of the resources, each of them could also experience a long-term economic benefit from the implementation of the project. For example, end-consumers in the building level would experience considerable economic savings in energy consumption or procurement heat companies would acquire revenues from supplying community based heat.

Finally, the thesis also aims to create value within the concept of new methodologies to address energy transition processes. In particular, a holistic urban and energy planning approach was used which is expected to serve as basis of knowledge to other research studies.

Following the structure of the canvas model, a business plan for the energy transformation process described in the thesis would involve:

1. **Key partners:** end-consumers in the building level, energy supply companies, local governments, research institutes which may include engineers, architects and urban planners.
2. **Key activities:** refurbishment of building stock, district heating extension, retrofit of heating systems and solar thermal collectors installations.
3. **Key resources:** knowledge of research institutes, heat supply infrastructure and heat production units.
4. **Value proposition:** reduction of energy related CO$_2$ emissions, reduced heat consumption and economic savings.
5. **Customer relationships:** to achieve an efficient and clean heating sector with reduced costs
6. **Customer segments:** urban and regional communities, which include end-consumers in the building level and energy supply companies.
7. **Channels:** active collaboration between the administration, research institutes and energy supply companies. Communication to end-users in the building level.
8. **Cost structure:**
   a. **Fixed costs:** implementation costs including thermal renovation activities, investment in new heating supply systems, district heating extension infrastructure, new construction of heating plants.
   b. **Variable costs:** heat production cost.
9. *Revenue streams*: reduction of heat related energy bills in the long term for end-consumers in the building level, revenue from distributing heat for the district heating supply company/organism in charge.
REFERENCES


[29] DIN 4108-6, "Thermal protection and energy economy in buildings,Part 6 - Calculation


[44]  Convenant of Mayors, "Technical annex to the SEAP template instructions document: The emission factors".


Appendix A: Support material for Chapter 3

Table A. 1. Initial heating system and fuel source categorization and its clustering in final 8 categories

<table>
<thead>
<tr>
<th>Provided current Heating System</th>
<th>Categorized heating system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomasse</td>
<td>Biomass</td>
</tr>
<tr>
<td>Elektro</td>
<td>Electricity</td>
</tr>
<tr>
<td>Elektro Heizungen</td>
<td>Electricity</td>
</tr>
<tr>
<td>Fernwärme</td>
<td>District Heating</td>
</tr>
<tr>
<td>Fernwärme Solar</td>
<td>District Heating</td>
</tr>
<tr>
<td>Gas</td>
<td>Gas</td>
</tr>
<tr>
<td>Gas Solar</td>
<td>Gas</td>
</tr>
<tr>
<td>Gas-Nahwärme</td>
<td>Gas</td>
</tr>
<tr>
<td>Hackschnitzel</td>
<td>Biomass</td>
</tr>
<tr>
<td>keinen</td>
<td>None</td>
</tr>
<tr>
<td>Kohle</td>
<td>Coal</td>
</tr>
<tr>
<td>Öl</td>
<td>Oil</td>
</tr>
<tr>
<td>Pellets</td>
<td>Biomass</td>
</tr>
<tr>
<td>Solare-Biowärme</td>
<td>District Heating</td>
</tr>
<tr>
<td>Sonstiges</td>
<td>Others</td>
</tr>
<tr>
<td>Stückholz</td>
<td>Biomass</td>
</tr>
<tr>
<td>Stückholz Solar</td>
<td>Biomass</td>
</tr>
<tr>
<td>Wärmepumpe</td>
<td>Heat pump</td>
</tr>
<tr>
<td>Wärmepumpe Solar</td>
<td>Heat pump</td>
</tr>
</tbody>
</table>

Table A. 2. Irregular buildings identified and its correction of attributes

<table>
<thead>
<tr>
<th>Building ID</th>
<th>Modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>2145</td>
<td>Change to residential sector</td>
</tr>
<tr>
<td>1507</td>
<td>Change to industry sector</td>
</tr>
<tr>
<td>1714</td>
<td>Change to communal sector</td>
</tr>
<tr>
<td>1763</td>
<td>Change to residential sector</td>
</tr>
<tr>
<td>126</td>
<td>Object elimination due to wrong spatial definition</td>
</tr>
<tr>
<td>2149</td>
<td>Object elimination due to wrong spatial definition</td>
</tr>
</tbody>
</table>

1 Given in German language
Table A. 3. HWB values in the actual, usual and advanced state for each building category, used to estimate a renovation state of the existing building stock of Gleisdorf.

<table>
<thead>
<tr>
<th>Period</th>
<th>Type</th>
<th>Initial state</th>
<th>Usual</th>
<th>Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1918</td>
<td>Single Family House</td>
<td>253,66</td>
<td>72,13</td>
<td>54,11</td>
</tr>
<tr>
<td></td>
<td>Terraced House</td>
<td>177,46</td>
<td>59,86</td>
<td>47,79</td>
</tr>
<tr>
<td></td>
<td>Multi Family House</td>
<td>194,63</td>
<td>56,67</td>
<td>50,88</td>
</tr>
<tr>
<td></td>
<td>Apartment Block</td>
<td>154,39</td>
<td>56,04</td>
<td>52,36</td>
</tr>
<tr>
<td>1919-44</td>
<td>Single Family House</td>
<td>227,12</td>
<td>57,94</td>
<td>51,19</td>
</tr>
<tr>
<td></td>
<td>Terraced House</td>
<td>160,47</td>
<td>58,88</td>
<td>48,27</td>
</tr>
<tr>
<td></td>
<td>Multi Family House</td>
<td>186,10</td>
<td>62,41</td>
<td>48,31</td>
</tr>
<tr>
<td></td>
<td>Apartment Block</td>
<td>136,43</td>
<td>52,17</td>
<td>45,16</td>
</tr>
<tr>
<td>1945-59</td>
<td>Single Family House</td>
<td>175,87</td>
<td>57,51</td>
<td>45,29</td>
</tr>
<tr>
<td></td>
<td>Terraced House</td>
<td>311,91</td>
<td>76,73</td>
<td>61,00</td>
</tr>
<tr>
<td></td>
<td>Multi Family House</td>
<td>158,77</td>
<td>83,51</td>
<td>55,42</td>
</tr>
<tr>
<td></td>
<td>Apartment Block</td>
<td>107,54</td>
<td>47,97</td>
<td>41,92</td>
</tr>
<tr>
<td>1960-79</td>
<td>Single Family House</td>
<td>237,50</td>
<td>78,13</td>
<td>62,14</td>
</tr>
<tr>
<td></td>
<td>Terraced House</td>
<td>266,16</td>
<td>74,61</td>
<td>72,72</td>
</tr>
<tr>
<td></td>
<td>Multi Family House</td>
<td>161,05</td>
<td>57,55</td>
<td>45,00</td>
</tr>
<tr>
<td></td>
<td>Apartment Block</td>
<td>134,24</td>
<td>56,73</td>
<td>51,97</td>
</tr>
<tr>
<td>1980-89</td>
<td>Single Family House</td>
<td>227,24</td>
<td>92,43</td>
<td>62,04</td>
</tr>
<tr>
<td></td>
<td>Terraced House</td>
<td>182,97</td>
<td>72,58</td>
<td>59,17</td>
</tr>
<tr>
<td></td>
<td>Multi Family House</td>
<td>85,16</td>
<td>69,32</td>
<td>59,33</td>
</tr>
<tr>
<td></td>
<td>Apartment Block</td>
<td>80,39</td>
<td>52,92</td>
<td>45,67</td>
</tr>
<tr>
<td>1990-99</td>
<td>Single Family House</td>
<td>139,32</td>
<td>96,69</td>
<td>75,59</td>
</tr>
<tr>
<td></td>
<td>Terraced House</td>
<td>96,17</td>
<td>70,33</td>
<td>51,41</td>
</tr>
<tr>
<td></td>
<td>Multi Family House</td>
<td>86,39</td>
<td>58,67</td>
<td>51,66</td>
</tr>
<tr>
<td></td>
<td>Apartment Block</td>
<td>85,94</td>
<td>57,17</td>
<td>45,39</td>
</tr>
</tbody>
</table>

Table A. 4. Abbreviations of the different attributes

<table>
<thead>
<tr>
<th>Building use</th>
<th>Fuel type</th>
<th>Type of residential</th>
<th>Period</th>
<th>Renovation state</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wohnen</td>
<td>W</td>
<td>Elektro</td>
<td>SFH SFH</td>
<td>&lt;1918</td>
</tr>
<tr>
<td>Beides</td>
<td>B</td>
<td>Solare-Biwärme</td>
<td>MFH MFH</td>
<td>1919-44</td>
</tr>
<tr>
<td>Sonstiges</td>
<td>S</td>
<td>Wärmepumpe</td>
<td>TH TH</td>
<td>1945-59</td>
</tr>
<tr>
<td>Industrie</td>
<td>I</td>
<td>Kohle</td>
<td>AB AB</td>
<td>1960-79</td>
</tr>
<tr>
<td>Gewerbe</td>
<td>G</td>
<td>Öl</td>
<td>Napp Na</td>
<td>1980-89</td>
</tr>
<tr>
<td>Kommunal</td>
<td>K</td>
<td>Gas</td>
<td></td>
<td>1990-99</td>
</tr>
<tr>
<td>Industrie/G</td>
<td>I</td>
<td>Sonstiges</td>
<td></td>
<td>2000-20</td>
</tr>
<tr>
<td>gewerbe</td>
<td>G</td>
<td>Biomasse keinen</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Holistic urban energy planning in temporal and spatial resolution for the city of Gleisdorf

Table A. 5. Weighted average values of HWB of building groups in the mixed sector

<table>
<thead>
<tr>
<th>HWB [kWh/(m²·a)] of building groups in the mixed sector (Beides)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1_B_B/Na:NR</td>
<td>230,00</td>
</tr>
<tr>
<td>1_E_B/Na:NR</td>
<td>176,23</td>
</tr>
<tr>
<td>1_G_B/Na:NR</td>
<td>173,11</td>
</tr>
<tr>
<td>1_O_B/Na:NR</td>
<td>152,30</td>
</tr>
<tr>
<td>1_S_B/Na:NR</td>
<td>94,33</td>
</tr>
<tr>
<td>1_SB_B/Na:NR</td>
<td>190,00</td>
</tr>
<tr>
<td>2_G_B/Na:NR</td>
<td>186,43</td>
</tr>
<tr>
<td>3_G_B/Na:NR</td>
<td>128,11</td>
</tr>
<tr>
<td>3_O_B/Na:NR</td>
<td>192,35</td>
</tr>
<tr>
<td>4_B_B/Na:NR</td>
<td>170,00</td>
</tr>
<tr>
<td>4_E_B/Na:NR</td>
<td>150,00</td>
</tr>
<tr>
<td>4_G_B/Na:NR</td>
<td>153,80</td>
</tr>
<tr>
<td>4_O_B/Na:NR</td>
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</tr>
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Table A. 6. Weighted average values of HWB of building groups in the residential sector

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<td>50,54</td>
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</table>
Appendix B: Support material for Chapter 5

B.1 Estimation of buildings ‘rooftop areas

Assumptions

- Commercial, Mixed, Industry and Communal sectors: flat roofs
- Residential sector: pitched roof with 45° angle

Formula

- If flat roof: \( A_{\text{rooftop}} = A_{\text{ground floor}} \)
- If pitched roof: to correct the horizontally measured roof area to its actual pitched area, sloped roof pitch correction factors are used. For a pitch angle of 45°, the roof pitch consisting on rise/span results in 12/12, and the correction factor takes a value of 1,414 \([51][52]\). Then, \( A_{\text{rooftop}} = A_{\text{ground floor}} \cdot 1,414 \).

\( A_{\text{ground}} \) corresponds to the horizontal area measured on the ground level. These values are obtained from the attribute of built area of each polygon provided in the GIS DB.

B.2 Estimation of the rooftop area suitable for collector instalment

The proportion of rooftop area that is suitable for collector installation corresponds to the one properly orientated and without shadowing effects with neighboring elements. In this basis, the following assumptions are taken.

Assumptions

Orientation factor

- For flat rooftops, the totality of the rooftop area is considered to be properly orientated, therefore \( f_o \) takes 1.
- For pitched rooftops, only the areas faced to the south are considered, therefore \( f_o \) takes 0.5.

Shadow factor

The utilization factor resulting from considering shading from other parts of the roof or neighbouring buildings and trees; roof space for other applications such as ventilations, heating/air conditioning or chimneys or space reduction from the installation of the collectors, is a highly volatile value depending on the assumptions taken in each location. However, after a review of external sources and literature, a value of \( f_s \) equal to 0.3 is taken for this fraction \([53][54]\).

Formula

The calculation of suitable rooftop area for collector instalments follows as \( A_{\text{suitable}} = A_{\text{rooftop}} \cdot f_s \cdot f_o \)

Finally, the conversion factors applied to transform rooftop areas to collector areas are:

- For flat roofs: 3 m\(^2\) rooftop per each m\(^2\) of collector
- For pitched roofs: 1,335 m\(^2\) rooftop per each m\(^2\) of collector
Appendix C: energyPRO input parameters

Table C. 1. Technical parameters of the energy conversion units of heating plants in the main DH network [10].

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<th>Storage Volume [m³]</th>
<th>Rated load [kW]</th>
<th>Min. Partial load [kW]</th>
<th>n-control (min-%)</th>
<th>n-control (max-%)</th>
<th>Duration start [min]</th>
<th>Duration shutdown [min]</th>
<th>Efficiency Rated load [-]</th>
<th>Efficiency Partial load [-]</th>
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<th>Min. Partial load [kW]</th>
<th>n-control (min-%)</th>
<th>n-control (max-%)</th>
<th>Duration start [min]</th>
<th>Duration shutdown [min]</th>
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<th>n-control (max-%)</th>
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<th>n-control (max-%)</th>
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Heizwerk Gartengasse

Heizzerne Kloster

Heizzentrale GenWohnen

Heizzentrale Neue Mittelschule