PRELIMINARY STUDY OF BUILDING A DISTRICT HEATING SYSTEM IN SAN FAUSTO

Analysis of Project's Impact on Consumers' Economy and Examination of Similar Projects in the Region

Aalborg University
Sustainable Energy Planning and Management
Master Thesis
Leire Gorroño Albizu

Title: Preliminary Study of Building a District Heating System in San Fausto - Analysis of Projects' Impact on Consumers' Economy and Examination of Similar Projects in the Region

Project period: 3rd February 2014 to 7th August 2014

Author: Leire Gorroño Albizu

Supervisor: Frede Hvelplund

Number of pages: 100

Appendix: Appendix + CD

Abstract

In a context of economic crisis with high rates of unemployment, an undermined construction sector, lessened household economies and increasing energy poverty rates, Durango's town council started a project for the renovation of San Fausto, a low income neighbourhood characterised by the poor energy performance of its buildings. Even if the project started as a proposal for energy renovation, scope was expanded by adding accessibility and sewage pipeline improvement. The latter entails a fantastic opportunity for building a district heating system because doing both works at the same time would significantly reduce required investment.

The context in which the project is developed implies investment and costs to be covered by consumers are decisive factors for project implementation. Uncertainty regarding amount of buildings that will decide to get connected to the district heating system and on how many of them will accomplish energy renovation makes it necessary to analyse economy of different heat producing technologies in relation to different demand scenarios. Lack of awareness of district heating systems and lack of experience in developing such projects in Spain may result in unexpected obstacles, problems and citizens reactions that could prevent successful project development.

The objective of the preliminary economic analysis carried out in this study is to find out the most economical heat producing technology for further examination in following stages of analysis. In addition, interviews are held to gain knowledge from similar experiences in the region in order to define an effective guideline for future stages of analysis.

Preface

This report is written during the 4th semester of the MSc programme Sustainable Energy Planning and Management at Aalborg University. The study belongs to the initial stage of analysis of building a district heating system in San Fausto, one of the neighbourhoods of Durango, a town in northern Spain.

Harvard method is used for referencing, i.e. (author's surname, year of publication). ‘n.d’ (no date) is written instead of year of publication for the cases in which publication date is not specified.

Appendix A is the interview model used for analysis of district heating projects developed in the Basque Autonomous Community. A CD containing the rest of the appendixes is attached to the report. energyPRO models as well as Excel files with result analysis can be found in it.

Special thanks are given to Igor Zorrakin and Aitor Larruzea, from Durango's town council, and to Jorge Mallagarai and Ángel M. Cea Suberviola, from Maab Arquitectura y Urbanismo, for allowing my collaboration in this project and for their valuable information and time.

I would also like to thank for their time and useful input during interviews and phone calls to:

Begoña Garmendia – Mayor of Beizama

Andrés Fernández – Building engineer at Abadiño town council

Ismael Aranda – Head of Industry Area, Basque Energy Agency

Felipe Pérez – Research and Planning Department, Basque Energy Agency

Ramon Ajuria – Mayor of Aramaio

Idoia Beitia – Town Environment Councillor of Aramaio

Finally my appreciation for provided guidance and support goes to my supervisor Frede Hvelplund.

Table of Contents

1 Introduction

San Fausto is a low income neighbourhood located in Durango. Low living conditions and bad energy performance of its buildings motivated a renovation project that includes improvement of energy efficiency and sewage pipeline and reduction of accessibility barriers. Currently, it is also being considered whether to build a district heating system or not. (Maab, 2014 (a)) Investment and future costs of the system to be covered by householders will be a determinant parameter for its implementation (Maab, 2014 (a)), therefore it is essential to do a deep analysis of system's economy. Nevertheless, economy is expected not to be the only parameter taken into account by San Fausto's residents to approve of dismiss the project.

Negative experience with collective heating systems is well-known in the Basque Autonomous Community, meaning resistance to replace current individual boilers by a district heating system could be found. Apart from that, District heating systems and their project development is new for consumers, town councils and project developers. Hence it is important to analyse similar initiatives in the area in order to find out what aspects are relevant for developing a successful project, what problems could appear during planning process and how to solve them.

The objective of this chapter is to explain the presented problem, which leads to the research question of this study. Accordingly, the chapter starts by explaining the historical reasons why the neighbourhood was built using such low quality building materials. Afterwards, the current Spanish economic crisis and building sector's undermined situation are explained followed by the benefits both, the building sector and energy poverty rates, could achieve from existing buildings' energy performance improvements. Once the case of San Fausto is explained, the issues about lack of awareness of district heating systems and potential resistance to change are introduced. Thereafter the problem is formulated and the research question defined. Finally, the structure of the report is presented.

1.1 Industrialisation, Migration and Poor Quality Buildings

The Spanish Civil War took place between 1936 and 1939 and ended up with the victory of the Francoist side, resulting in a dictatorship that lasted until 1975 (Casanova & Gil, 2012). The Civil War, the autarkist policies of the Francoist Regime and the international isolation led Spanish economy to a precarious situation in the post-war decade. Underdeveloped in science and technology, Spain was a country with high levels of illiteracy, scarcity of raw materials and a small internal market. All of it together with the limited budget and the insufficient and inefficient financial system delayed the reconstruction of the country after the war. GDP and GDP per capita rates did not equal their levels of the year 1935 until 1951 and 1952 respectively. (Barciela, 2014)

Supported by the United States, the liberalisation of the Spanish market and new international relationships started at the beginning of the 50's. With the aim of reducing inflation and external deficit, an economic plan was adopted in 1959 (*el Plan de Estabilización*), which led to the economic development that characterised the 60's. (Barciela, 2014)

This way, Spain joined the second industrial revolution in the mid-20th century. Industry was gathered in the coastal areas and in some of the interior cities such as Madrid, Seville, Zaragoza and Valladolid. Industrialisation brought economic development to those areas and their high labour demand resulted in a significant migration movement from rural areas to industrialised ones. (IGN, n.d.) Between 1950 and 1970, some regions experienced a pronounced increase in population (population increased 97% in Madrid, 77% in the Basque

Autonomous Community and 58% in Cataluña) whereas it was reduced in some other areas such as Castilla y León, Castilla-La Mancha, Extemadura and Galicia (calculated with data from (INE, n.d.)).

The massive immigration rates of the industrialised areas entailed a huge demand on housing, resulting in many cases in chaotic and barely planned urbanism and rapidly built working-class neighbourhoods characterised by their poor quality buildings and infrastructure (Grualba & Pennese, 2014) (Agirre, 1993) –the first mandatory Spanish building code was approved in 1977 (Ministerio de Vivienda, 1977). These neighbourhoods became a clear sign of class distinctions and social imbalances due to their bad living conditions (Grualba & Pennese, 2014).

Most of those poorly constructed working-class neighbourhoods still remain and in spite of some improvements, their comfort standards are far from nowadays' and from other neighbourhoods' they coexist with. (Grualba & Pennese, 2014)

1.2 The Current Economic Crisis and the Drop of the Building Sector

The financial crack of the United States was the trigger for the current Spanish economic crisis. Nevertheless, its gravity and prolonged period are consequences of the Spanish economy's idiosyncrasy and its limited capacity for adjustments as it is a member of the Economic and Monetary Union of the EU. (Ortega & Peñalosa, 2012) (Ruesga, 2013)

Lack of confidence in the international financial market made the Spanish housing market bubble burst due to difficulties to obtain financing and the consequent decline in demand (Ortega & Peñalosa, 2012) (Ruesga, 2013). The building sector was one of the pillars of the country's economy during the decade preceding the crisis –it accounted for 22% of the GDP in 2007– but it was oversized and its drop had a chain effect on other sectors, starting from banking and related industry and services. (Ortega & Peñalosa, 2012) Since the recession began until the third trimester of the year 2011, investments in building were reduced by 40% (Ortega & Peñalosa, 2012), resulting in a large stock of non-sold dwellings and in the reduction of housing and land prices (Ruesga, 2013). In addition, due to its labour intensive character and the low flexibility of the Spanish labour market, the drop of the building sector has had a notorious impact on the unemployment rate (Ortega & Peñalosa, 2012), which was 26% at the end of 2013 (INE, 2014 (a)).

The long duration and seriousness of the current economic crisis has significantly worsened public and private economy (Ortega & Peñalosa, 2012) (Ruesga, 2013). At the end of the year 2013, the percentage of households with all of their active members unemployed was 10.5% (calculated with data from (INE, 2014 (a))) in comparison to 2.5% in 2007 (Fundación FOESSA & Cáritas, 2013). Unemployment, lower salaries (reduced by approximately 4% since 2007) and higher living expenses (increased by 10%) have had a major repercussion on household economies making poverty rate increase from 19.7% in 2007 to higher than 21% in 2012 (Fundación FOESSA & Cáritas, 2013).

1.3 Energy Poverty and Energy Efficiency

The Association of Environmental Sciences (*Asociación de Ciencias Ambientales* (ACA)) defines energy poverty as being *"unable to afford an adequate amount of energy services to satisfy domestic needs"* and/or having *"disproportionate energy expenses as a proportion of income"* (Tirado Herrero, et al., 2012, p. 10). The World Health Organization states indoor temperature should be 18-21 °C in winter and below 25 °C in summer and warns about the negative effects of too low or too high indoor temperatures on health. Cardiovascular and brain damages and illnesses, worsening of infectious and immune illnesses, psychological problems and premature deaths are some of the consequences of living in energy poverty and affect elder people, children and people with chronic diseases in particular.

(Tirado Herrero, et al., 2012) estimates that one out of ten families lived in energy poverty in Spain in 2010. The estimation takes into account households who spend more than 10% of their income on energy bills (this is double the national average) and those who state they cannot keep warm enough temperatures in their dwellings in winter (Tirado Herrero, et al., 2012). Some experts affirm energy poverty to have increased since 2010 and do not consider the number provided by the report to be valid anymore. In 2012, the National Statistic Institute (*Instituto Nacional de Estadística* (INE)) assessed that 18% of the Spanish families could not warm up their homes to an acceptable temperature in winter and 25% could not cool them down enough in summer. (Romero, 2014)

In spite of the gravity of the situation and EU Directives 2009/72/CE and 2009/73/CE, which establish Member Countries should develop plans to address energy poverty issue, Spain does not have an energy poverty strategy yet. In this context, low household income, increasing energy prices and poorly insulated buildings are risk factors for energy poverty. (Tirado Herrero, et al., 2012) According to (Tirado Herrero, et al., 2012), energy policies should approach the issue of energy poverty, establish higher requirements for building insulation and promote energy renovation of buildings –authors consider the latter to be the most long-lasting and effective action to mitigate energy poverty. Apart from that, buildings renovation can reactivate the construction sector and generate employment (17 full-time employments/million EUR), what means it is also beneficial for national economy (Tirado Herrero, et al., 2012).

Improvement of energy performance of existing buildings is one of the targets of the Plan for Energy Savings and Energy Efficiency designed by the Institute for the Diversification and Saving of Energy (*Instituto para la Diversificación y Ahorro de la Energía* (IDAE)) for the period 2011-2020. Total investment required to achieve all the targets defined by the plan is calculated to be 45,985 million EUR, from which 2,883 million EUR will be covered by public subsidies. 59.4% of the investment and 57.7% of the public subsidies will be used for buildings and equipment, making the building sector be the one investing the most in energy efficiency improvements. (IDAE, 2011 (c)) However, (Tirado Herrero, et al., 2012) considers the most vulnerable households are not benefiting from public subsidies for buildings energy renovation.

1.4 San Fausto and its Energy Renovation Project

San Fausto is one of the working-class neighbourhoods of Durango (Maab, 2014 (a)), a town with 28,691 inhabitants (INE, 2014 (b)) located in one of the industrialised areas of the Basque Autonomous Community (Agirre, 1993), northern Spain. Built between mid 50's and mid 60's, the neighbourhood occupies an area of 3.2 hectares and consists of 53 buildings (Maab, 2014 (a)), see Figure 1 on the following page, which sum 508 dwellings and 24 trade premises.

As most of the working-class neighbourhoods built during that period, buildings and infrastructure were poorly built using law quality materials and no insulation (Maab, 2014 (a)). Despite some renovations such as changing windows or installing natural gas boilers, the comfort rate is considerably below the average in Durango (Maab, 2014 (a)), see Figure 3 on page 5. The comfort rate was designed by EUSTAT (Basque Statistics Institute) to measure level of comfort and well-being dwellings provide to householders based on dwellings' facilities and services (EUSTAT, n.d.).

Energy performance of buildings is also poor. According to Maab Architect Studio, the energy performance of the most common dwelling type (i.e. a dwelling with 49 m^2 of heated area) can be categorised as an E performance according to the Energy Performance Certificate scale. (Maab, 2014 (a))

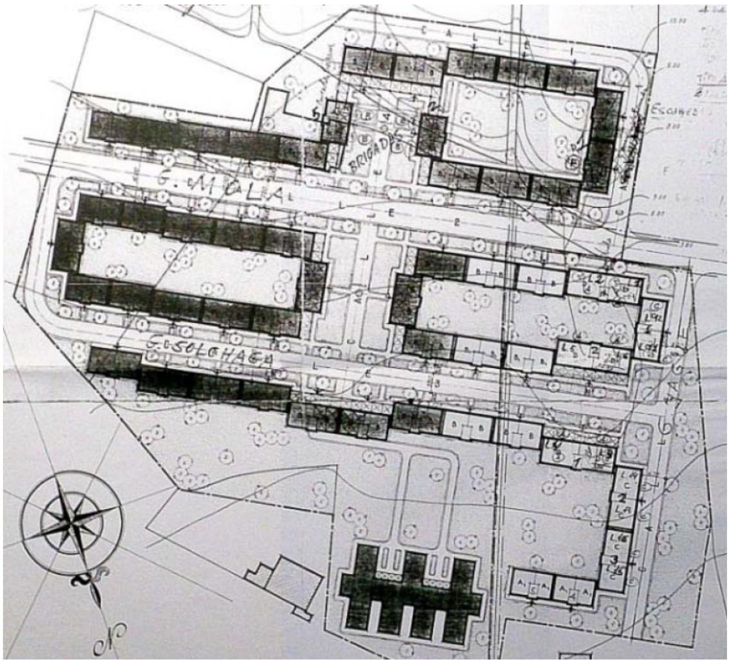

Figure 1: San Fausto. Plan of the neighbourhood drawn in 1953. (Maab, 2014 (a))

Figure 2: San Fausto. Pictures of the current appearance of the neighbourhood and its buildings.

The presented issues of low comfort and poor energy performance of buildings, aggravated by the remarkable difference with the average levels in town, were the reasons that motivated the project "Berritu San Fausto", meaning renovate San Fausto. The project started as an energy renovation project with the purpose of improving neighbours' living conditions. However, surveys conducted by the town council and project consultants showed actual priorities of neighbours: improving accessibility and sewage pipeline. The incorporation of the latter entails a great opportunity to add a district heating system to the project in order to replace less efficient individual boilers and stoves because realising both works at the same time would significantly reduce costs. (Maab, 2014 (a))

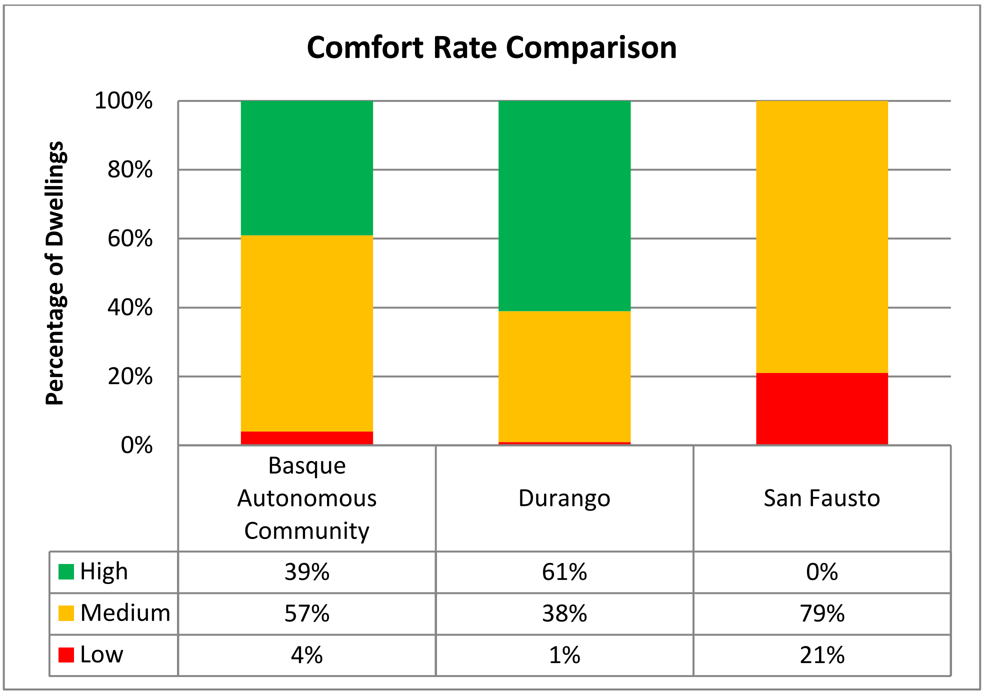

Figure 3: Comparison of comfort rate levels of dwellings in the Basque Autonomous Community, Durango and San Fausto. (Maab, 2014 (a))

As explained in the previous section, the project could receive public subsidies for energy efficiency improvements, but part of the investment will have to be covered by householders (Maab, 2014 (a)). This implies a problem due to the fact that San Fausto is a low income neighbourhood with lessened household economies as a consequence of the current economic situation of the country. Therefore, the amount of money to be spent per household will be one of the determinant parameters to implement any of the proposal described in (Maab, 2014 (a)), including building a district heating system.

The report named as the project contains a thorough technical and economic analysis of the improvements related to building insulation, accessibility and sewage pipeline improvement. Nevertheless, the option of building a district heating system has not been deeply examined yet. (Maab, 2014 (a)) This means that an economic analysis of different potential technical alternatives is essential in order to be able to make a decision on building a district heating system or not. However, it can be expected the economic parameter not to be the only one to be taken into account to approve or reject building a district heating system for the neighbourhood.

1.5 Lack of Awareness of District Heating Systems and Potential Resistance to Change

District heating systems are uncommon in Spain, where only 56 district heating networks existed in 2011 according to a study done by IDAE and ADHAC (Association of Heating and Cooling Network Companies). According to the same study, 52% of those networks are used by service sector, 35% by domestic consumers and 13% by industry and only 7 of them are located in the Basque Autonomous Community. (Perez de Lema, 2012) More recent studies done by ADHAC estimate 13 networks existed in the Basque Autonomous Community in 2013 (ADHAC, 2013), but this information is not reliable because some of the listed projects, such as Bolueta in Bilbao and the Scientific Park of the Basque University (Aranda, 2014), were cancelled and some others, such as Aramaio's district heating system (Ajuria & Beitia, 2014), have not been built yet. Anyway, results presented by the study show an increasing interest in developing district heating projects in the region and in the country in general. Nevertheless, district heating systems are still unknown for many consumers and new for town councils and project developers (Aranda, 2014), who have to deal with unexpected problems and obstacles that cannot be foreseen because of lack of awareness and experience (Ajuria & Beitia, 2014) (Garmendia, 2014).

Lack of information and trust, feeling excluded from planning and decision-making processes, apprehension to the unknown and fair that benefits from change might not worth the effort to obtain them are some of the reasons that may cause resistance to change according to (University of Wisconsin, n.d.), (Brookins, n.d.) and (Lefcovich, 2006). Analysing the possibility of building a district heating system in San Fausto in order to replace current individual heating systems is not householders initiative –neither their priority–, but it is town council's and project consultants' (Maab, 2014 (a)). According to (Díaz, 2014), householders have felt abandoned for the last 30 years due to the small work done by the town council to improve the neighbourhood and do not understand the sudden interest and insistence to implement such a big project, they are suspicious of town council's interest in the project.

Apart from that negative experience with collective heating systems installed mostly during the 70's and 80's is well-known. Individual boilers are the most usual heating systems for domestic consumers, but there are some apartment complexes in which a central boiler (usually oil-fired) supplies space heating and domestic hot water (DHW) to every dwelling in the building and very few cases in which 3-5 buildings, located very close to each other and built at the same time, share a common heating system. Consumers' experience with those collective heating systems was negative, and still is in some cases. Space heating was (and still is in many cases) turned on and shut down at the same time for every consumer, resulting in a mix of too warm and not warm enough dwellings. Nowadays collective systems usually have temperature sensors to calculate the need of heat for each day, but it was not common when systems were built back in the 70's and 80's, so it sometimes happened they were running for too long or too short. On top of that, no individual metering was installed and every household paid the same amount independent on consumption, e.g. a family of 5 members paid the same as a couple with no kids living in the same building. Nowadays, most collective heating systems have individual metering for DHW, which has reduced heat demand as consumers are aware of their own consumption, and space heating costs are sometimes divided in relation to consumers' heated area. (Maab, 2014 (b)) The negative experience led to the will for individual boilers and, in spite of improvements, collective heating systems are still associated with lose of comfort and money issues with neighbours for many consumers (Maab, 2014 (b)), which could entail a problem for district heating implementation.

Lack of awareness of consumers, town council and project developers is a threat for successful development of district heating projects because unexpected problems, obstacles and consumers' reactions could be found. As explained at the beginning of this section, there are already a few experiences with district heating projects in the Basque Autonomous Community and not all of them were successful. The positive side of it is that possibility for knowledge transfer regarding development of district heating projects in the Basque Autonomous Community is possible, which could reduce time, problems and expenses during planning process, implementation and operation.

From what it is explained in this section it can be concluded that, apart from examining technical and economic aspects of implementing a district heating in San Fausto, it is also important to learn from similar initiatives developed in the region in order to increase chances of successful project development.

1.6 Problem Formulation

San Fausto is a low income neighbourhood where buildings were constructed with poor quality materials and no insulation (Maab, 2014 (a)). As a consequence, dwellings in San Fausto have poor indoor environments and high energy demand (Maab, 2014 (a)), which is a risk factor for health problems and for energy poverty (Tirado Herrero, et al., 2012). With the objective of improving living conditions of residents in the neighbourhood, the town council started an energy renovation project. Delimitations of the project have been expanded during planning process and other potential improvements were also added as a result of householders' request. Improving sewage pipelines entails a fantastic opportunity for building a district heating system in order to replace less efficient current individual heating systems. Doing both works at the same time would considerably reduce required investment. (Maab, 2014 (a))

Unlike other potential improvements, building a district heating system has not been deeply analysed yet. No decision on heat producing technology has been made yet and uncertainty regarding amount of buildings that will decide to get connected to the district heating system and how many of them will implement energy renovation is high. Taking into account San Fausto is a low income neighbourhood with lessened household economies as a result of the current economic crisis in Spain, investment and future expenses to be covered by householders will be determinant for project implementation or rejection (Maab, 2014 (a)). Hence, it is essential to carry out a thorough economic analysis which examines different potential heat demand scenarios and applicable heat producing technologies.

Apart from that, there is the issue about lack of awareness in developing such projects in Spain and future consumers' reaction to them. Therefore, it is considered to be essential to learn from other similar initiatives developed in the region in order to define a proper project guideline that facilitates successful project development.

1.7 Research Question

Based on the problem formulation of the previous section, the research question of this study and three sub-questions are formulated:

What are investment and monthly costs to be covered by householders of San Fausto when building a district heating system for the neighbourhood and what aspects should be taken into account so that the project is developed successfully?

1. *What is heat demand to be covered by the district heating system, what heat producing technologies are applicable and what is their technical and economic data?*

   The energy demand to be covered by the district heating system depends on how many buildings decide to get connected to the system, on when they do it and on how many of them have implemented the proposed energy renovation. At the moment there is a huge uncertainty about those three aspects. Therefore, it is necessary to design different demand scenarios to be analysed. Besides, there are several heat producing technologies to be used and it is essential to decide which ones to examine and to find out what their technical and economic features are.

2. *What is the economy of applicable heat producing technologies in relation to potential heat demand scenarios?*

   It can be expected that different combinations of demand scenarios and applicable technologies will result in different investment and monthly costs to be covered by consumers. Hence, the economy of every possible combination has to be analysed so that consumers can make educated decisions. As further explained in Chapter 2, this report belongs to a initial stage of analysis that will be completed in following stages. As a consequence only technology and energy related expenses are included in the economic analysis –financial costs, subsidies and ownership model related costs are excluded. In the same way, it is not analysed whether current policies and subsidies are appropriate and sufficient for district heating promotion in Spain or not, neither how policies could be improved in order to mitigate or even eliminate energy poverty. This is out of the scope of this study.

3. *What aspects should be taken into account so that the district heating project is successfully developed?*

   District heating systems and their development projects are new for consumers, town councils and project developers in Spain. Learning from other similar initiatives in the region will facilitate the process, reduce problems and obstacles and increase chances for achieving aimed objectives. Therefore, information about experiences of similar initiatives in the area is gathered and conclusions are drawn from obtained information for project improvement and future guideline definition. It is important to clarify no district heating promotion policy is defined as a result of the conclusions obtained from this analysis, it is neither examined results and consequences of different policy scenarios.

1.8 Report Structure

Report structure follows the order of the defined sub-questions in order to answer the research question of this study, see Figure 4 on the following page. In Chapters 4 and 5 sub-question 1 is answered and technical and economic data to be used for system modelling and economic analysis are presented. In Chapter 6 economic results obtained from the analysis are introduced, explained and discussed according to different parameters calculated for each of the analysed potential heat demand scenarios and applicable heat producing technologies. This way sub-question 2 and the first part of the research question are answered. Finally, in Chapter 7 examined similar initiatives in the region are described, information gathered during held interviews is elaborated and considerations to be taken into account for following stages of analysis are listed and explained, i.e. sub-question 3 and the second part of the research question are answered. The entire research is done based on the frame set by the theoretical approach defined in Chapter 2 and the methods explained in Chapter 3.

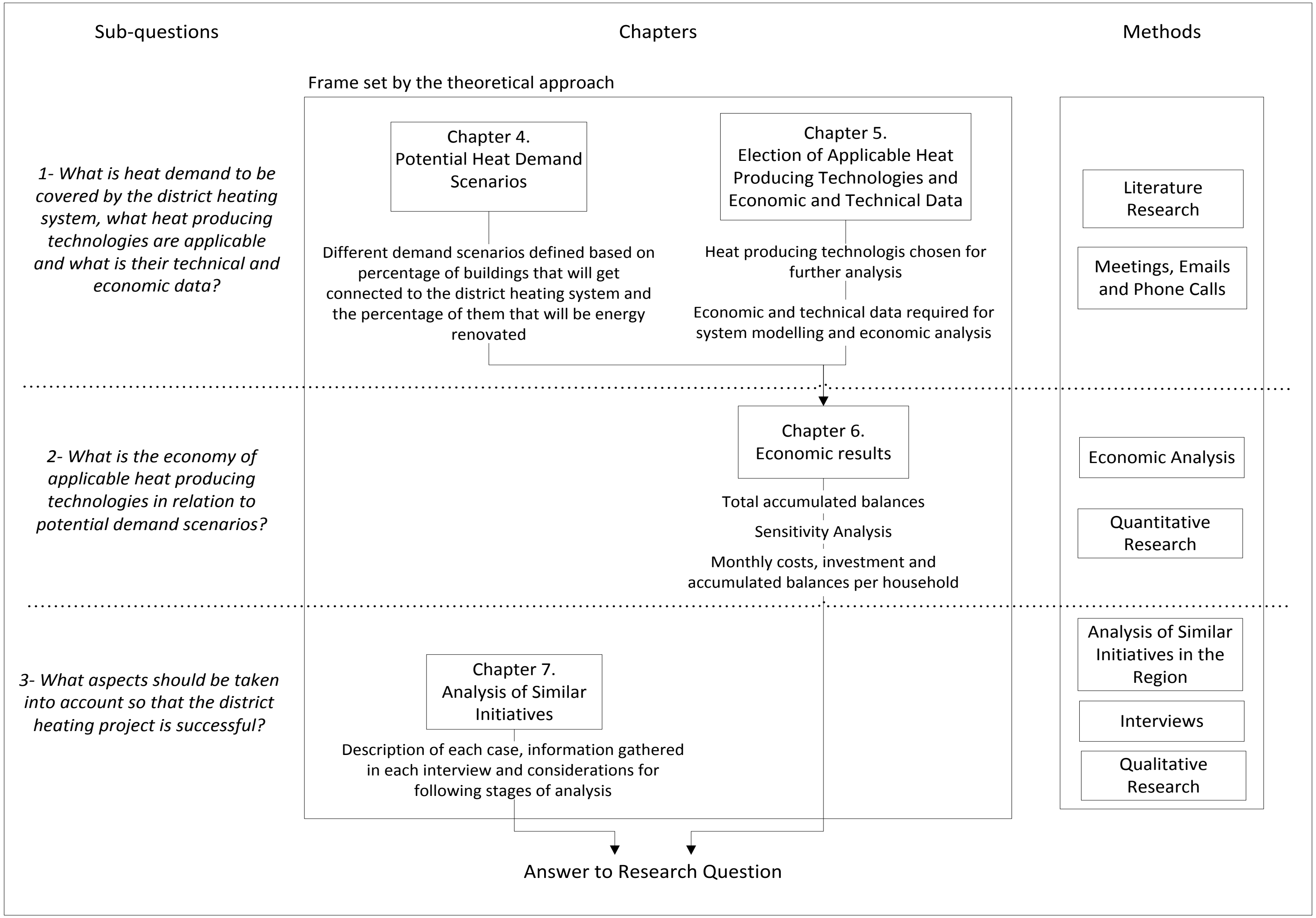

Figure 4: Report Structure. How and in which chapter the research question and sub-questions are answered.

2 Theoretical Approach

This chapter presents the context of the study by introducing and explaining every aspect or agent that could directly or indirectly influence the outcome of the project for the implementation of a district heating system in San Fausto. It is also explained and reasoned which of those aspects and agents are taken into account in this study and which one are not. Afterwards, it is described how the research process has been in order to explain how it evolved from initial ideas to current ones. Finally, different stages of analysis defined for the planning process are presented, their objectives, outcomes and interrelations are described and the stage of analysis this study and report belongs to is clarified.

2.1 General Context of the Study

The project "Berritu San Fausto" is considered part of the town's plan for sustainable development promoted by Udal Sarea 21 (Maab, 2014 (a)), the Basque town council network for sustainability. The network is formed by 198 towns and cities and the Department of Environment and Domestic Policy of the Basque Government, which is represented by the Regional Directorate of Transport, the Basque Water Agency, the Basque Department of Health and the Basque public society for environmental management (Ihobe). Collaboration between local and regional government supported within this network aims for effective sustainable development in member towns and cities. (Udalsarea 21, n.d.)

As already explained in Section 1.4, the main objective of the project "Berritu San Fausto" is to improve the quality of life of residents in the neighbourhood by renovating the existing buildings and sewage pipeline. All of it will result in better indoor environment, better energy performance of dwellings, mitigation of risk factors for energy poverty, minimisation of accessibility barriers and improved healthiness conditions. Apart from that, the project intends to reduce environmental impacts from household energy consumption in the neighbourhood by increasing the share of renewable energy and replacing current individual heating systems by a district heating system. (Maab, 2014 (a)) At this point it is important to clarify renovation of sewage pipeline has already been approved, whereas there is no definitive decision on reduction of accessibility barriers, energy renovation of buildings and building a district heating system (Town council & Maab, 2014 (b)).

This study focuses on the possibility of building a district heating system in San Fausto and, consequently, only the proposals of the project "Berritu San Fausto" that may influence the outcome of this study are taken into account, these are the energy renovation and increasing the share of renewable energy. This means no actors or aspects that may influence the outcome of reduction of accessibility barriers and sewage pipeline renovation are taken into account intentionally, neither included in Figure 5 on the following page, which presents the general context and the delimitations of this study in a schematic way.

The figure shows the context of the project by grouping the actors and aspects that may directly or indirectly affect the outcome of the study of building a district heating system in San Fausto in 4 different levels: San Fausto (neighbourhood), Durango (town), Basque Autonomous Community (region) and Spain (country). San Fausto is delimited with an oval while the other three areas are delimited with an square. The reason for this is that there is no regulation defined at neighbourhood level, whereas there is at town, regional and national levels. Therefore, the squared delimitation represents the existence of particular regulation at the specific level.

The target buildings of the project "Berritu San Fausto" are the 53 buildings mentioned in Section 1.4. However, it is important to mention that other buildings exist quite close to them, see Figure 6 on the following page, and that it is planned to build some new buildings (200-300 dwellings) nearby the existing ones (Town council & Maab, 2014 (a)). As the other existing buildings and the planned new buildings are not part of the project "Berritu San Fausto", they are not taken into account in this study, but it is recommended to analyse the possibility of connecting them to the district heating system as well. Furthermore, it could also be interesting to analyse whether to include other nearby neighbourhoods or even the whole town in the district heating system, but this is out of the scope of this specific study.

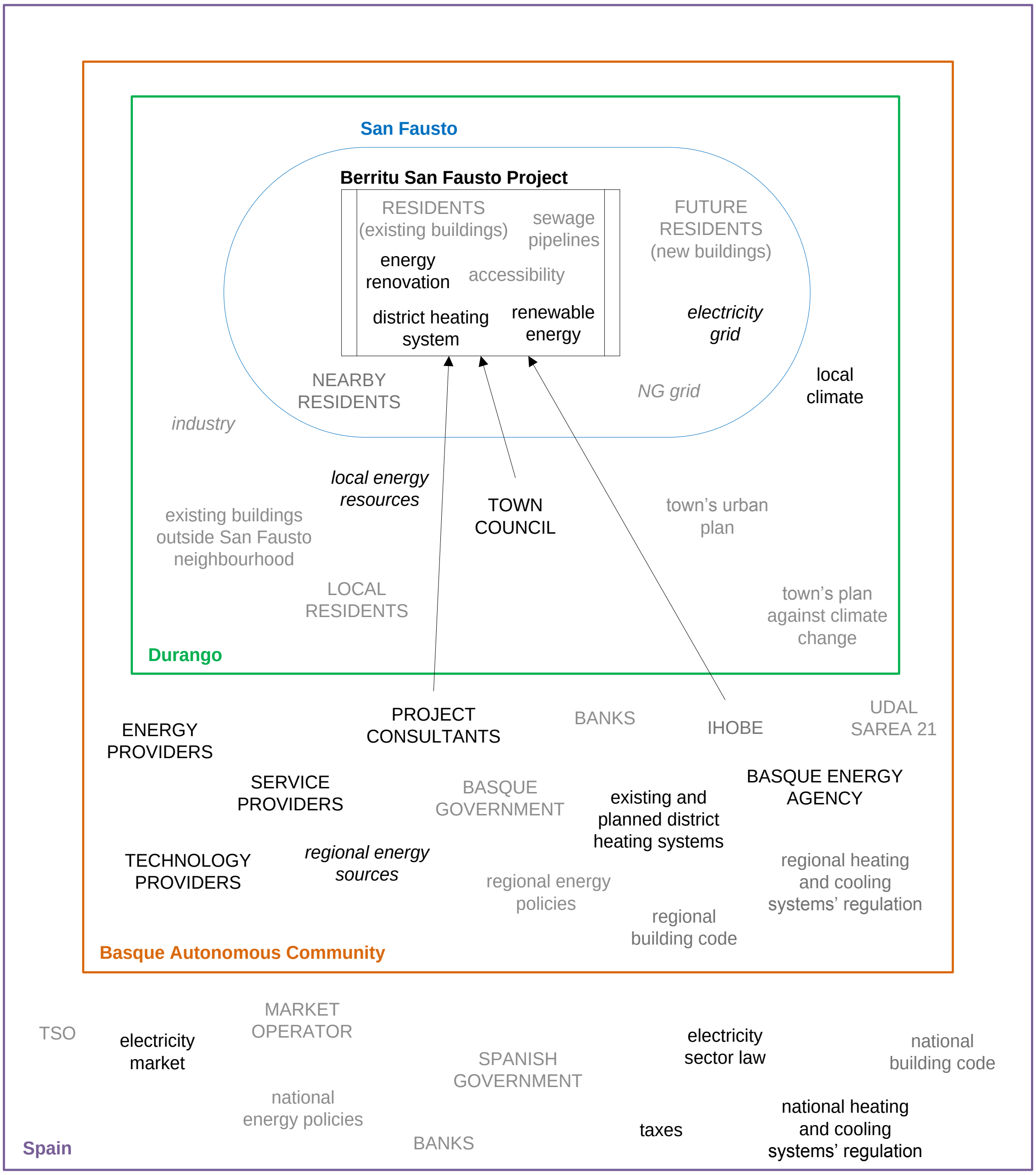

Figure 5: Map of the general overview of the study. It includes actors and aspects that may directly or indirectly affect the district heating project outcome. Actors are shown in capital letters, aspects in small letters and energy resources in italic. Further, actors and aspects taken into account in this study are in black, whereas those not taken into account are in grey. For deeper understanding of how this delimitation is done, read Section 2.3.

Figure 6: Nearby buildings. The newly constructed nearby buildings are not included in the project "Berritu San Fausto", either in this preliminary study of building a district heating system in spite of their proximity.

Technical solutions chosen for the district heating project are dependent on the 4 factors explained in the following: (1) law, regulation and policies at different levels, (2) available energy resources, (3) economy of analysed alternatives and (4) actors with a direct influence on the project.

Spain is divided into 17 autonomous communities and two autonomous cities (Ceuta and Melilla). Each autonomous community has its own Statute where its specific autonomic competences are defined. Autonomous communities may establish their particular law and regulation in regard to their competences, but have to follow basic principles and directives established by estate laws and regulation. (Spanish Goverment, 1978)

Zoning, urbanism and housing is one of the competences of the autonomic communities (Spanish Goverment, 1978). This way national building code (*Código Técnico de la Edificación*) (PRC Bouwcentrum International, 2011) and national buildings' heating and cooling systems' regulation (*Reglamento de Instalaciones Térmicas en los Edificios*) (Departamento de Industria, Comercio y Turismo del Gobierno Vasco, 2008) can be adapted by autonomous communities. This means autonomic regulation should be taken into account for buildings' energy renovation and construction of a district heating system.

Town councils are in charge of defining general urban planning for the specific city or town and can also define partial plans for particular areas. Partial plans are more detailed than general plans and may define specific use of land, appearance of buildings, environmental regulation or building density of a particular area of the specific town or city (PRC Bouwcentrum International, 2011). When analysing the possibility of implementing a district heating system, it should be found out whether any restrictions exist in the area under analysis. In this case, it is possible to build a district heating system, but it could be relevant to take into account neighbourhood's appearance when designing the building where the heat producing centre should be placed. Project consultants' have already taken this into account for energy renovation of buildings (Maab, 2014 (a)).

With respect to policies, national as well as regional policies exist, the former being the basis for the latter. This way, there are national plans for renewable energy (*Plan de Acción Nacional de Energías Renovables de España 2011-2020*) and for energy savings and efficiency (*Plan de Ahorro y Eficiencia Energética 2011-2020*), for instance, and regional energy strategies such as *Estrategia Energética de Euskadi 2020*.

Regarding available energy resources, the neighbourhood is currently connected to the electricity distribution grid and the natural gas network. Apart from those, other local energy resources, such as solar energy or wind energy, waste heat from nearby industry and other regional energy resources (e.g. biomass) should also be considered for the current study. As explained previously in this chapter, the project "Berritu San Fausto" includes the target of increasing the share of renewable energy used to cover neighbourhood's energy demand (Maab, 2014 (a)), hence, it is decided every analysed energy source has to meet this requirement. In order to define an approachable scope for the study, only technologies for heat production are examined; this is, only energy sources that may directly be converted into heat are analysed, e.g. wind energy is not, but electricity is. Finally, waste heat from industry is dismissed since the closest factory that produces usable waste heat is considered to be too far from the neighbourhood (Town council & Maab, 2014 (a)).

The economy of analysed alternatives is one of the decisive parameters of the study, as explained in Sections 1.4 and 1.6., and is dependent on (1) technology and fuel costs (including taxes), (2) obtainable subsidies, (3) financial costs and (4) applied ownership. The first factor is dependent on market prices and chosen providers and is the only one which is taken into account for the economic analysis of this report. Obtainable subsidies can vary in relation to the chosen technical solutions, household economies (Maab, 2014 (a)) and applied ownership model (Ajuria & Beitia, 2014). Financial costs are dependent on investors' financial resources, need and/or possibility to get loans and loans' interest rates. Finally, the applied ownership model influences initial investment and monthly costs (Ajuria & Beitia, 2014), e.g. it can be expected investment to be reduced when a private company owns the system instead of consumers, on the other hand higher monthly costs are probable because the company will seek for benefits. Factors (2), (3) and (4) as well as their related aspects and agents will be analysed during next stages of analysis as explained in the following section.

All of those factors are somehow influenced by the 4 actors who have a direct influence on the project: residents in the neighbourhood, town council, project consultants and Ihobe. The former three are the decision-makers, see Table 1. Householders are the ones who will decide whether they will implement the project or not (Maab, 2014 (a)), whereas town council and project consultants will mainly decide on technical alternatives and system design. The reason why householders have the right to approve or disapprove the project is that they will have to cover at least part of the required investment and the totality of system's costs . The remaining part of the investment will depend on defined ownership model, potential contribution of the town council and expected subsidies from Ihobe (Maab, 2014 (a)). Due to the current stage of analysis, see following section, only town council and project consultants are taken into account in this study.

Table 1: Actors with a direct influence on the outcome of the district heating project of San Fausto and their roles.

	Decision-makers	Payers
Residents in San Fausto	√	√
Town council	√	√
Project consultants	√	
Ihobe		√

The Basque Energy Agency (*Ente Vasco de la Energía* (EVE)) is a relevant agent to be taken into account as well because its duty is to develop "*projects and initiatives in line with government policies*" –which are based on "energy *efficiency, diversification of energy sources and promotion of renewable energies*" (EVE, n.d. (d)). The Agency has been involved in various district heating projects in the last years (Aranda, 2014) and is therefore a good source of information to gain knowledge of similar initiatives developed in the region.

Finally, it has to be mentioned other agents involved in experiences with existing or planned district heating systems in the Basque Autonomous Community are also examined in order to answer sub-question 3 and the second part of the study's research question, see Section 1.7.

To sum up, no every influencing actor and aspect is taken into account in this study (as represented in Figure 5 on page 11 and explained along this section), the reasons for including some and ignoring others are strongly related to the stage of the analysis (explained in the following section) and every actor and aspect taken into account in this study influences the economic analysis, but the Basque Energy Agency and agents involved in existing or planned district heating systems. It has to be pointed out it is not stated the actors and aspects included in the figure are the only ones that may affect the outcome of the project, but it can be affirmed they are the most relevant ones.

2.2 Process Description, a Participative Research

This study is a participative research, a research done in collaboration with Durango's town council and "Berritu San Fausto" project consultants. The process of this participative research, how it started, it evolved and reached current state, is described in the following.

In December 2013 it is found out Durango's town council was developing a project that included energy renovation and district heating for San Fausto. At the beginning of January, a meeting is arranged with Aitor Zorrakin, architect at the town council, in order to express interest in collaborating in the project. He says it is possible and, once the main project consultant (Maab Arquitectura and Urbanismo) has confirmed his approval, the study starts.

All information collected by project consultants and results from their analysis are accessed. It is surprising how developed the project is at this point. Maab has already done a detailed analysis about energy renovation which includes current demand, how to insulate façades and roofs, demand after energy renovation, cost of energy renovation, household income, obtainable subsidies, alternative ways of obtaining financing, etc. (Maab, 2014 (a)) Further, a public meeting has already been held to inform householders of San Fausto about the project, how it would improve their living conditions and its economy. During this meeting householders had show their concern about required investment and expressed their priority was to renovate sewage pipeline and reduce accessibility barriers. Those two proposals are also included in the project, required investment to accomplish them is assessed and obtainable subsidies when implementing different combination of proposals are found out. (Maab, 2014 (a))

When householders of San Fausto expressed one of their priorities was to renovate the sewage pipeline to improve healthiness conditions, town council and Maab started to think about the possibility of building a district heating system at the same time with the objective reducing environmental impact of households' heating system. Investment and monthly costs to be covered by householders is a determinant parameter for project approval and it was considered important to analyse them.

Maab gets into contact with another project consultant, who develops projects of district heating systems consisting of wood-chip-fired boilers. The fact that the new consultant carried out an study of implementing a wood-chip-fired boiler for San Fausto is confidential. This way, the author of the results presented in (Maab, 2014 (a)) is not mentioned in the report and it is not been possible to contact him to ask questions, collect information or gain knowledge.

At this stage of the process, it is found out the analysis done regarding building a district heating system in San Fausto is too narrow. No other possible heat producing technologies than boilers and energy sources than wood chips have been analysed and the study only includes one proposal for management and ownership (Maab, 2014 (a)). The consultant is a private Energy Service Company who would be in charge of wood-chip supply and system operation and management, from which he would gain benefits. To do this, the Energy Service Company would cover investment and be the owner of components needed for heat production, storage and system control. As the building for the heat production centre, the heat distribution network and the consumer network and their investment and costs have not been analysed by the consultant, another consultant (Visesa, a public project developer) is contacted to examine those. (Town council & Maab, 2014 (a))

From this analysis it is decided to examine economy of different heat producing technologies in relation to different potential heat demand scenarios. The objective of the preliminary economic analysis (which should be finished by end of April or beginning of May) is to get an idea of the system's investment and costs before presenting the proposal to householders. The presentation will include explanation of what a district heating system is, how it works, what ownership models exist, what advantages the system has for consumers and, of course, what its approximate investment and monthly cost would be in San Fausto. It is planned to spend some time after the presentation on discussion and doubts clarification and to do a survey. The survey will include questions related to householders' opinion, interest and possibility to invest in the project. Information and comments from householders will serve to measure their interest in going on with the project proposal, to add some improvements and to proceed with a more accurate economic analysis.

However, some problems and difficulties are found on the way. It is very hard to find some of the needed economic and technical data. No economic data for biomass boilers, heat pumps and solar collectors is accessed –technology providers do not provide data unless consultancy is hired and energy agencies do not have it–, hence, it is decided to use Danish market values. Biomass energy price data is hard to find and no biomass price projection for Spain is found. Finally, electricity price and understanding of the electricity market is the most complicated and time expensive task done for this study. It is asked Observa el Mercado Eléctrico and EVE whether it is more recommendable to buy electricity from the spot market or from a retailer. The former answers it depends on specific consumer consumption (Observa el Mercado Eléctrico, 2014). Only one high voltage electricity tariff is found and it is decided to analyse spot market price data. 3 days of work have already been spent in getting hourly spot market price data of the last 4 years, when an email from EVE says it is going to be more economical to buy electricity from a retailer (EVE, 2014 (a)). It is tried to contact other retailers to be able to compare prices of various tariff offers. Further it is important to find out the process to be followed to get connected to a high voltage power grid and what investment is. After speaking to EVE, who does not have the answer, Iberdrola is contacted, because they are electricity retailers and also own the biggest share of the electricity distribution grid in Biscay (EVE, 2014 (a)). But every time the only received answer is to contact another department of the company or another employee. Finally it is decided to give up. Finding out electricity price projections and the evolution of the access fee to be paid by consumers is a similar process. Contacting different agencies, transmission grid operator and market operator does not help, not even for access fee data, which is supposed to be public. Finally assumption on electricity price projection is done and access fee information is obtained by means of a non official website –at this time more than one week has already been spent in looking for access fee evolution.

Economic analysis is prolonged as a result of difficulties in accessing data and because data on building, heat distribution network and consumer network is not obtained until the end of may, when analysis of similar initiatives in the region is being done. During the economic analysis and meetings held with project consultants and town council it is found out the main obstacle for project implementation is lack of awareness of district heating projects –district heating projects are new in Spain and therefore nobody is completely sure on how to develop them and what the reaction of potential consumers will be. Furthermore, the only ownership that seems to be applicable is a private company ownership and one of the main parameters for project implementation is company's profitability. Apart from that, various cases of project failure have been heard and every time the project is explained to friends, family, etc. the comment is collective heating systems imply problems, especially in regard to cost distribution among neighbours. Having economic results based on investment and O&M cost data from the Danish market and having found out knowledge transfer from similar initiatives is indispensable, it is decided to postpone the presentation to householders in San Fausto and to gain knowledge from other district heating projects in the region instead. It is easy to contact people involved in district heating projects and to arrange an interview with them. In fact, contact has been kept with some of them after the interviews.

During the entire process meetings have been arranged with Maab and town council in order to collect valuable information and to present obtained results and drawn conclusions.

It can be concluded unexpected difficulties and findings have led to redesign the research and current and future stages of analysis, which are explained in the following section.

2.3 Current Stage of Analysis

The study for the implementation of a district heating system in San Fausto is divided into three stages of analysis: initial, intermediate and final. The objective of the initial stage is to get a general idea of different applicable technologies' economy and a deeper insight of key factors for successful development of district heating projects in the Basque Autonomous Community. This is, it is a combination of a preliminary economic analysis and a series of interviews to stakeholders of other district heating systems in the region. The preliminary economic analysis, further explained in Section 3.2, only includes technology, fuel costs and taxes, so it excludes obtainable subsidies, financial costs and applicable ownership, as mentioned in the previous section. Interviews are only conducted to agents involved in district heating projects in the Basque Autonomous Community because those projects share 2 out of the 4 levels of the context presented by means of Figure 5 on page 11. Any actor or aspect that may influence the district heating project outcome, but is not necessary to be examined for this stage of the analysis is not taken into account in the study.

Results and knowledge obtained during the initial stage will serve as basis for next stages of analysis, i.e. they will make it possible to choose the most economical heat producing technology for further analysis and to improve project guideline of next stages aiming for successful project development.

In the intermediate stage of analysis delimitations of the economic analysis will be expanded. Chosen heat producing technology's (or technologies') economy will be analysed more accurately by including financial costs, obtainable subsidies and applicable ownership models –3 factors that are excluded in the economic analysis done for this report as a result of delimitations of the initial stage of analysis already explained. Further, this stage of analysis will aim for a more detailed understanding of households' economy and residents' opinion on the project. In order to do so, a public meeting will be held so that obtained results can be presented to residents in San Fausto and they can give their opinion and clarify any doubts they could have. This meeting could be the perfect opportunity to obtain required data by means of a survey, which can include questions related to household income, current annual expenses in energy bills, affordable investment and monthly costs, need for financing, possibility to obtain financing, interest in the project, opinion and so on. Analysis of residents comments and survey answers will be relevant for possible project improvements. At the end of the intermediate stage a clear picture of the economy and social characteristics of the project and amount of potential consumers should be reached and actual economic feasibility should be measured.

If project economy was affordable and residents were positive to build a district heating system, the final stage of analysis would start. At this stage an external consultant should be hired for system design and extremely accurate economic analysis. In addition, it will be necessary to contact technology, energy and service providers and energy service companies (if they should be the owners or be in charge of system management) to find out whether they could be interested in getting involved in the project. New results will be presented to residents again and they will have to make a decision on building the district heating system or not. If the project was approved, a preliminary stage of the implementation process would start afterwards, contracts would be signed with every provider, applications for permits and subsidies would be processed, etcetera.

Delimitation expansion from one stage of analysis to another enables a much more detailed analysis, which becomes more and more concrete and specific for the case under examination. Finally, it has to mentioned stages of analysis are flexible, meaning variation from presented description can be expected as a result of necessary adaptations observed during the process.

3 Methodology

This chapter presents the research design of the study and the methods used to answer the research question. At the end of the chapter the limitations of the study, consequence of the defined theoretical approach and chosen methodology, are listed and explained.

3.1 Research Design

This study belongs to the initial stage of the analysis of the possibility of replacing the current individual heating system in San Fausto by a district heating system, as explained in Section 2.3. Hence, it can be stated this is a case study because it is in line with the definition of Roberts K. Yin "*empirical inquiry that investigates a contemporary phenomenon in depth and within its real life context*" (Skogerbø, 2011). As already explained in Sections 1.4 and 2.1, implementing a district heating system for the neighbourhood is only one of the proposals included in the project "Berritu San Fausto", therefore, this study does not analyse the project in its totality, but a share of it. This way other proposals are part of the context of the study, but are not part of the unit of analysis.

The objective of the study is to find out the most economical technical solution for the neighbourhood and to gather information from similar experiences in order to ensure appropriate approach of next stages of analysis and successful project development. The first part of the study (this is, the economic analysis) is a single-case study since every examined alternative meets the requirements of the project "Berritu San Fausto" and is adjusted to the needs of San Fausto's different potential heat demand scenarios. Single-case studies enable to get a deeper knowledge of the analysed issue, but their results and finds are hard to generalise (Andersen, 2008). This way economic data regarding technology investment and operation and maintenance (O&M) cost as well as energy prices could be valid for preliminary economic analysis of similar cases in the area, whereas meteorological data and heat demand are specific for the case of San Fausto. This entails economic results are only valid for the concrete neighbourhood of 53 buildings, even if parallels could be done to other urban areas with similar heat demand, heat demand density and climatologic conditions.

The second part of the study (i.e. the one regarding gathering information about similar initiatives) is considered a multiple-case study as various cases are analysed (Baxter & Jack, 2008). The target of multiple-case studies is comparing results obtained from analysing various cases in order to be able to replicate finds in other cases (Baxter & Jack, 2008). Here the target is to find out what aspects should be taken into account in the planning process of a district heating system for successful project development, what problems and obstacles could be found in order to avoid them or mitigate their gravity and what factors, actions, approaches, etcetera would make it possible to involve householders in district heating systems. The information will serve to define an effective guideline for next stages of analysis.

From what it has been explained, it can be concluded the first part of the study is a quantitative research and the second part is a qualitative research. This is, the economic analysis is based on numerical data examined using mathematical methods –it is an objective research method (Laws & McLeod, n.d.)–, whereas experiences of similar projects are analysed by describing each of the cases and comparing them –it is a subjective research method and so are obtained results and conclusions (Laws & McLeod, n.d.).

3.2 Economic Analysis

Economic analysis and its results are based on decisions made regarding system modelling and on approaching the analysis from a business economic perspective.

3.2.1 System Modelling

System modelling is done for a period of 20 years as this is the technical lifetime of main heat producing units analysed in this study (DEA & energinet.dk, 2012 (b)). The period starts on 1st January 2016, as decisions on whether to build a district heating system or not are going to be made before the end of 2014 (Town council & Maab, 2014 (a)) and one year is assumed to be enough time for system construction based on (DEA & energinet.dk, 2012 (b)).

Demand is the factor that determines system size and, as a result, it has a strong effect on required investment and system costs. Because of the current uncertainty regarding householders connection to the district heating system and energy renovation implementation (explained in detail in Chapter 4) various potential demand scenarios are defined. Each scenario sets the requirement of a minimum percentage of buildings getting connected to the district heating system just before system operation start and assumes other buildings will also get connected linearly to the system in a period of 10 years, this means heat demand to be covered by the heating system will increase from 2016 to 2026 and then keep constant. Further, different percentages of energy renovated buildings are analysed.

Heat demand is comprised of space heating demand, domestic hot water (DHW) demand and system losses. The former is dependent on outdoor temperature and restricted to the period October-May, the second is assumed to be constant during the whole year and the latter is assumed to be constant for the entire analysed period and to account for 20% of the sum of space heating demand and DHW demand in 2016 as done in (Grundahl, et al., 2013). According to (DEA & energinet.dk, 2012 (a)) Danish district heating systems' energy losses usually range from 15% to 20%. Large scale heating systems can have lower losses (down to 7%) and small scale systems' losses can be up to 50% if conditions are very poor. High temperature district heating systems also have bigger losses than lower temperature ones. (DEA & energinet.dk, 2012 (a)) San Fausto's future district heating system could be categorised as a small system using high temperature water, however, outdoor temperature is higher in Spain than in Denmark, which reduces losses. Hence, it is assumed system losses are equivalent to the 20% of the heat demand.

Heat producing technologies are either considered main heat producing technologies or additional or supplementary technologies in this study. The difference between them is that those considered main heat producing technologies use non-fluctuating energy sources for heat production and can therefore be the only heat producing unit of the system, whereas additional or supplementary technologies are those that, due to their characteristics, would only improve system's operation and economy in combination with other technologies. It is important to point out there is no regulation in Spain that establishes the requirement of having a back-up system in district heating systems (Maab, 2014 (b)), this is the reason why a main heat producing technology may be the only producing unit of a heating system. Chosen main heat producing technologies are analysed individually as well as in combination with additional and supplementary heat producing technologies.

In any case, the district heating system consists of one or two heat producing technologies and a thermal storage tank. Heat producing technologies and the storage tank are dimensioned so that they can cover heat demand after 2026, this is, after connection to the system is finished. It is important to clarify that no modular alternatives are examined, meaning heat demand dependent units will turn on and shut down more often in proportion to produced heat during the first 10 years of operation than during the last 10 years. Data regarding cost of turning on and shutting down different technologies has not been accessed, so comparing obtained results with those of using various modular units would have been impossible.

Further, 3 options for heat producing units and storage tank dimensioning are analysed: (1) optimum combination of units' capacity and storage volume, (2) storage volume may cover 2 days of summer demand in 2026 and (3) storage volume may cover 1 week of summer demand in 2026. The former option is only analysed for cases in which changes in heat producing unit and heat storage tank dimensions result in variations of required investment but do not alter operation and maintenance (O&M) cost. The option of having a heat storage tank that may cover 2 days of summer consumption in 2026 is only analysed for alternatives which do not include technologies that use fluctuating energy sources, as the size of the heat store implies a restriction for those technologies, resulting in inefficient use of them and lower accumulated balance reductions. The option of having a heat storage tank that may cover 1 week of summer heat demand is analysed for every examined heat producing technology.

Regarding dimensioning of heat producing units running on fluctuating energy sources, two options are analysed. The first one is sizing heat producing units to cover 100% of summer heat demand in 2026 and the second one is installing half of the capacity required to cover 100% of summer heat demand in 2026. Summer period is considered to be that in which no space heating demand is needed, i.e. from 1st June to 30th September.

Required meteorological data is accessed from the weather station called Garaizar, located approximately 700 m away from San Fausto's main street (measured in a straight line using Google Maps). Hourly outdoor temperature data is known for the years 2006-2013 (excluding 2007) and hourly solar radiation data is known for 2006, 2008, 2009, 2010 and 2013 (OPEN DATA EUSKADI, 2014). However, data for specific hour/s or for specific days is missing in some years. In those cases, depending on the number of hours with no data, gaps are filled in with data from previous hours, from same hours of previous days or from same day and month of another year.

Finally it has to be mentioned that other data needed for system modelling, such as location, is specific for San Fausto.

3.2.2 Business Economic Analysis

The economic analysis of this study is a cost analysis done from a business economic perspective. Costs and investment to be covered by householders when implementing a district heating system are examined for different demand scenarios and different heat producing technologies. Investments take into account every technology component required for heat production, storage and distribution, and costs include energy purchase (if any) and heat production units' and heat distribution network's O&M costs. Both, investments and costs, include inflation and taxes and exclude social costs, such as cost of emissions, since it is a business economic analysis.

Investments and O&M costs of heat producing technologies and heat storage tanks are calculated based on data from (DEA & energinet.dk, 2012 (b)) and (DEA & energinet.dk, 2012 (a)). As it has not been able to access data regarding prices of different heat producing technologies and of heat storage tanks in Spain, it is assumed values provided in (DEA & energinet.dk, 2012 (a)) and (DEA & energinet.dk, 2012 (b)) are also valid for Spain, assuming lower live expenses are counteracted by the fact that the Spanish big-scale heat producing technology market is significantly new in comparison to Denmark's (Perez de Lema, 2012).

Energy purchase prices are affected by price projections foreseen for the analysed period. Due to uncertainties related to price projections for 22 years (from 2014 to 2035), it is decided to do a sensitivity analysis on how lower or higher energy price rises would affect obtained results. In order to do so, it is decided to compare the results obtained using expected price increases with the case in which prices would rise only as much as inflation and the case in which prices would rise twice the expected plus inflation.

The total inflation from February 2004 to February 2014 was 22.4% (INE, 2014 (d)), this is equivalent to an average annual inflation of 2.24%, value used in the economic analysis.

21% VAT is added to every investment and cost and 5.1% electricity tax (EVE, 2014 (a)) is also added to electricity price. This means all applicable taxes are included in the calculation.

Regarding economic result analysis, first of all economy of different technical alternatives is analysed taking into account accumulated balance of the examined period, i.e. the sum of every investment and cost to be covered in 20 years or, in other words, a Net Present Value (NPV) calculated over 20 years with a discount rate equal to cero. Discount rate is a subjective variable dependent on investor as it is related to aimed profitability and investment risk perception (Ledec, 1987). As no ownership model is analysed in this stage of analysis, the applied discount rate is cero. This way it is found out how different demand scenarios and different combinations of production unit capacity and thermal store size affect economic results of each analysed heat producing technology. Furthermore, the most economical technical alternative is found out.

Afterwards, each technology's impact on household economy is analysed by calculating investment and monthly payments to be covered by consumers. This calculation is realised for two types of dwellings –a *surrounded* dwelling of a B type building (the most common dwelling type in the neighbourhood and a *surrounded* dwelling of a D type building (which represents one of the biggest consumers), as explained in Chapter 4. The reason to choose *surrounded* and not other positions within building, see Figure 7 on page 28, is that they are the most common position. Further two possible cases are analysed for each type of consumer –having done the energy renovation proposed in (Maab, 2014 (a)) or not. As no ownership is taken into account in this analysis, investment is presented as a sum of different investment components: (1) heat producing units and thermal store, (2) the building where the heat production centre is placed, (3) heat distribution network, (4) consumer network and (5) other initial expenses. This way consumers know what the total investment would be if a consumer ownership was applied, but may also have an idea of how much investment could be reduced if alternative ownership models were chosen. Those investment components are distributed among consumers using three methods. Heat producing units and thermal store investment to be covered by a specific consumer is calculated in relation to his heat demand, i.e. it is calculated the percentage of total heat demand an specific consumer's heat demand accounts for in 2026 and the obtained value is multiplied by the total investment required for heat producing units and thermal store. Building investment, heat distribution network investment and other initial expenses are equally divided among the number of consumers connected to the district heating system in 2026. Finally, consumer network investment is related to each building connection to the heat distribution network and is therefore equally divided among consumers of a specific building. Regarding monthly costs, they are divided in relation to specific consumer demand. In order to do so, price per produced kWh-heat of each year is calculated by dividing system's running costs by total heat demand of the same year and the obtained value is multiplied by the heat demand of the specific consumer. The sum of monthly costs over 20 years and every investment component results in accumulated balance per household (note that total accumulated balance refers to the sum of investment and running costs of the system in its totality and accumulated balance refers to the sum of investment and monthly costs of a household). The explained method of investment and monthly cost distribution supports energy renovation and savings and it is fair for every size of consumers, which are the reasons why this method is chosen.

3.3 Analysis of Similar Initiatives in the Region

The objective of this analysis is to gain knowledge from similar initiatives developed in the region –from their success and failures– so that an appropriate project guideline (which will increase chances of successful project development and will reduce problems, obstacles and costs) can be defined for future stages of analysis. In order to do so, interviews are held with town councils where implementing a district heating system was analysed, is being currently analysed or has already been done.

An interview model, included in Appendix A, is designed in order to find out the most relevant information in every analysed case. Asking mainly the same questions makes it possible to compare the various cases among them and with San Fausto. However, questions out of the defined interview model are asked in some cases in order to clarify doubts or to find out more about case's particularities. The interview model is divided into the following parts:

1. General description of the town/city and the analysed area.
2. Technical and economic aspects of the district heating system.
3. Project motivation and promoters.
4. Project development.
5. Residents' participation and point of view.
6. Made decision.
7. System performance and consumers' opinion after implementation.
8. Recommendations.

Each analysed case is presented and described individually using information gathered during interviews and literature research (when necessary). Thereafter main considerations to be taken into account when developing a district heating project in the Basque Autonomous Community are listed based on carried out analysis.

3.4 Data Collection

Data is collected through literature research, meetings, emails, phone calls and interviews.

Literature research
Data and information obtained through literature research is mainly used for problem contextualisation and as input data for the economic analysis. However, it is also used for additional input for some of the analysed initiatives. Both, qualitative and quantitative data are used. Further, it has to be mentioned some of the used data was specifically produced for the project Berritu San Fausto (e.g. dwelling's annual space heating demand), whereas some other was not (e.g. energy prices or heat producing units' investment and O&M cost).

Meetings, emails and phone calls
Necessary data not accessible by means of literature research is obtained by contacting experts either by email or phone. Apart from that, meetings with project consultants and town council have been an important source of data.

Interviews
Interviews are held for analysis of similar initiatives in the region.

3.5 Tools

Two computer programs are used for the economic analysis of this study: Microsoft Excel and energyPRO. Excel is used for data handling and result analysis, whereas energyPRO is used for district heating modelling and economic result obtainment.

3.5.1 Microsoft Excel

Microsoft Excel is a spreadsheet software for mathematical calculation and data analysis. Tables, formulas and graphs make it easy for users to examine data and to present it in a visual way. (Microsoft Office, n.d.) It is a user friendly software that meets data handling and result analysis needs of this study.

3.5.2 energyPRO

energyPRO is a modelling software package developed by EMD International A/S for energy projects' techno-economic analysis. It enables to examine energy systems with heating, cooling and/or electricity demands, multiple energy producing units, different energy storages, various energy sources and different types of electricity markets. (EMD, 2013) This makes energyPRO an appropriate tool for district heating projects' analysis. Further, when FINANCE or ACCOUNT mode are chosen, analysis over more than one year is allowed (EMD, 2013). This is an advantage in comparison with other programs for energy system analysis as EnergyPLAN (developed by Aalborg University) which only enables one year period analysis (Department of Development and Planning, Aalborg University, n.d.).

Demands are defined on annual basis and can be distributed over certain time periods if necessary. Heating and cooling demands may also be dependent on external conditions such as outdoor temperature. (EMD, 2013)

One or more energy producing units are assigned to cover a specific demand. Users may specify fuels, energy producing units and storages' technical characteristics (e.g. fuels' calorific value, energy producing units' efficiency and thermal storages' losses) and their economic data (e.g. fuel prices and units' O&M cost and investment). Further, it is possible to define each heat producing unit's operation strategy, which can be either user defined or automatic minimisation of net production costs (EMD, 2013) –option chosen for this study. The latter optimises operation of the various energy producing units and their energy storages against technical and economic parameters. This means, energyPRO calculates the cost of producing 1 MWh with each energy producing unit, so that the unit with lowest costs is first turned on, then the second with the lowest costs and so on until heat demand is met or every energy producing unit is exhausted. Optimisation can be done on monthly or annual basis. In both cases, storages are emptied for the end of the chosen period, which may entail problems to cover energy demand of next period. (EMD, 2013) It has to be mentioned this does not happen in reality, hence, even if calculation takes longer time (EMD, 2013), annual optimisation is chosen as it is closer to reality.

3.6 Limitations

This studies limitations are related to the defined context of the study, the stage of analysis, applied methodology, used data and assumptions. There are some limitations that affect the whole study in general and some other which are related to specific analysis parts.

General

- The context and delimitations described in Chapter 2 set the frame for the analysis done in this study and, as a consequence, condition obtained results and conclusions. This means other context approaches and delimitations could have led to different results.
- This study belongs to the first out of three stages of analysis defined for the planning process to implement a district heating in San Fausto. Being the initial stage, not every single aspect to be taken into account is included in the study and obtained results and conclusions are not definitive, but input for following stages of analysis, as already explained in Section 2.3 and further elaborated in Chapter 9.
- In spite of being a case study, it is impossible to analyse every single detail of it (de Vaus, 2006), not even when reducing the scope of the study to the boundaries of the initial stage of analysis. Even if the current uncertainty regarding implementation of energy renovation and connection to the district heating system (explained Section 4.2) could result in infinite demand scenarios, it is necessary to simplify the analysis. As a consequence, only 6 demand scenarios are analysed. In the same way, only 6 heat producing technologies are taken into account in this study and, after dismissing two, only the economy of 4 of them is analysed. This does not mean only 6 demand scenarios are probable or only 6 technologies meet project's requirements.

Demand calculation

- Buildings' energy demand does not only depend on buildings' energy performance but it also depends on consumers behaviour, as it is discussed in Chapter 4. This means difference may exist between calculated energy demand and real energy demand. Differences between calculated and real heat demand could entail changes in system dimensioning and, thereby, result in variation of investment and monthly costs. Obviously those changes and variations are dependent on how big the difference between the calculated and the real heat demand is. The more detailed the analysis of demand, the smaller differences will be between calculated and real. Nevertheless, at this stage of analysis is not considered relevant to carry out a more detailed analysis than that done in Chapter 4, as a more accurate analysis is going to be done for the final analysis stage, when which and how many householders are willing to get connected to the district heating system will be known.
- (Maab, 2014 (a)) only provides space heating demand data for 4 position of dwellings within buildings, as explained in Section 4.1.1.. However, this study adds two more positions, whose space heating demand calculation is based on an assumption. This means, dwellings located in those two extra positions inside buildings might not have the calculated demand of space heating, which would result in system's lower or bigger heat demand.
- It is assumed trade premises' space heating demand is equal to the space heating demand of the dwelling they replace and DHW demand is calculated in proportion to space heating demand. Once again, it possible that calculated values are not the real ones. However, in this case it is expected differences will not have major impact on system's total heat demand since trade premises heated area accounts for a small percentage of the total heat demand.

Economic analysis

- Examined technologies' investment and O&M costs are those provided by (DEA & energinet.dk, 2012 (a)) and (DEA & energinet.dk, 2012 (b)) because no Spanish big-scale heat producing technology market data has been found. As already explained in Section 3.2.2, economic values provided by those reports might not be valid for Spain, meaning economic results are just indicative estimations. The aim of the economic analysis done in this study is not to obtain definitive results anyway, but to find out the most economical heat producing technology so that it is further examined in following stages of analysis, see Section 2.3 and Chapter 9.

- It has not been possible to access data regarding cost of turning on and shutting down heat producing units. This implies that calculated optimum combination of heat producing units' capacity and thermal store size might not be the most economical. Hence, it is important to get data regarding this cost so that calculation of the optimum combination can be redone in following stages of the analysis as explained in Chapter 9.
- System modelling does not include modular alternatives. Various smaller heat producing units usually require higher investments than a single and larger heat producing unit, but may result in lower running costs as it is usually the case for biomass-fired boilers (FOREST, n.d.). Therefore, as mentioned in Chapter 9, it is necessary that following stages of analysis examine if a modular alternative would result in lower accumulated balances.
- No limitation regarding installed solar collectors' total area is taken into account. Analysed solar collector can either be installed on ground or on buildings' roof (TÜV Rheinland DIN CERTCO, 2013), but it is not specified which option should be chosen and is not examined whether there is enough ground area or roof area to install required solar collectors to meet define heat demand. This means technical feasibility of this alternative is not analysed in this stage of the analysis. If installing solar collectors was chosen as an alternative to be further analysed in next stages, available area for their installation and advantages and disadvantages of ground and roof installation should be examined as mentioned in Chapter 9.
- Heat producing unit investment only includes the unit itself, but not other components that may be necessary for its operation. Consumer network does not include cost of installation of radiators and other expenses such as renegotiating or cancelling a contract with current energy suppliers. All those expenses should be added to the calculation in following stages of analysis, as explained in Chapter 9.
- Used energy prices are for Spanish market in general, meaning slight variations could be found among different energy provider prices. Regarding electricity price, a 3-period tariff offered by a specific electricity retailer is taken into account for the economic analysis of the heat pump. As well as examining other retailers' prices, it should also be analysed whether a 6-period tariff would be more or less economical than a 3-period tariff (which is only applicable for capacities lower than 450 kW). Apart from that, energy price projections for 22 years entail a big uncertainty, so, as explained in Section 3.2.2, a sensitivity analysis is done to find out how lower or higher energy prices could affect economy of different heat producing technologies.
- Inflation is assumed to be the same as the average annual inflation of the last 10 years. However, lower or higher inflation could be experienced, which would result in lower or higher investment, O&M cost and energy purchase cost than those calculated in this study. Nevertheless, as inflation affects every analysed technology and scenario in the same way, the most economical alternative will remain the most economical and the most expensive will remain the most expensive independent on inflation.

Analysis of similar initiatives

- Only district heating projects developed in the Basque Autonomous Community are taken into account because their context is more similar than the context of district heating projects from other regions –Basque projects share 2 out of the 4 levels of the context specified in Figure 5 on page 11. Nevertheless, useful knowledge could have also been gained from interviewing other district heating projects at national level.
- This study only examines some of the district heating projects developed in the Basque Autonomous Community. The analysed initiatives are not the only existing ones, which means more considerations could have been defined if every existing initiative had been analysed.
- The designed interview seeks to find out the most important information of the most relevant aspects and phases of a district heating project in a way that the obtained information can be compared and serves for conclusion drawing. However, it is not possible to include every possible question in an interview. Additional or different questions could have resulted in different conclusions.
- Differences have existed in regard to interviewees' willingness level in being interviewed for this study and time allocation for it. Hence, some interviewees did not answer every question, whereas some others provided additional information.
- Other initiatives, not directly related to district heating projects, but to citizens participation in sustainable society building, for instance, could have also been analysed for guidance in householders involvement in the project. However, this is out of the scope of this study, but it is taken into account for future work as explained in Chapter 9.

4 Potential Heat Demand Scenarios

This chapter analyses San Fausto's current heat demand and its potential evolution in order to find out heat demand to be met by the district heating system. With that aim the chapter starts with a detailed description of consumers' heated area and current heat demand and heating system. Afterwards, uncertainty regarding future heat demand is explained and potential heat demand scenarios for system modelling are defined.

4.1 San Fausto's Current Heating System and Heat Demand

As mentioned in Section 1.4, San Fausto consists of 53 buildings (Maab, 2014 (a)), all of them but two have 5 storeys (the two 4-storey buildings are as high as the others, but do not have a ground floor). In general, buildings have two dwellings per storey however few of them have trade premises at ground floor level instead. This way, dwellings sum 508 and trade premises 24.

Table 2: Buildings in San Fausto grouped according to their dwellings' heated area. (*) Trade premises do not have the same heated area as dwellings.

Building type	Buildings	Dwellings	Trade premises (*)	Heated area [m^2/dwelling]
A	10	96	4	39
B	37	361	3	49
C	3	24	8	65
D	3	24	9	75

As shown in Table 2, buildings can be grouped in four types –A, B, C and D– according to their dwellings' heated area, which ranges from 39 to 75 m^2 (Maab, 2014 (a)). B type buildings are the most common ones and their dwellings account for 71.5% of the total amount of dwellings and 71.3% of the total dwellings' heated area, which is 24,793 m^2. Unlike dwellings of same building type, trade premises do not have the same heated area. In order to calculate trade premises' total heated area it is assumed they have the same heated area as the dwelling type they replace. However, there are some cases in which two trade premises replace a single dwelling and, in those cases, each trade premises' heated area is assumed to be half the heated area of a dwelling. This way trade premises' heated area is 1,094 m^2, 4% of the total heated area, which is 25,887 m^2.

Buildings' energy consumption depends on various factors. One of them is what activities are carried out inside them, i.e. what buildings are used for. (IDAE, 2011 (c)) This means that, in spite of having been built using the same materials, dwellings and trade premises of the same building do not necessarily have the same heat demand. Therefore, dwellings' and trade premises' heat demand is analysed separately in the following.

4.1.1 Dwellings' Heat Demand

Dwellings can also be grouped according to their space heating demand due to their location within buildings, see Figure 7 on the following page. Following this grouping 6 types of demand are found: *Surrounded, Ground floor (GF), Roof, Exterior (Ext), Exterior Ground Floor (Ext GF)* and E*xterior Roof (Ext Roof)*. In (Maab, 2014 (a)) only the former 4 types are taken into consideration, but all of them are taken into account in this study aiming for a more accurate space heating demand calculation. Table 3 on the following page shows annual demands of different dwelling locations in kWh per dwelling's heated area. The values for S*urrounded, GF, Roof* and *Ext* are provided in (Maab, 2014 (a)) and *Add Ext* is the difference between *Surrounded* and *Ext*, which is summed to *GF* and *Roof* to calculate the demand of *Ext GF* and *Ext Roof*, respectively. When multiplying those values by the amount of dwellings of their type and summing the resulting demands, a total space heating demand of 1,046,717 kWh/year is obtained.

Figure 7: Types of dwellings according to their location within buildings.

Table 3: Annual space heating demand per dwelling in kWh per heated area. Values calculated based on thermography analysis. (Maab, 2014 (a))

Space heating demand per dwelling [kWh/m²/year]	
Surrounded	84
GF	145
Roof	138
Ext	127
Add Ext	43

It has to be mentioned the values in Table 3 do not represent real space heating demand, but theoretical heat demand calculated based on thermography analysis (Maab, 2014 (a)). Real demand, calculated from householders' bills, is remarkably lower –53 kWh/m²/year for a *Surrounded* type dwelling (Maab, 2014 (a)). According to (Maab, 2014 (a)) the reason for this difference is that residents of San Fausto do not use as much heating as needed to keep an acceptable indoor temperature in their homes. A clear sign of it is observed in Figure 8 on the following page, where no real heat demand is shown for the month of may even though heating is calculated to be necessary. October is the only moth when real demand –3 kWh– is higher than calculated demand –2.4 kWh.

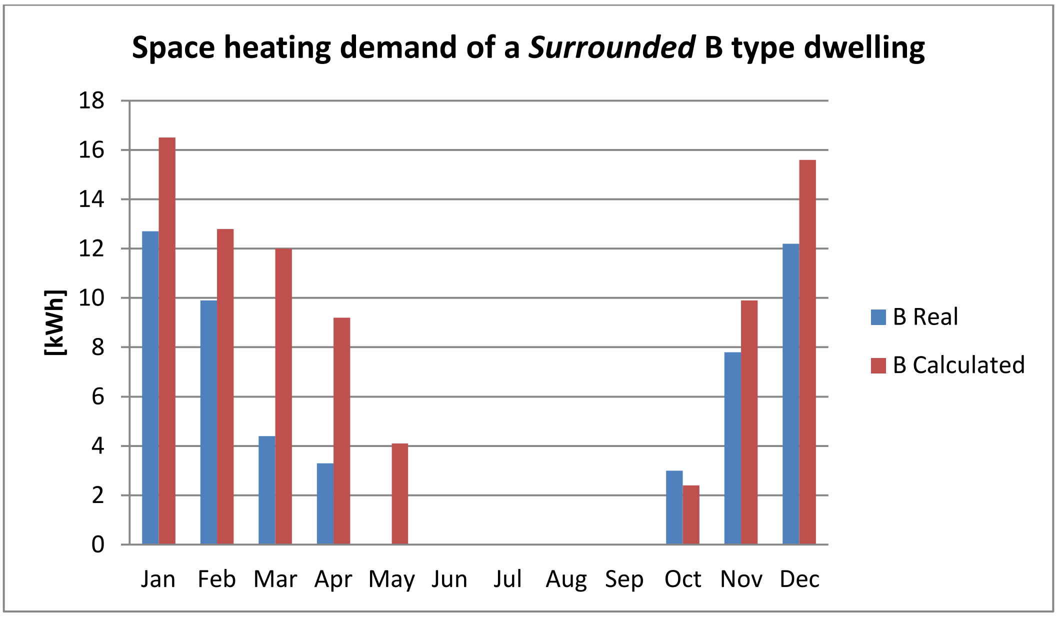

Figure 8: Monthly comparison of real and calculated space heating demand for a *Surrounded* B type dwelling over a year. (Maab, 2014 (a))

Regarding DHW demand, it is calculated to be 36 kWh/m^2/year based on householders' bills (Maab, 2014 (a)). Multiplying this value by dwellings' total heated area results in total annual DHW demand, 892,548 kWh.

In Spain dwellings' DHW demand is approximately 28% of dwellings' total heat demand (calculated with data from (IDAE, 2011 (a))). Nevertheless, it has to be pointed out that different climatologic areas are found in the country, resulting in significant differences of this ratio from area to area (IDAE, 2011 (a)). In the Basque Autonomous Community, located in the north of Spain and influenced by the Atlantic Ocean, DHW demand accounts for 35% of dwellings' total heat demand (calculated with data from (IDAE, 2011 (a))). In San Fausto, based on numbers provided in (Maab, 2014 (a)), DHW demand accounts for 30% of the total heat demand when using calculated space heating values, see Table 3 on the previous page, and 40% of the total heat demand when using real space heating demand values. The reason why the former is lower than average is San Fausto's buildings' poor thermal insulation, whereas the reason for the latter to be higher is related to the fact that heating is not used as much as needed as already discussed before in this section. In the following only the values calculated based on thermography analysis are taken into consideration because this study analyses the possibility of building a district heating system and, therefore, being able to cover heat demands that ensure good environmental indoor climate and good living conditions is an essential requirement.

As space heating demand, DHW demand has seasonal character too, see Figure 9 on the following page, mainly as a result of higher input water temperatures. However, DHW demand's seasonal character is not as emphasised as space heating demand's. The difference in space heating demand between the coldest two-month and the warmest is approximately 29 kWh, while in the case of DHW demand the difference is 3 kWh (calculated with data from (Maab, 2014 (a))).

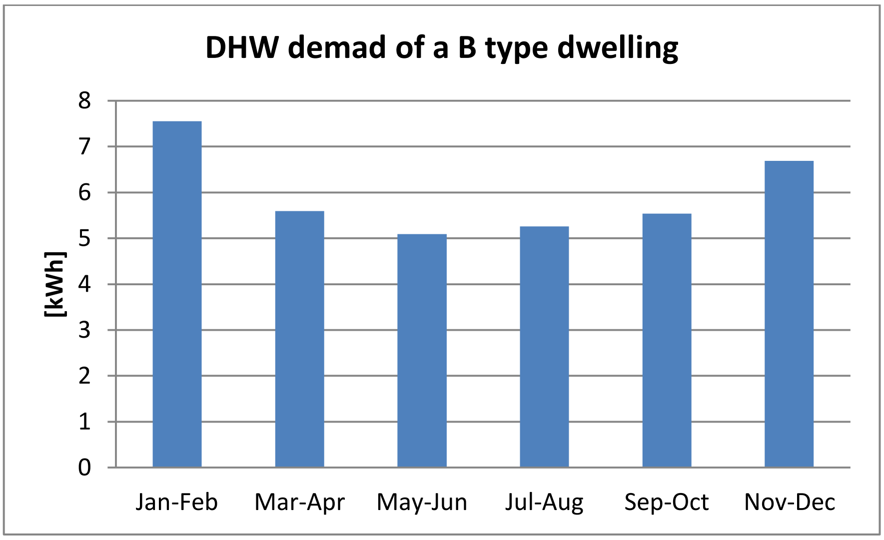

Figure 9: Two-month DHW demand of a B type dwelling (49 m^2 of heated area, see Table 2 on page 27) over a year (elaborated with data provided in (Maab, 2014 (a))).

In spite of the fact that buildings in the neighbourhood are very similar, space heating and DHW equipment vary from building to building (Maab, 2014 (a)), see Figure 10. Natural gas is the most common energy source for both, space heating and DHW, followed by electricity and butane gas. Every dwelling has an individual heating system, but 5% of the dwellings do not have a system for space heating and plug-in stoves are used instead (Maab, 2014 (a)). It has to be pointed out that some buildings do not have radiators for space heating (Maab, 2014 (b)), but the percentage they account for is not known. Furthermore, it is not known which energy source 8% of dwellings use for DHW.

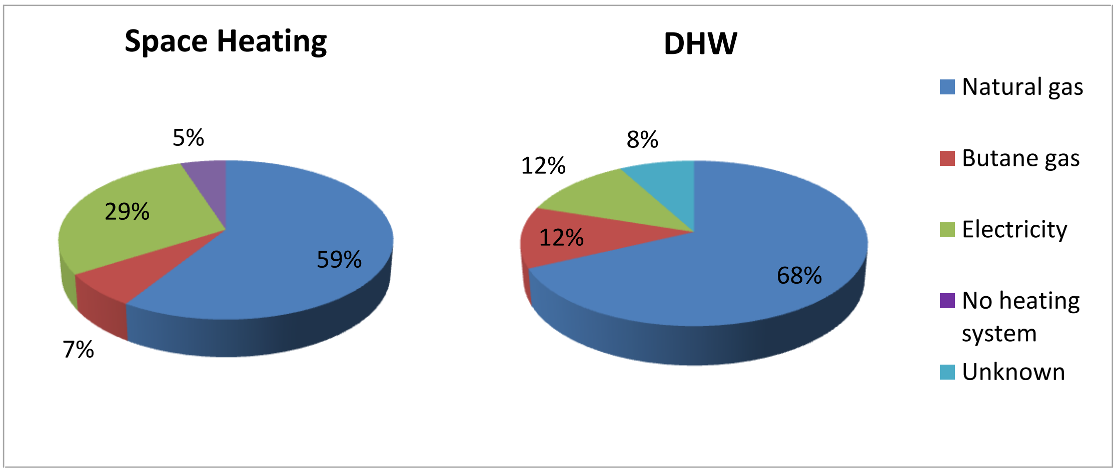

Figure 10: Energy sources used for space heating and DHW in San Fausto. (Maab, 2014 (a))

4.1.2 Trade Premises' Heat Demand

(Maab, 2014 (a)) does not analyse trade premises' heat demand. Even if some reports like (IDAE, 2011 (c)) provide residential buildings' and service sector buildings' energy consumption by energy use in relation to their total energy consumption, no estimation of energy demand per square meter has been found, neither a way to relate dwellings' consumption to trade premises'. Therefore, and not having access to real data, it is decided to assume trade premises have the same space heating demand as dwellings of their same type, i.e. A, B, C or D and with the same heat demand type. All trade premises are located at ground floor level, meaning only *GF* and *Ext GF* demand types are found in this case, see Figure 7 and Table 3 on page 28. This way, dwellings' annual total space heating demand is calculated to be 187,773 kWh. Service sector buildings' DHW demand accounts for 11% of their space heating demand according to (IDAE, 2011 (c)). Therefore, trade premises' total annual DHW demand is 20,655 kWh, resulting in total annual heat demand of 208,428 kWh –5% of dwellings' total annual heat demand.

Regarding space heating and DHW equipment, no data has been obtained and, hence, it is completely unknown what heating equipment trade premises have.

4.1.3 San Fausto's Current Total Annual Heat demand

Based on results presented in the previous sections, San Fausto's current total annual heat demand is calculated, see Table 4. Current demand is expected to be reduced in the near future as a consequence of the energy renovation proposed by project consultants and the town council as part of the project "Berritu San Fausto". Hence, it is indispensable to examine how neighbourhood's heat demand will evolve in the future in order to adjust and optimise the dimension of the district heating system.

Table 4: San Fausto's current annual total heat demand. Space heating demand values are calculated based on data obtained from thermography analysis and not on householders' energy bills.

	Dwellings	**Trade premises**	**TOTAL DEMAND**
Space heating demand [kWh/year]	2,990,062	187,773	3,178,393
DHW demand [kWh/year]	892,548	20,655	913,203
TOTAL DEMAND [kWh/year]	3,883,168	208,428	**4,091,596**

4.2 Neighbourhood's Future Heat Demand

As part of the project "Berritu San Fausto" project consultants and town council propose improving buildings' energy performance by adding thermal insulation to façades and roofs. Project consultants suggest adding more insulation than the minimum required by the building code in order to maximise benefits, i.e. money savings from lower heat demand minus initial investment.

The proposed energy renovation will reduce buildings' current space heating demand to 35%. As a result, their energy performance will improve from E to C according to the Energy Performance Certificate Scale. (Maab, 2014 (a)) Assuming the same demand reduction is applicable to every building type and dwelling demand type, values shown in Table 3 on page 28 would change to the ones shown in Table 5 on the following page. In the same way as it has been done for the calculation of neighbourhoods' current heat demand, it is assumed that trade premises have the same heated area and same heat demands as the dwellings they replace. This way, total space heating demand after renovation is calculated to be 1,112,438 kWh/year when all the buildings implement the proposed energy performance improvements. However, this is not very likely to happen as explained later on in this section.

Regarding DHW demand, no energy savings are mentioned in (Maab, 2014 (a)) as a result of the energy renovation. Therefore it is assumed no DHW demand reduction will happen, i.e. DHW demand will still be 931,932 kWh/year after energy renovation regardless of how many buildings decided to implement energy efficiency improvements.

Table 5: Annual space heating demand per dwelling in kWh per heated area after energy renovation. (Maab, 2014 (a))

Space heating demand per dwelling after energy renovation [kWh/m^2/year]	
Surrounded	29
GF	48
Roof	51
Ext	44
Add Ext	15

Data from interviews held by consultants shows householders' first priority is to replace the current sewage pipeline, which is the least expensive work to be done –1,000-1,200 EUR/household (Maab, 2014 (a))– because the town council will cover a significant percentage of it (Town council & Maab, 2014 (b)). Energy renovation is voted the 5th out of a list of 6 improvement proposals and the required investment is 9,000-12,000 EUR/household (Maab, 2014 (a)). Taking into account the limited budget of many households and their priority list, it could be expected that not many buildings will implement the energy renovation, if any. However, householders are encouraged to implement it as it increases the chances for getting subsidies and the amount to be received, which is dependent on improvements to be implemented and household's annual income. A clear example of the advantage of implementing energy performance improvements is that the investment to be covered by householders when implementing "replacement of sewage pipeline + building an elevator + energy renovation" is lower than when implementing "replacement of sewage pipeline + building an elevator" because the subsidy is much bigger for the former combination. (Maab, 2014 (a)) Taking into account obtainable subsidies, the most economical combination of those analysed in (Maab, 2014 (a)) is "replacement of sewage pipeline + energy renovation".

Heat demand is one of the factors with the highest impact on district heating systems' costs as it influences both, investment and O&M costs (DEA & energinet.dk, 2012 (a)) (DEA & energinet.dk, 2012 (b)). Hence, due to the high uncertainty regarding energy renovation and replacing current individual heating system by a district heating system, it is essential that the comparison of the economy of different applicable heat producing technologies is done in relation to different heat demand scenarios.

4.3 Potential Heat Demand Scenarios

Six different potential demand scenarios, study arisen from combination of different percentages of energy renovation and connection to the district heating system, are decided to be analysed in this, see Table 6 and Table 7 on next two pages. Obviously, these are not the only possible scenarios, but it is indispensable to set some delimitations as already explained in Section 3.6. Examining other potential scenarios is considered as an extension of this preliminary economic analysis and is therefore included in Chapter 9, as explained in Section 3.6.

One of the project consultants has already analysed the possibility of implementing a district heating system in San Fausto using biomass as energy source. His analysis concludes that at least 100 dwellings, i.e. 20% of dwellings, should get connected to the district heating system so that it is economically feasible. (Town council & Maab, 2014 (a)) Based on this statement, it is decided that connecting 20% of dwellings to the district heating system from the beginning (this is from the moment of operation start) should be taken as the minimum requirement for its implementation. In Denmark, a country with decades of experience in district heating systems (DEA & energinet.dk, 2012 (a)), it is common to set the minimum for system construction at 60% of buildings within the target area (Grundahl, et al., 2013). Therefore, those two options are taken into account. Furthermore, based on experience from district heating projects in other countries, it can be expected that other buildings will get connected to the system in the future. Hence, it is assumed 40% of the remaining buildings will get connected to the district heating system in 10 years. It is further assumed new connections will imply a linear increase of demand, i.e. the same heat demand is added to the district heating system every year during 10 years. This way, two possible options regarding connection to the district heating system are analysed, both of them with a minimum initial percentage of connections as requirement and assuming 40% of buildings will gradually get connected in 10 years, see Table 6.

Regarding energy renovation, it is decided to analyse three possible options. The first one assumes 25% of buildings will implement the proposed energy renovation, the second one assumes 50% will do it and the third one that 75%, see Table 6. Following the piece of advice given by Maab, it is decided not to analyse 0% energy renovation and 100% energy renovation as those two option are considered to be very improbable.

Combining the two options to be analysed regarding connection to the district heating system and the three options regarding energy renovation implementation, 6 different demand scenarios are obtained, see Table 7 on the following page. The annual heat demand evolution for each of the scenarios (including space heating demand, DHW demand and 20% system losses, as explained in Section 3.2.1) is shown in Figure 11 on the following page. The reason why the lines in the graph are not completely straight is that heating demand is dependent on outdoor temperature, see Section 3.2.1.

Table 6: Potential connection to the district heating system and energy renovation implementation shown in building percentages.

Connection to district heating system
20% (from beginning)+ 40% (in 10 years) = 60%
60% (from beginning)+ 40% (in 10 years) = 100%

Energy renovation implementation
25%
50%
75%

Table 7: Potential heat demand scenarios to be analysed. These scenarios arise from combining options regarding connection to district heating system and energy renovation implementation presented in Table 6 on the previous page.

	Potential heat demand scenarios
S1	Connection to DH system: 20% (from beginning)+ 40% (in 10 years) = 60% Energy renovation implementation: 25%
S2	Connection to DH system: 20% (from beginning)+ 40% (in 10 years) = 60% Energy renovation implementation: 50%
S3	Connection to DH system: 20% (from beginning)+ 40% (in 10 years) = 60% Energy renovation implementation: 75%
S4	Connection to DH system: 60% (from beginning)+ 40% (in 10 years) = 100% Energy renovation implementation: 25%
S5	Connection to DH system: 60% (from beginning)+ 40% (in 10 years) = 100% Energy renovation implementation: 50%
S6	Connection to DH system: 60% (from beginning)+ 40% (in 10 years) = 100% Energy renovation implementation: 75%

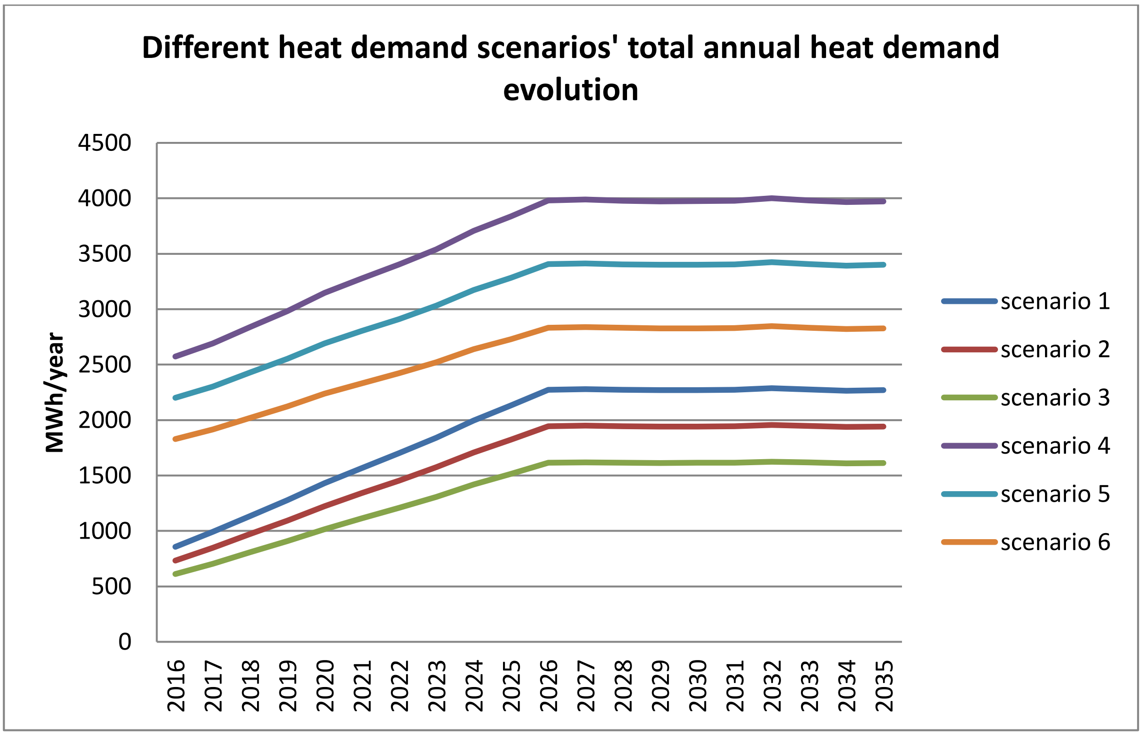

Figure 11: Different heat demand scenarios' total annual heat demand evolution, including space heating demand, DHW demand and 20% system losses.

5 Election of Applicable Heat Producing Technologies and Economic and Technical Data

District heating systems consist of one or various heat production centres, a heat distribution network and consumer networks (DEA & energinet.dk, 2012 (a)). Heat production centres are buildings where heat production units, hot water storage tanks and system control and operation devices are placed (FOREST, n.d.). Depending on chosen heat producing technology, components such as fuel storage tanks or warehouses, fuel feeding and handling systems and chimneys may also be required. Heat distribution networks deliver heat from heat producing centres to end users (i.e. consumer networks in each building) by means of pre-insulated pipelines, water pumps and other hydraulic components. Consumer networks –or district heating substations– are usually equipped with heat exchangers placed between the primary side (district heating water) and the secondary side (DHW and space heating water). Apart from that they also include other components such as controllers, pumps, filters and valves. (DEA & energinet.dk, 2012 (a))

This chapter starts by presenting some heat producing technologies applicable to the case of San Fausto. Presented options are analysed and some of them are chosen for further analysis. Afterwards economic and technical data needed for system modelling and economic analysis is introduced for every system component.

5.1 Applicable Heat Producing Technologies

The objective of this section is to present different technical alternatives for heat production in line with project objectives. One of the aims of the project "Berritu San Fausto" is increasing the share of renewable energy used in the neighbourhood (Maab, 2014 (a)), hence, no fossil-fuel-fired technologies are examined in this study, as already mentioned in Section 2.3.

Biomass, electricity and solar energy are the energy sources chosen for analysis as they can be directly converted into heat and would meet the mentioned objective. Every heat producing technology presented in the following is run on one of those three energy sources.

5.1.1 Biomass

Biomass Energy Centre defines biomass as *"biological material derived from living or recently living organisms"* (Biomass Energy Centre, n.d. (b)). It is categorised as renewable energy source and may come from forestry, industry waste, agriculture and livestock farming waste, sewage water or cities' organic waste among others (EVE, n.d. (a)). This means it is possible to produce biomass locally, which reduces energy dependency and supports local economic development (Gonzalez Perez, 2012). These and other attributes of biomass are the reasons why an increase of utilization of biomass for energy uses (for both, electricity and thermal generation) is included in Spanish and Basque energy strategies for 2020 (IDAE, 2011 (b)) (IDAE & MINETUR, 2010) (EVE, 2012). The latter aims to increase renewable energy share by 87% in comparison to 2010 levels in order to cover 14% of Basque Autonomous Community's net energy consumption with renewable energy in 2020. It is expected biomass will account for 63% of the total growth of renewable energy share aimed for that year. (EVE, 2012)

Biomass coming from forestry is the most abundant type of biomass in the Basque Country according to (EVE, 2012), which estimates 370,000 tons of forestry biomass are produced every year in the region and that approximately half of it is useful for energy purposes. Taking this into account and aiming for locally produced biomass, wood pellets and wood chips are analysed as potential biomass fuels.

Two technologies for heat production are taken into account in this study: biomass-fired combined heat and power (CHP) plants and biomass-fired boilers. However, it is decided not to analyse the economy of CHP plants due to the current uncertain and instable situation of the Spanish electricity sector, consequence of its recent reform. The reform and its correspondent law (*Ley 24/2013 del Sector Eléctrico*) were approved in December 2013 (Jefatura de Estado, 2013 (a)). One of the major changes is that electricity generation from renewable energy, waste and co-generation does not receive subsidies in relation to produced energy (i.e. feed-in tariff) anymore, but regarding investment of technology type in order to ensure what has been named as "reasonable profitability" (*rentabilidad razonable*) (Jefatura de Estado, 2013 (b)). This measure was approved with retroactive effect, meaning it is not only applicable to future electricity generation plants but also to already existing ones, whose profitability is being negatively affected (Urresti, 2014). The reform has been highly controversial and 12 parties of the opposition signed an agreement to repeal the law as soon as Government is changed (Expansión, 2013) (Mosquera, 2013) (CE NEWS, 2013). This instable legal framework makes changes be very expectable in the near future and increases investments' risks. Hence, it is decided not to analyse biomass-fired CHP plants' economy in this study and to analyse only economy of biomass-fired boilers, i.e. wood-chip-fired boilers and wood-pellet-fired boilers.

5.1.2 Electricity

Electricity is a secondary energy source obtained from conversion of primary sources such as wind energy, nuclear energy or fossil fuels. Each country's electricity demand is met by means of a particular mix of energy resources −either local or imported. In Spain 33% of the gross electricity consumption was covered by renewable energy in 2010 (IDAE, 2011 (b)) and 36% in 2012 (calculated with data from (MINETUR, 2014 (a))). This means the share of renewable energy used in San Fausto would be increased by replacing butane gas or natural gas fired boilers with heat producing units that use electricity for that purpose.

Integration of heat and power systems contributes to flexibility of the power network, indispensable for electric systems with increasing shares of fluctuating energy sources (DEA & energinet.dk, 2012 (a)). This is the case of Spain where wind and solar energy already accounted for approximately 26% of the gross electricity consumption in 2012 (calculated with data from (MINETUR, 2014 (a))), share that is expected to increase in order to meet national and European energy targets (IDAE, 2011 (b)). Spanish Renewable Energy Plan 2011-2020 aims for an increase of renewable energy in the system and estimates electricity production from renewable energy will increase approximately 70% from 2010 to 2020 due to new installed capacity. However, this estimation became dubious as a consequence the recent reform of the electricity sector, where subsidies for renewable energy, waste and co-generation have been reduced as already explained in the previous section.

Two technologies that use electricity to produce heat are considered in this study: heat pumps and electric boilers. Heat pumps, although dependent on type, can produce approximately 3 times as much heat as electric boilers utilising the same electric energy (DEA & energinet.dk, 2012 (b)). Hence, heat pumps are much more efficient than electric boilers. On the other hand, electric boilers have the advantage of being able to start their production much faster, enabling some electric boilers to be used as downward regulation units in electricity systems (they can also be utilized as upward regulation units when being in operation). (DEA & energinet.dk, 2012 (b))

Because of their particular characteristics, heat pumps and electric boilers are approached differently in this study. Heat pumps are considered to be main heat production units, whereas electric boilers are seen as supplementary or additional heat producing units. This means an electric boiler cannot be the only heat producing unit of a heating system. Its objective is to reduce heat system's operation costs by receiving remuneration from electricity balancing markets and to work as a back-up unit when necessary. At this point, it is important to mention there is no regulation in Spain that provides a back-up system as a requirement for a district heating system (Maab, 2014 (b)), as already mentioned in Section 3.2.1, and electricity consumption units are not allowed to take part in Spanish balancing markets –except from hydro pumping stations (REE, 2014). As a result, it is decided not to examine electric boilers any further and focus only on heat pumps. Various types of heat pumps exist (DEA & energinet.dk, 2012 (b)) however only air-to-water heat pumps are chosen for further analysed in this study.

5.1.3 Solar Energy

Solar energy is radiation energy of electromagnetic waves emitted by the sun (EVE, n.d. (b)) and can be converted into heat by means of solar collectors (DEA & energinet.dk, 2012 (b)). Due to solar energy's fluctuating character, it is necessary solar heating systems to be combined with other types of heating technologies (such as boilers and CHP units) in order to ensure heat demand is met at any time (DEA & energinet.dk, 2012 (b)). Hence, solar collectors are analysed as additional or supplementary heat producing units and in combination with the technologies specified in Sections 5.1.1 and 5.1.2, i.e. wood-chip-fired boiler, wood-pellet-fired boiler and air-to-water heat pump.

Regarding choice of solar collector type, it is decided to analyse flat-plate solar collectors and dismiss evacuated tube collectors. Flat-plate collectors are more common for large heating systems (Trier, 2012), they are cheaper, widely available and more appropriate for sunny and medium-to-warm climates (NVI Solar, n.d.). Besides, according to (Trier, 2012) durability of evacuated tube collectors has not been proven yet in district heating systems.

5.2 Economic and Technical Data

Every economic and technical data related to district heating components that is utilised for system modelling and economic analysis is presented in the following, starting by heat producing technologies chosen in the previous section.

5.2.1 Heat Producing Units

A. Wood-Chip-Fired Boiler and Wood-Pellet-Fired Boiler

Wood-chip- and wood-pellet-fired boilers' investment, O&M costs and efficiencies are shown in Table 8 on the following page. Because of the fact that no economic data has been accessed for the Spanish market as explained in Section 3.2.2, values in the table are taken from (DEA & energinet.dk, 2012 (b)) and investment values are the average of those provided in the report. It has to be mentioned values in Table 8 are applicable to boilers with capacities higher than 1 MW, meaning investment per installed capacity could be higher than those in the table if boiler capacity was below 1 MW.

In addition to the heat production unit, the are other components that are also needed for optimal performance of biomass heating systems including biomass warehouses, fuel feeding and handling systems, central control devices connected to an outdoor temperature sensor, other boilers, ash extraction facilities, chimneys and thermal stores. All components must be compatible to each other and, at the same time, be suitable for the particular heat demand and site (FOREST, n.d.). Therefore (FOREST, n.d.) recommends to hire experts' consultancy for system design and to buy as many components as possible from the same manufacturer. It has to be taken into account all those components add investment and O&M costs which are not included in this analysis but for the case of thermal stores examined in Section 5.2.2.

Table 8: Investment, O&M cost and efficiencies of wood-chip-fired boilers and wood-pellet-fired boilers in the year 2015. Investment and O&M cost exclude VAT. (DEA & energinet.dk, 2012 (b))

	Wood-chip-fired boiler	**Wood-pellet-fired boiler**
Investment [million EUR/MW]	0.8	0.4
O&M cost [EUR/MWh]	6.68	3.34
Efficiency [%]	108	108

Regarding biomass purchase, in 2013 prices of wood chips and wood pellets in Spain were 112 EUR/ton and 225 EUR/ton respectively (both prices include transportation costs and exclude VAT) (Enciso, 2013). Wood pellets have lower moisture content and are more compact than wood chips due to wood's transformation process to obtain wood pellets (Biomass Energy Centre, n.d. (a)). As a consequence, wood pellets' calorific value –18.828 GJ/ton (Enciso, 2013)– is higher than wood chips' –14.226 GJ/ton (Enciso, 2013)– resulting in smaller storage spaces (Biomass Energy Centre, n.d. (a)). Requiring more transformation process and being a higher quality product are the reasons why wood pellets are more expensive than wood chips.

Biomass price projection is difficult to be foreseen. Biomass price is dependent on numerous factors (energy targets, energy strategies, incentives, demand, production, etc.), which results in high uncertainty regarding price projections even if demand growth is foreseen (IEA & Danish Technological Institue, 2012). Furthermore, (Oxford Economics, Biomass Energy Centre, Forest Research, 2011) estates wood-pellet and wood-chip market is still *"immature and sensitive to short term supply side shortages or periods of high demand"* (p. ix), which could result in sudden rises in demand and prices. The report estimates an increase of 9-31% in wood-pellet price and of 14-25% in wood-chip price between 2011 and 2020. As a consequence of market development, lower price increases are forecasted for the period between 2020 and 2030, –8%-6% in wood-pellet price and 0% in wood-chip price (Oxford Economics, Biomass Energy Centre, Forest Research, 2011). Danish Energy Outlook 2012 calculates biomass prices will rise 15% from 2012 to 2030. Taking into account these estimations, it is assumed both, wood-pellet price and wood-chip price, will rise 15% between 2012 and 2030. In the case of wood pellets, 80% of the increase will happen from 2012 to 2020 and 20% from 2021 to 2030, whereas in the case of wood-chip price the entire increase will take place between 2012 and 2020. Further it is assumed the same tendency of the decade 2021-2030 will continue after 2030. This way, and adding VAT and the correspondent inflation (2.24% each year, see Section 3.2.2), wood-pellet and wood-chip prices used for the economic analysis are those shown in Figure 12 on the following page.

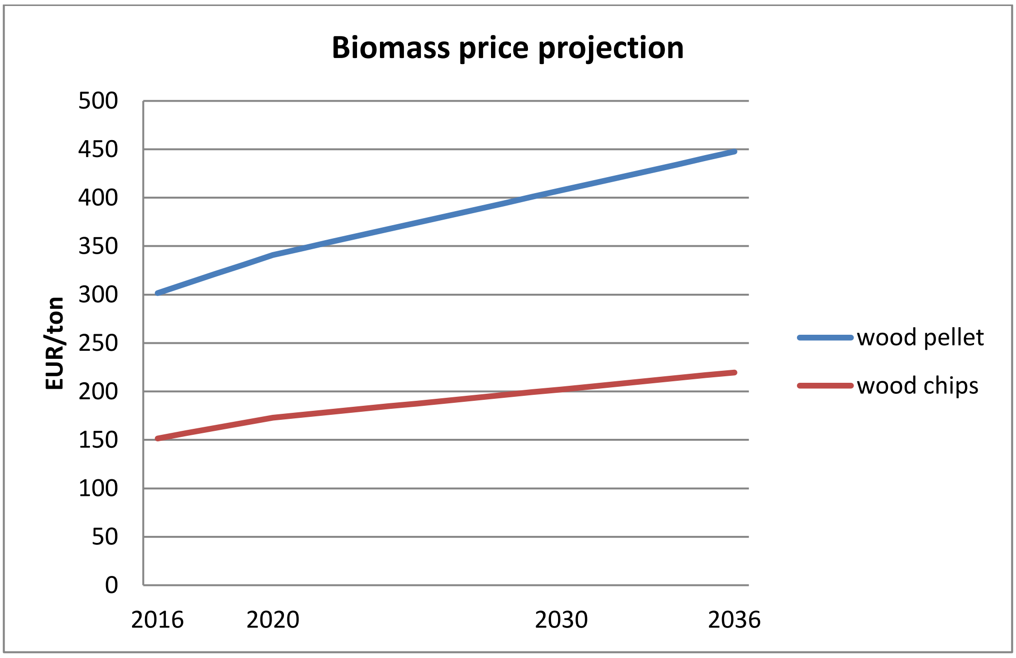

Figure 12: Biomass price projection 2016-2036. Prices include fuel cost, transportation, Vat and inflation.

B. Air-to-Water Heat Pump

Coefficient of performance (COP), investment and O&M costs of air-to-water heat pumps are obtained from (DEA & energinet.dk, 2012 (b)) and shown in Table 9. Investment is the average of values provided in the report and only includes the heat pump itself. Other necessary components such as electrical system, pipes and their installation would increase investment to 0.52-0.84 million EUR per MJ/s. Since no investment has been found for other components needed when using biomass boilers, it is decided not to add the extra cost of components to heat pump investment either. It has to be pointed out the investment value showed in the table is for heat pumps with capacities over 1 MJ/s, meaning investment per installed capacity could be higher if a smaller heat pump was installed.

Table 9: Investment, O&M cost and COP of air-to-water heat pumps in 2015. Investment and O&M cost exclude VAT. (DEA & energinet.dk, 2012 (b))

Air-to-water heat pump	
Investment [million EUR/MJ/s]	0.4
O&M cost	
Cost 1 [EUR/year]	2,500
Cost 2 [EUR/MJ/s out/year]	1,500
COP	2.8

Regarding electricity costs, heat pumps can either buy electricity from spot market (as a direct large consumer) or from electricity retailers (El Observatorio Crítico de la Energía, 2012). Even if buying electricity from spot market presumably reduces electricity costs, it must be taken into account human resources have to be assigned to be in charge of this task or a market agent has to be outsourced for it. It is consumers' own responsibility to analyse which option, buying electricity from the spot market or from a retailer, is the most beneficial for themselves. (Observa el Mercado Eléctrico, 2014) In this case, buying electricity from a retailer is chosen as no data has been found regarding costs of hiring such a service and because (EVE, 2014 (b)) considers this alternative the most economical for a consumer of this size.

After Spanish electricity market liberalisation in 1997 and since 1998 electricity prices paid by consumers consist of two main components: a non-regulated component (which is the payment for the consumed energy) and a regulated component known as "access fee" (*peaje de acceso*) whose purpose is to cover system's costs (El Observatorio Crítico de la Energía, 2012). The access fee is comprised of an element related to consumers' electricity consumption and an element related to hired capacity (Martí Scharfhausen, 2009), both elements are equal in the whole country and defined in advanced (Martí Scharfhausen, 2009). Apart from that, consumers also have to pay rent of meters (EVE, 2014 (a)), which is also a regulated component (IDAE, 2014). Retailers' electricity tariffs include non-regulated as well as regulated components to be paid by consumers. In addition to it, electricity tax (5.1%) and VAT (21%) have to be paid. (EVE, 2014 (a)) This way electricity price paid by consumers is that shown in Formula 5.1.

(5.1) $electricity\,price = retailers'\;tariff \cdot (1 + 5.1\%) \cdot (1 + 21\%)$

where

$$retailers'tariff = consumed\;electricity + access\;fee + meter\;renting =$$
$$= consumed\;electricity + (consumed\;electricity\;element + hired\;capacity\;element) +$$
$$+ meter\;renting$$

In the same way as access fee, retailers' tariffs are divided into low voltage tariffs (below or equal to 1 kV) and high voltage tariffs (over 1 kV) (Martí Scharfhausen, 2009). Due to San Fausto's heat demand, a high voltage tariff has to be hired. Since December 2008, high voltage tariffs differentiate various periods with different prices along the day and over a year (MINETUR, 2008). The period with the highest price is the one with the highest electricity demand and the period with the lowest price the one with the lowest demand. The objective of this differentiation is to decrease consumption during the highest demand periods and thereby to reduce system's costs. (Ruiz Luna, 2011)

According to the amount of periods they differentiate, two types of high voltage tariffs are found: 3-period tariffs and 6-period tariffs. The 3-period tariff's name is 3.1A and is applicable to voltages ranging from (1 to 36 kV) and installed capacities lower than 450 kW. Regarding 6-period tariffs, 5 subtypes exist: 6.1 (1-36 kV), 6.2 (36-72.5 kV), 6.3 (72.5-145 kV), 6.4 (>145 kV) and 6.5 (international connections). (Martí Scharfhausen, 2009) It is decided to carry out the economic analysis of heat pumps based on a 3-period tariff as it simplifies the analysis and because it is the only type of tariff for which retailer prices have been accessed. Retailer prices for each of the three periods are shown in Table 10 and periods' delimitation in Table 11 on the following page.

Table 10: Retailer prices for a 3-period high voltage tariff in 2014. Prices exclude electricity tax and VAT. (ENDESA, 2014 (a))

	Period 1 (Punta)	**Period 2 (Llano)**	**Period 3 (Valle)**
Hired capacity [EUR/kw/year]	59.475288	36.676813	8.410411
Consumed electricity [EUR/kWh]	0.123310	0.106111	0.077121

Table 11: Electricity tariff's periods delimitation over a year and over a day. Period 1 (Punta) in red, Period 2 (Llano) in white and Period 3 (Valle) in green. (ENDESA, 2014 (b))

Hours	0-1	1-8	8-9	9-10	10-16	16-17	17-18	18-23	23-24
Winter weekdays									
Summer weekdays									
Weekends and national holidays									

Regarding electricity price projection, it is assumed hired capacity will follow the same tendency as the hired capacity element of the access fee during the period 2008-2012, this is a total annual average increase of 4.6125 €/kW (calculated with data from (MINETUR, 2008) and (MINETUR, 2012)), which related to retailer's tariff, see Table 10 on the previous page, implies an annual increase of 4.41% (including inflation). Consumed electricity price is assumed to be affected by both, spot market price increase and access fee's consumed electricity element price increase. It is assumed annual average spot market price rise for the period 2014-2035 will be the same as for the period 1998-2013; this is 19.20 EUR/MWh (calculated with data from (OMIE, 2014)), which in a period of 21 years results in an annual average increase of 0.9143 EUR/MWh. It is further assumed access fee's consumed electricity element will increase following the same tendency of the period 2008-2012. This means the price for consumed electricity will experience an annual increase of 4.35% regarding period 1, 4.59% regarding period 2 and 3.92% regarding period 3 (all values include inflation). In order to simplify the economic analysis, it is decided to apply the same annual increase to the three periods: 4.29% (average of the previously mentioned percentages). The reasons for only using data from 2008 to 2012 to calculate access fee price projection are that values before 2008 are not comparable to values after 2008 (when access fee first differentiated various periods over a year and over a day for high voltage tariffs) and that the drastic change in access fee values as a consequence of the Electricity Sector reform of 2013 would have resulted in an unrealistic tendency –hired capacity increased 125% and consumed electricity decreased 68-69% from 2012-2013 (calculated with data from (MINETUR, 2012) and (MINETUR, 2013)).

C. Flat-Plate Solar Collectors

Solar collectors' investment, O&M cost and technical data used for the economic analysis is shown in Table 12. Investment (which includes not only solar collectors but also pipes) and O&M cost are those provided in (DEA & energinet.dk, 2012 (b)), whereas technical data is specific data for solar collectors Saunier Duval SRV 2.3 and Saunier Duval SRH 2.3 (TÜV Rheinland DIN CERTCO, 2013) chosen randomly.

Table 12: Solar collectors' investment and O&M cost (DEA & energinet.dk, 2012 (b)) and technical data (TÜV Rheinland DIN CERTCO, 2013) used for economic analysis.

Flat-plate solar collector	
Investment [EUR/m^2]	227
O&M cost [EUR/MWh]	0.57
Collector's area [m^2/collector]	2.51
Start efficiency (η_0)	0.79
Loss coefficient 1 (a_1)	3.721
Loss coefficient 2 (a_2)	0.016
Incidence angle modifier (K_θ), 50 °	0.9

Solar collectors are place facing south and with a tilt angle of 41° as recommended by (Photovoltaic Solar Panels, 2013) for a place located in 43,168 latitude and -2,624 longitude.

5.2.2 Hot Water Storage Tank

Hot water storage tanks improve performance of heat producing units in particular and of district heating systems in general. Having a hot water storage tank makes it possible to reduce producing units' capacity, prevents heat producing units from turning on and shutting down too often and improves units' producing efficiencies as they may work at full load. All of it results in lower investment in and O&M cost of heat producing units and reduces systems' overall cost. (FOREST, n.d.) (Hargassner, n.d.)

Investment for hot water storage tanks of 1,000 m^3 was 230 EUR/m^3 (excluding VAT) in 2010 (DEA & energinet.dk, 2012 (b)). No data has been found for smaller large-scale hot water storage tanks, hence, this value is used for every storage volume analysed. It has to be mentioned higher investments per m^3 are probable for smaller size storages.

5.2.3 Building

A public project developer called Visesa calculated the investment required to construct the building where the energy production centre should be placed. The calculation was done for the case in which a wood-chip-fired boiler was used as main heat producing unit and obtained value is 0.5 million EUR (Visesa, 2014). Heating and cooling systems' regulation (*Reglamento de Instalaciones Térmicas de los Edificios*) specifies heating systems using biomass must have a warehouse for biomass where fuel for at least two weeks of consumption can be stored. Since energy density of wood chips is lower than wood pellets' (Francescato, et al., 2008), warehouse dimension has to be bigger when using wood chips. This means investment for a building where a wood-pellet-fired boiler is placed could be lower than the provided value. Heat pumps do not need a warehouse for fuel storage, which would result in even lower building investment.

Lack of knowledge and time make it impossible to calculate investment for a building when a wood-pellet-fired boiler is used and when a air-to-water heat pump is used. Hence, it is assumed building investment is the same independent on applied heat production technology and heat demand scenario.

5.2.4 Heat Distribution Network

Required heat distribution network characteristics and investment was also analysed by the public project developer Visesa. The analysis was done for three different demand scenarios, one for each of the three potential total annual heat demands calculated assuming 100% of buildings in San Fausto will get connected to the system (Visesa, 2014). These scenarios are named scenario A, scenario B and scenario C in this report as they do not coincide with the potential heat demand scenarios defined for this study in Section 4.3. Estimated annual demands and investments for scenarios A, B and C are shown in Table 13 on the following page. It has to be mentioned investment does not include cost of digging trenches for pipe installation (Visesa, 2014) as this cost results from sewage pipeline improvement work and not from the district heating project itself. This means investment of heat distribution network should be recalculated if the district heating system was not to be built at the same time as improving the sewage pipeline.

In order to calculate heat distribution network investment for the 6 potential heat demand scenarios defined for this study, it is assumed the network will have the same length independent on demand scenario (i.e. the length required for 100% connection) and total annual heat demand is considered to be the only variable factor that may influence investment. This way, due to scenarios' similar total annual heat demand, heat distribution network investment in scenarios 1, 2 and 3 is assumed to be the same as in scenarios A and B and investment in scenario 6 the same as in scenario C, see Table 13 and Table 14. Heat distribution network investment in scenarios 4 and 5 is calculated by adding to scenario C 0.134 million EUR per additional GWh –value calculated by comparing demand and investment of scenarios 1 and C.

Table 13: Total annual heat demand and heat distribution network investment in 2015 for each of the three scenarios defined by Visesa. Investment does not include cost of digging trenches for pipe installation and includes VAT. (Visesa, 2014)

	Total annual heat demand (GWh)	Investment (million EUR)
Scenario A	1.72	0.335
Scenario B	2.21	0.335
Scenario C	2.78	0.402

Table 14: Total annual heat demand and heat distribution network investment for each of the 6 demand scenarios defined for this study in Section 4.2. Investment values are for the year 2015 and include VAT.

	Total annual heat demand in 2026 (GWh)	Investment (million EUR)
Scenario 1	2.28	0.335
Scenario 2	1.95	0.335
Scenario 3	1.62	0.335
Scenario 4	3.98	0.556
Scenario 5	3.41	0.480
Scenario 6	2.83	0.402

According to (DEA & energinet.dk, 2012 (a)) annual O&M cost of heat distribution networks in 2015 will be 250 EUR/TJ (excluding VAT), this is approximately 900 EUR/GWh (excluding VAT).

5.2.5 Consumer Network

The public project developer also analysed investment of consumer network (Visesa, 2014). According to his calculations, total investment for 53 buildings in 2015 is 0,1 million EUR (including VAT) for every potential demand scenario. This value does not include cost of installing radiators in dwellings (Visesa, 2014) –no every dwelling has radiators as electric heating and plug in stoves are used in some of them as explained in Section 4.1.1. Apart from that, consumers will have to cancel or renegotiate their contracts with their former energy suppliers, which may entail an extra cost which is not included in the value given by the consultant either.

Neither cost of installing radiators nor cost of cancelling or modifying a contract with an energy supplier are examined or added in this study, because of lack of time for the former and expected variability of the latter. Nevertheless, it is recommended to add those costs in the next stage of analysis, see Chapter 9.

Annual O&M cost of district heating substations for apartment complexes in 2015 will be 1,250 EUR/unit (excluding VAT) (DEA & energinet.dk, 2012 (a)).

5.2.6 Other Initial Expenses

Apart from the system itself, there are other initial expenses to be covered such as project consultancy and permits. According to (Visesa, 2014), other initial expenses sum 0,15 million EUR (including VAT) in 2015 for every potential heat demand scenario.

6 Economic Results

This chapter presents the economic results obtained from system modelling in energyPRO. The chapter starts with total accumulated balances resultant of the installation of the three main heat producing technologies (i.e. wood-chip-fired boiler, wood-pellet-fired boiler and air-to-water heat pump), which are examined as system's only heat producing unit and also in combination with solar collectors. Afterwards, total accumulated balances obtained for different heat producing technologies are compared and results obtained from the sensitivity analysis presented. Finally, monthly costs, investment, accumulated balance and cost per kWh per household are introduced and explained.

6.1 Total Accumulated Balances

Before introducing results it is important to remind some of the explanations given in Section 3.2. Total accumulated balances are the sum of system investment and running cost over the analysed 20-year period. Three different sizes of thermal stores are examined for biomass boilers –*1 week, 2 days* and *optimum*– only *1 week* and *2 days* sizes are analysed for the heat pump and only *1 week* when solar collectors are added. Further, two solar collector areas are analysed –*100% solar collectors* and *50% solar collectors*. The former is the area needed to cover 100% of summer heat demand in 2026 and the latter half of the area needed to meet that demand.

6.1.1 Wood-Chip-Fired Boiler

Table 15 on the following page shows total accumulated balances of implementing a wood-chip-fired boiler (only heat producing unit) in combination with different thermal store sizes. As expected, optimum combination of boiler capacity and thermal store size results in lower accumulated balances than having *2 days* or *1 week* size thermal stores for every demand scenario, but in scenarios 1 and 3 where, by chance, optimum boiler capacity and thermal store size combination turned out to be the same as with *1 week* thermal store size and with *2 days* thermal store size respectively. Excluding those two exceptions, total accumulated balances are reduced 0.03-0.13 million EUR depending on demand scenario as a result of maximum possible reduction in boiler and the thermal store investment and of having similar running costs. In spite of having same efficiency and O&M costs and even if turn on and shut down costs are not included, *1 week, 2 days* and *optimised* do not have equal, but similar running costs. The reason for this is that the thermal store is emptied at the end of each year, as explained in Section 3.2.1, making it impossible to cover 100% of heat demand at the beginning of some years. As thermal store size and boiler capacity differ in *1 week, 2 days* and *optimised*, the amount of years in which demand cannot be met because of software limitations is different in each case, resulting in similar but not equal running costs.

Implementing solar collectors as supplementary or additional heat producing units lowers total accumulated balances in every scenario, see Table 15 and Table 16 on the following page, despite higher investment, see Table 17 on the following page. Total accumulated balances calculated for *solar collectors 100%* and *solar collectors 50%* are respectively 0.05-0.16 million EUR and 0.02-0.10 million EUR lower than those calculated for optimum combination of boiler capacity and thermal store size with no solar collectors. In every demand scenario installing solar collectors to cover 100% of summer heat demand in 2026 results in total accumulated balances that are lower than when implementing half of the solar collector area required to meet that heat demand. The difference between the former and the latter is 0.02-0.09 million EUR depending on scenario.

It has to be mentioned, decision regarding installing solar collectors or not should be made before boiler capacity and thermal store dimensioning, as later decision on installing solar collectors could end up in higher total accumulated balances. In scenario 1 the optimum thermal store size is equivalent to 1 week of summer demand in 2026, which makes it possible to reduce total accumulated balance from 2.72 million EUR to 2.60 million EUR when installing 100% solar collectors, see Table 15 and Table 16. However, in scenario 3, where the optimum thermal store size is equivalent to 2 days of summer heat demand in 2026, the total accumulated balance would increase from 3.83 million EUR, see Table 15, to 6.96 million EUR when adding *100% solar collectors* because a much larger area of solar collectors would be needed to cover 100% of summer heat demand as a consequence of thermal store restrictions.

Table 15: Total accumulated balances of a wood-chip-fired boiler in combination with different thermal store sizes and for every potential heat demand scenario.

Total Accumulated Balance [million EUR]. Wood-chip-fired Boiler						
Thermal store size	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
1 week	4.69	4.29	3.89	8.13	7.20	6.34
2 days	4.72	4.33	3.83	8.07	7.14	6.28
optimum	4.69	4.26	3.83	8.00	7.11	6.22

Table 16: Total accumulated balances of a wood-chip-fired boiler in combination of a *1 week* thermal store and different solar collector areas for every potential heat demand scenario in million EUR.

Total Accumulated Balances [million EUR]. Wood-Chip-Fired Boiler and Solar Collectors						
Solar collectors	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
100%	4.57	4.18	3.78	7.88	6.95	6.12
50%	4.59	4.20	3.81	7.94	7.04	6.17

Table 17: Investments related to combining a wood-chip-fired boiler with solar collectors to cover 100% of summer heat demand in 2026, to combining the same boiler with half of the solar collector area required to cover 100% of summer heat demand in 2026, and to installing only a wood-chip-boiler with optimum thermal store size.

Investment [million EUR]. Wood-Chip-Fired Boiler and Solar Collectors						
Solar collectors	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
100%	2.19	2.06	1.97	3.57	3.08	2.83
50%	1.97	1.86	1.75	3.14	2.72	2.44
0% (optimum)	1.75	1.62	1.49	2.58	2.26	1.92

6.1.2 Wood-Pellet-Fired Boiler

Total accumulated balances of installing a wood-pellet-fired boiler in combination with different thermal store sizes and no solar collectors in different demand scenarios are shown in Table 18 on the following page. Once again it is observed right dimensioning of boiler capacity and thermal store reduces investment and, as a result, total accumulated balances are down to 0.01-0.14 million EUR lower (when *1 week* and *2 days* thermal store sizes do not coincide with optimum thermal store size).

It is also observed *2 days* thermal store size results in lower total accumulated balances than *1 week* thermal store size in every scenario. The reason for this is the low investment required for each installed MW in comparison to wood-fired-boilers, see Table 8 on page 38, which makes bigger boilers and smaller thermal stores a more economical combination. It has to be taken into account this study does not include turn on and shut down costs, meaning different conclusion could be obtained when doing so. For instance, in scenario 1, the boiler is turned on and off 1,211 times in 20 years when having a *1 week* size thermal store and 2,920 times when having a *2 days* size thermal store. As no data that allows turning on and shutting down cost calculation has been accessed, as explained in Section 3.2.1, it is not possible to state whether the cost of turning on the boiler 1,709 times more is higher or lower than the difference in total accumulated balances, i.e. 0.01 million EUR.

Table 18: Total accumulated balances of a wood-pellet-fired boiler in combination with different thermal store sizes and for every potential heat demand scenario.

Total Accumulated Balance. Wood-Pellet-Fired Boiler. [million EUR]						
Thermal store size	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
1 week	5.11	4.67	4.21	8.90	7.92	6.96
2 days	5.10	4.66	4.15	8.79	7.82	6.86
optimum	5.10	4.63	4.15	8.79	7.78	6.82

In spite of higher investments, see Table 20, installing solar collectors reduces accumulated balances in every scenario, see Table 19, and *100% solar collectors* results in the lowest accumulated balances, which are 0.22-0.54 million EUR lower than those calculated for *optimum* thermal store size with no solar collectors. The difference between *solar collectors 100%* and *solar collectors 50%* is 0.10-0.26 million EUR depending on demand scenario.

Table 19: Total accumulated balances of a wood-pellet-fired boiler in combination with a *1 week* thermal store and different solar collector areas for every potential heat demand scenario.

Total Accumulated Balance [million EUR]. Wood-Pellet-Fired Boiler and Solar Collectors						
Solar collectors	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
100%	4.80	4.31	3.93	8.25	7.31	6.38
50%	4.91	4.43	4.03	8.49	7.57	6.58

Table 20: Investments related to combining a wood-pellet-fired boiler with solar collectors to cover 100% of summer heat demand in 2026, to combining the same boiler with half of the solar collector area required to cover 100% of summer heat demand in 2026, and to installing only a wood-pellet-boiler with optimum thermal store size.

Investment [million EUR]. Wood-Pellet-Fired Boiler and Solar Collectors						
Solar collectors	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
100%	1.90	1.83	1.75	2.99	2.65	2.49
50%	1.68	1.62	1.56	2.56	2.28	2.10
0% (optimum)	1.45	1.37	1.30	2.03	1.78	1.57

6.1.3 Air-to-Water Heat Pump

Table 21 shows total accumulated balances of implementing an air-to-water heat pump in combination with different thermal store sizes for different demand scenarios. In this case, only *1 week* and *2 days* thermal store sizes are analysed and it is not examined which would be the optimum combination of heat pump capacity and thermal store size as the calculation does not only entail finding out the lowest investment, but it implies finding out the combination that minimises the sum of investment and running costs. The reason for this is that heat pump capacity and thermal store size influence on when to consume electricity and, as a result, on purchased electricity price, which is different for each of the 3 periods defined in the electricity tariff, see Table 10 on page 40. Hence, finding the optimum combination requires to analyse whether increasing heat pump capacity (either keeping the same thermal store size or reducing it), increasing thermal store size (either keeping the same heat pump capacity or reducing it) or increasing both, heat pump capacity and thermal store size, would result in lower total accumulated balances than those calculated or not. This calculation is therefore more complicated and time expensive than for wood-chip- and wood-pellet-fired boilers and is decided not to be carried out unless an air-to-water heat pump is the chosen alternative for further analysis in following stages.

Table 21: Total accumulated balances of an air-to-water heat pump in combination with different thermal store sizes and for every potential heat demand scenario.

Total Accumulated Balance [million EUR]. Air-to-Water Heat Pump						
Thermal store size	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
1 week	5.61	5.08	4.61	9.61	8.52	7.41
2 days	5.73	5.18	4.56	9.69	8.41	7.31

Table 22: Total accumulated balances of an air-to-water heat pump in combination of a *1 week* thermal store and different solar collector areas for every potential heat demand scenario.

Total Accumulated Balance [million EUR]. Air-to-Water Heat Pump and Solar Collectors						
Solar collectors	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
100%	5.43	4.90	4.41	9.23	8.14	7.05
50%	5.48	4.95	4.48	9.35	8.28	7.15

Table 23: Investments related to combining an air-to-water heat pump with solar collectors to cover 100% of summer heat demand in 2026, to combining the same heat pump with half of the solar collector area required to cover 100% of summer heat demand in 2026, and to installing only the heat pump (the most economical alternative of those presented in Table 21).

Investment [million EUR]. Air-to-Water Heat Pump and Solar Collectors						
Solar collectors	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
100%	1.90	1.82	1.75	2.94	2.64	2.49
50%	1.68	1.62	1.55	2.51	2.28	2.11
0% (most economical)	1.46	1.41	1.30	1.99	1.76	1.58

As shown in Table 21 on the previous page, *2 days* thermal store size is more economical than *1 week* thermal store size in scenarios 3, 5 and 6, whereas the opposite happens in scenarios 1, 2 and 4. Differences in total accumulated balances as a result of different thermal store sizes are 0.05-0.12 million EUR depending on scenario.

In every scenario total accumulated balance is reduced when installing solar collectors, see Table 22 on the previous page. As with the previously analysed technologies, even if a higher investment is required see Table 23 on the previous page, installing solar collectors to cover 100% of summer heat demand in 2026 results in the lowest total accumulated balances, which, dependent on scenario, are 0.05-0.14 million EUR lower than installing half of the area required to meet 100% of summer heat demand in 2026 and 0.15-0.38 million EUR lower than the most economical alternative of not adding solar collectors.

6.1.4 Comparison and Sensitivity Analysis

From the results presented in the previous section it can be concluded that independent on potential heat demand scenario the ascendant order of total accumulated balances is the following:

1. Wood-chip-fired boiler + 100% solar collectors
2. Wood-chip-fired boiler + 50% solar collectors
3. Wood-chip-fired boiler
4. Wood-pellet-fired boiler + 100% solar collectors
5. Wood-pellet-fired boiler + 50% solar collectors
6. Wood-pellet-fired boiler
7. Air-to-water heat pump + 100% solar collectors
8. Air-to-water heat pump + 50% solar collectors
9. Air-to-water heat pump

This means adding solar collectors, either 100% or 50%, results in lower costs than only installing a single unit of a main heat producing technology and that wood-chip-fired boilers are the most economical main heat producing technology to be installed from a 20-year period perspective.

Regarding solar collectors, it should be assessed whether the reduction in total accumulated balances compensates the additional investment, especially in the case of combining them with a wood-chip-fired boiler because reductions when installing *100% solar collectors* are 0.05-0.16 million EUR depending on scenario, see Table 15 on page 45, and investment increases 0.44-0.99 million EUR, see Table 17 on page 45. More concretely, in scenario 5, the one that obtains the highest reduction in total accumulated balance when adding solar collectors, total accumulated balance is reduced 0.16 million EUR (2%) when installing *100% solar collectors* and 0.07 million EUR (1%) when installing *50% solar collectors*, while investment increases 0.82 million EUR (36%) and 0.46 million EUR (20%) respectively. As energy prices are higher for wood-pellet-boilers and heat pumps, the reduction is more significant, but still it would be recommendable to analyse whether the reduction in total accumulated balances compensates the increase in investment. In order to carry out this analysis it is necessary to include financing costs and calculate NPVs with a discount rate that is not cero, this is discounted accumulated balances where more importance is given to initial expenses than to later ones (Ledec, 1987). On the other hand, it has to be pointed out that installing solar collectors also has some other advantages, such as reducing number of main heat producing units turn on and offs (which entails cost reduction), higher supply security and emission reduction. None of these advantages is taken into account in this study, but they should also be analysed before making a decision on installing solar collectors or not. Apart from that, it is important to remind no limitation in available area is taken into account in this study, meaning it is not examined whether the necessary solar collector area to cover 100% of summer heat demand in 2026 or even half of that area is available for collectors' installation, i.e. it is not assessed whether it is technically feasible. At this point it is relevant to mention than smaller areas of solar collectors imply lower reductions in total accumulated balances, which means it could happen that, if the available area is not big enough, installing solar collectors might not be economically advantageous.

With the objective of assessing how differences between foreseen wood-chip, wood-pellet and electricity prices and actual future prices could affect system's economic results, a sensitivity analysis is done by recalculating total accumulated balances for a lower energy price scenario (where energy price only increases as much as inflation) and a higher energy price scenario (where energy price increases twice the expected projection plus inflation), as explained in Section 3.2.2. Obtained results show the order presented at the beginning of this section remains for both energy price scenarios, see Table 24 on the following page. Further, wood-chip-fired boiler turns out to be the most secure technology from investment point of view because, when the system only consists of a heat producing unit, a wood-chip-fired boiler is always a more economical alternative than installing a wood-pellet-fired boiler or an air-to-water heat pump, even when wood-pellet and electricity prices only increase as much as inflation and wood-chip price increases twice the projection plus inflation. Nevertheless, when analysing the main heat producing units in combination with solar collectors, this is not so clear.

If wood-pellet price increased according to expected and wood-chip price increased twice the projection plus inflation, the order presented at the beginning of the section would remain for heat demand scenarios 3 and 4, but a wood-pellet-fired boiler with *100% solar collectors* would be the third in the list, this is, right before the option of installing a wood-chip-fired boiler with no solar collectors. If wood-pellet price increased as much as inflation and wood-chip price increased as expected, a wood-chip-fired boiler in combination with *100% solar collectors* would remain the most economical alternative, but a wood-pellet-fired boiler with *100% solar collectors* would go up to the second or third position on the list depending on demand scenario. Finally, if wood-pellet price increased only as much as inflation and wood-chip price increased twice the expected projection plus inflation, a wood-pellet-fired boiler with *100% solar collectors* would be the alternative that resulted in the lowest total accumulated balances in every demand scenario and a wood-pellet-fired boiler combined with *50% solar collectors* would be the third or fourth alternative with the lowest accumulated balances depending on demand scenario. However, it has to be mentioned this last situation is rather improbable, as both, wood pellets and wood chips, are forestry biomass, which means their prices will follow similar price tendencies.

Regarding the heat pump, it has to be mentioned it would be a more economical alternative than a wood-pellet-fired boiler when analysing them as only heat producing units of the district heating system if electricity price rose only as much as inflation and wood-pellet price rose as much as expected or double the projection plus inflation. When analysing those technologies in combination with solar collectors, a combination of a wood-pellet-fired boiler and solar collectors is more economical than a heat pump with solar collectors if electricity price increased as much as inflation and wood-pellet price as much as expected. However, if electricity price increased as much as inflation and wood-pellet price twice the projection plus inflation, a heat pump in combination with *100% solar collectors* (and even with *50% solar collectors* or with no collectors) results in lower accumulated balances than a wood-pellet-fired boiler combined with *50% solar collectors*.

Table 24: Total accumulated balances for every analysed heat producing technology and thermal store size and for every potential heat demand scenario.

Sensitivity analysis. Total Accumulated Balance [million EUR]

Technology	Thermal store size	Demand scenario 1 60% C; 25% R			Demand Scenario 2 60% C; 50% R			Demand scenario 3 60% C; 75% R			Demand scenario 4 100% C; 25% R			Demand scenario 5 100% C; 50% R			Demand scenario 6 100% C; 75% R		
		(-)	0	(+)	(-)	0	(+)	(-)	0	(+)	(-)	0	(+)	(-)	0	(+)	(-)	0	(+)
WCB	*1 week*	4.55	4.69	4.85	4.17	4.29	4.40	3.79	3.89	3.99	7.87	8.13	8.38	6.98	7.20	7.42	6.15	6.34	6.52
	2 days	4.58	4.72	4.85	4.21	4.33	4.44	3.73	3.83	3.93	7.81	8.07	8.32	6.92	7.14	7.36	6.10	6.28	6.46
	optimum	4.55	4.69	4.82	4.14	4.26	4.37	3.73	3.83	3.93	7.74	8.00	8.25	6.89	7.11	7.32	6.03	6.22	6.39
WPB	*1 week*	4.91	5.11	5.31	4.49	4.67	4.84	4.07	4.21	4.36	8.52	8.90	9.27	7.59	7.92	8.24	6.69	6.96	7.23
	2 days	4.89	5.10	5.30	4.48	4.66	4.83	4.01	4.15	4.29	8.41	8.79	9.17	7.49	7.82	8.13	6.58	6.86	7.11
	optimum	4.89	5.10	5.30	4.45	4.63	4.80	4.01	4.15	4.29	8.41	8.79	9.17	7.46	7.78	8.10	6.55	6.82	7.09
HP	*1 week*	5.05	5.61	6.20	4.60	5.08	5.58	4.21	4.61	5.04	8.60	9.61	10.67	7.66	8.52	9.41	6.71	7.41	8.15
	2 days	5.15	5.25	6.34	4.69	5.18	5.70	4.15	4.56	4.98	8.66	9.69	10.77	7.55	8.41	9.32	6.61	7.31	8.05
WCB + S (100)	*1 week*	4.47	4.57	4.67	4.10	4.18	4.26	3.72	3.78	3.85	7.70	7.88	8.06	6.80	6.95	7.10	6.00	6.12	6.00
WPB + S (100)	*1 week*	4.65	4.80	4.95	4.19	4.31	4.42	3.83	3.93	4.02	7.98	8.25	8.51	7.09	7.31	7.53	6.21	6.38	6.54
HP + S (100)	*1 week*	4.98	5.43	5.90	4.55	4.90	5.29	4.11	4.41	4.73	8.43	9.23	10.05	7.48	8.14	8.83	6.55	7.05	7.57
WCP + S (50)	*1 week*	4.47	4.59	4.70	4.10	4.20	4.30	3.73	3.81	3.89	7.73	7.94	8.15	6.85	7.04	7.22	6.02	6.17	6.31
WPB + S (50)	*1 week*	4.73	4.91	5.08	4.29	4.43	5.08	3.91	4.03	4.15	7.63	8.49	8.26	7.29	7.57	7.83	6.37	6.58	6.79
HP + S (50)	*1 week*	4.98	5.48	6.00	4.54	4.95	5.39	4.13	4.48	4.85	8.46	9.35	10.28	7.53	8.28	9.07	6.57	7.15	7.77

WCB: wood-chip-fired boiler
WPB: wood-pellet-fired boiler
HP: heat pump
S (100): solar collectors (100%)
S (50): solar collectors (50%)

C: connection to district heating system in building percentage
R: energy renovation implementation in building percentage

0: expected energy price scenario
(-): lower energy price scenario
(+): higher energy price scenario

This means, doubts exist about which option, an air-to-water heat pump or a wood-pellet-fired boiler, would be preferable from an economic perspective taking into account uncertainties in energy price projections. On the other hand, as already said before, it can be concluded a wood-chip-fired boiler is the most secure choice, especially in combination with solar collectors.

Finally, it has to be mentioned that reductions from installing solar collectors are smaller in lower energy price scenario and become more significant in higher energy price scenario. Hence, in the former energy price scenario investing in solar collectors would be less attractive and more attractive in the latter.

6.2 Monthly Costs, Investment and Accumulated Balance per Household

This section presents and compares monthly costs, investment and accumulated balances calculated over 20 years for four types of consumers, as explained in Section 3.2.2:

1) A *surrounded* B type dwelling that has not been energy renovated (estimated heat demand 5,880 kWh/year).
2) A *surrounded* B type dwelling that has been energy renovated (estimated heat demand 3,205 kWh/year).
3) A *surrounded* D type dwelling that has not been energy renovated (estimated heat demand 9,000 kWh/year).
4) A *surrounded* D type dwelling that has been energy renovated (estimated heat demand 4,905 kWh/year).

Results are presented for every potential heat demand scenario and for every analysed main heat producing technology, either as single heat producing unit of the system or in combination with solar collectors that may cover 100% of summer heat demand in 2026. It is decided to present only the results of combining main heat producing technologies with *100% solar collectors* as it is more economical than a combination with *50% solar collectors*. In the same way, only the most economical combinations of heat producing unit capacity and thermal store size of those analysed in the previous section are presented here, i.e. optimum combination of boiler capacity and thermal store volume for alternatives using biomass and the most economic combination of heat pump capacity and thermal store size in each demand scenario.

Investment is presented divided into different investment components as no ownership model has been analysed yet and no definitive investment distribution is known. This way, consumers know what total investment of a consumer owned district heating system would be and can also have an idea of what could be deducted from the investment that should be covered by consumers if alternative ownership models were applied. As an example, town council will probably cover investment of the heat distribution network (Town council & Maab, 2014 (b)) and an ESE company asked for consultancy stated he would cover every component for heat production and storage and for system management and control if he was chosen for system operation and management (Town council & Maab, 2014 (a)).

It has to be reminded that when calculating investment to be covered by a specific consumer three different methods are applied, as explained in Section 3.2.2. The value correspondent to the sum of heat producing technology and thermal store investment is calculated based on specific consumer annual heat demand in relation to aggregated heat demand in 2026; i.e. it is calculated what percentage of the aggregated heat demand in 2026 the specific consumer accounts for and the value is multiplied by the total investment in heat producing technology and thermal store. Investments related to building and district heating network and other initial expenses are calculated by dividing total investment of those components by number of consumers, this is, by connected buildings in 2026 and by 10 consumers/building. Consumer network is a fix investment independent on consumer demand and scenario and is calculated by dividing the total investment calculated by the project public developer for 53 buildings –0.1 million EUR (Visesa, 2014), see Section 5.2.5– by 53 buildings and by 10 consumers in each. In order to calculate monthly costs, total running cost of each year is divided by total heat demand of the same year, this way price per kWh-heat is found out for every year and is then multiplied for specific consumer annual heat demand and divided by 12 months, as explained in Section 3.2.2 as well.

Aiming for clear presentation of obtained results, they are grouped in three subsections –one for each analysed main heat producing technology– and compared in a separate subsection at the end of Section 6.2.

6.2.1 Wood-Chip-Fired Boiler

Table 25 and Table 26 on pages 53 and 54 show monthly costs, investment and accumulated balances calculated over 20 years to be covered by the analysed four types of consumers when getting connected to a district heating system with a wood-chip-boiler as single producing unit or in combination with solar collectors which can satisfy 100% of summer heat demand in 2026.

A non-renovated *surrounded* B type dwelling would pay 31-34 EUR a month in 2016 and up to 41-47 EUR a month in 2035 depending on heat demand scenario if the boiler was the only heat producing unit, see Table 25 on the following page. These monthly costs are reduced to 20-25 EUR a month in 2016 and to 32-37 EUR a month in 2035 for the same dwelling when getting connected to a district heating system with a wood-chip-fired boiler and 100% solar collectors, see Table 26 on page 54. In spite of monthly cost reduction, a higher investment is required if solar collectors are installed –1,200-1,900 EUR more. Nevertheless, accumulated balances are 300-700 EUR (2-5%) lower for a non-renovated *surrounded* B type dwelling when *100% solar collectors* are installed. This means lower monthly costs compensate 23-50% investment increases and result in accumulated balances that are 2-5% lower than those of a system with no solar collectors. It has to be mentioned scenarios with more consumers connected to the district heating system, i.e. scenarios 1, 2 and 3, obtain higher reductions in accumulated balances due to lower investment increases and more significant decrease of monthly costs.

Regarding a renovated *surrounded* B type dwelling, its accumulated balances are 4,800-5,3000 EUR lower (34-38%) than those of a non-renovated *surrounded* B type dwelling as a result of 14-21% lower investment and 46% lower monthly costs.

Heat demand of a *surrounded* D type dwelling is 1.53 times higher than the demand of a *surrounded* B type dwelling. Hence monthly costs are also 1.53 times higher, but accumulated balances are 1.41-1.45 times higher depending on scenario as investment is 1.18-1.23 times bigger. This way, a *surrounded* D type dwelling connected to a district heating system with a wood-chip-fired boiler as unique heat producing unit pays 47-53 EUR a month in 2016 and 63-72 EUR a month in 2035 when not being energy renovated and 26-29 EUR a month in 2016 and 34-40 EUR a month in 2035 when being renovated, see Table 25 on the following page. Depending on scenario, required investment for a non-renovated *surrounded* D type dwelling is 4,600-6,200 EUR and for non-renovated ones 3,500-4,900 EUR. The sum of monthly costs and investment results in accumulated balances of 18,800-21,200 EUR and 11,400-13,000 EUR respectively.

Table 25: Monthly costs, investment (divided into different components) and total accumulated balances per household of a wood-chip-fired boiler for 4 types of consumers.

		WOOD-CHIP-FIRED BOILER							
		MONTHLY COSTS [EUR]	INVESTMENT [EUR]						ACCUMULATED BALANCE [EUR]
			Heat production centre		Heat distribution network	Consumer network	Other initial expenses	TOTAL INVESTMENT	
			heat unit + thermal store	building					
Non-renovated *surrounded* B type dwelling (5,880 kWh/year)	S1	31-42	1,800	1,600	1,100	200	500	5,200	14,000
	S2	32-45	1,700	1,600	1,100	200	500	5,100	14,500
	S3	34-47	1,600	1,600	1,100	200	500	5,000	15,000
	S4	31-41	1,900	900	1,000	200	300	4,300	13,100
	S5	32-43	1,800	900	900	200	300	4,100	13,300
	S6	34-46	1,600	900	800	200	300	3,800	13,500
Renovated *surrounded* B type dwelling (3,205 kWh/year)	S1	17-23	1,000	1,600	1,100	200	500	4,400	9,200
	S2	18-24	1,000	1,600	1,100	200	500	4,400	9,400
	S3	19-26	900	1,600	1,100	200	500	4,300	9,700
	S4	17-23	1,000	900	1,000	200	300	3,400	8,300
	S5	18-23	1,000	900	900	200	300	3,300	8,300
	S6	19-25	900	900	800	200	300	3,100	8,400
Non-renovated *surrounded* D type dwelling (9,000 kWh/year)	S1	47-65	2,800	1,600	1,100	200	500	6,200	19,800
	S2	49-68	2,700	1,600	1,100	200	500	6,100	20,400
	S3	53-72	2,500	1,600	1,100	200	500	5,900	21,200
	S4	47-63	2,900	900	1,000	200	300	5,300	18,800
	S5	49-66	2,700	900	900	200	300	5,000	19,100
	S6	53-70	2,400	900	800	200	300	4,600	19,600
Renovated *surrounded* D type dwelling (4,905 kWh/year)	S1	26-35	1,500	1,600	1,100	200	500	4,900	12,300
	S2	27-37	1,500	1,600	1,100	200	500	4,900	12,600
	S3	29-40	1,400	1,600	1,100	200	500	4,800	13,000
	S4	26-34	1,600	900	1,000	200	300	4,000	11,400
	S5	27-36	1,500	900	900	200	300	3,800	11,500
	S6	29-38	1,300	900	800	200	300	3,500	11,700

Table 26: Monthly costs, investment (divided into different components) and total accumulated balances per household of a wood-chip-fired boiler with 100% solar for 4 types of consumers.

		WOOD-CHIP-FIRED BOILER + 100% SOLAR COLLECTORS							
		MONTHLY COSTS [EUR]	INVESTMENT [EUR]						ACCUMULATED BALANCE [EUR]
			Heat production centre		Heat distribution network	Consumer network	Other initial expenses	TOTAL INVESTMENT	
			heat units + thermal store	building					
Non-renovated *surrounded* B type dwelling (5,880 kWh/year)	S1	20-34	3,000	1,600	1,100	200	500	6,400	13,400
	S2	21-36	3,100	1,600	1,100	200	500	6,500	13,800
	S3	22-37	3,300	1,600	1,100	200	500	6,700	14,400
	S4	23-32	3,300	900	1,000	200	300	5,700	12,800
	S5	24-34	3,200	900	900	200	300	5,500	12,800
	S6	25-34	3,500	900	800	200	300	5,700	13,100
Renovated *surrounded* B type dwelling (3,205 kWh/year)	S1	11-19	1,600	1,600	1,100	200	500	5,000	8,800
	S2	11-19	1,700	1,600	1,100	200	500	5,100	9,000
	S3	12-20	1,800	1,600	1,100	200	500	5,200	9,300
	S4	12-18	1,800	900	1,000	200	300	4,200	8,100
	S5	13-19	1,700	900	900	200	300	4,000	8,000
	S6	13-19	1,900	900	800	200	300	4,100	8,200
Non-renovated *surrounded* D type dwelling (9,000 kWh/year)	S1	31-53	4,500	1,600	1,100	200	500	7,900	18,800
	S2	32-55	4,700	1,600	1,100	200	500	8,100	19,500
	S3	33-57	5,000	1,600	1,100	200	500	8,400	20,200
	S4	35-50	5,100	900	1,000	200	300	7,500	18,300
	S5	37-52	4,900	900	900	200	300	7,200	18,400
	S6	38-53	5,300	900	800	200	300	7,500	19,000
Renovated *surrounded* D type dwelling (4,905 kWh/year)	S1	17-29	2,500	1,600	1,100	200	500	5,900	11,700
	S2	17-30	2,600	1,600	1,100	200	500	6,000	12,100
	S3	18-31	2,700	1,600	1,100	200	500	6,100	12,500
	S4	19-27	2,800	900	1,000	200	300	5,200	11,100
	S5	20-28	2,700	900	900	200	300	5,000	11,100
	S6	20-29	2,900	900	800	200	300	5,100	11,300

When a *surrounded* D type dwelling is connected to a district heating system that consists of a wood-chip-fired boiler and *100% solar collectors*, monthly costs are reduced to 31-38 EUR in 2016 and 50-57 EUR in 2035 for a non-renovated dwelling, and to 17-20 EUR in 2016 and 27-30 EUR in 2035 for a renovated dwelling, see Table 26 on the previous page. As for a B type dwelling, the reduction in accumulated balances (500-1,000 EUR for a non-renovated D type dwelling and 300-600 EUR for a non-renovated D type dwelling) obtained by means of solar collectors is not very significant in comparison to required additional investment (1,700-2,900 EUR for a non-renovated D type dwelling and 1,000-1,600 EUR for a renovated D type dwelling).

6.2.2 Wood-Pellet-Fired Boiler

Table 27 and Table 28 on pages 56 and 57 gather investment, monthly costs and accumulated balances to be covered by the analysed four types of consumers when getting connected to a district heating system with a wood-pellet-boiler as single producing unit or with a wood-pellet-fired boiler in combination of solar collectors that can meet 100% of summer heat demand in 2026.

A non-renovated *surrounded* B type dwelling pays 38-42 EUR a month in 2016 and 52-58 EUR in 2035 if a wood-pellet-fired boiler is the only heat producing unit of the system, see Table 27 on the following page, and, depending on heat demand scenario, 23-28 EUR a month in 2016 and 40-45 EUR a month in 2035 if *100% solar collectors* are added, see Table 28 on page 57. Additional investment for installing *100% solar collectors* is 1,200-1,900 EUR depending on demand scenario, this is, investment increases 27-61%. Nevertheless, the already mentioned reduction in monthly costs results in accumulated balances that are 1,000-1,600 EUR lower than not installing solar collectors, which entails a reduction of 7-11% in accumulated balances. As for the case of installing a wood-chip-boiler in combination with 1*00% solar collectors* analysed in the previous section, it is observed installing solar collectors is more beneficial in scenarios 1, 2 and 3 as required additional investment is lower and monthly costs reduction bigger.

A similar tendency is observed for a renovated *surrounded* B type dwelling, whose accumulated balances are 36-39% lower than for a non-renovated *surrounded* B type dwelling. Monthly costs are 21-23 EUR in 2016 and 29-32 EUR in 2035 if a wood-pellet-fired boiler is the only heat producing unit of the district heating system, see Table 27 on the following page, and, depending on scenario, 12-15 EUR in 2016 and 22-24 EUR in 2035 if *100% solar collectors* are also installed, see Table 28 on page 57. Regarding additional investment for solar collector installation and accumulated balances reduction, the former is 600-1,000 EUR (15-37%) and the latter 600-900 EUR (6-9%), both depending on demand scenario. This means investment increase is proportionally lower than for a non-renovated *surrounded* B type dwelling, whereas obtainable reductions in total accumulated balances are proportionally similar because the additional investment is divided in relation to consumer heat demand (unlike other investment components) and monthly costs too.

A non-renovated *surrounded* D type dwelling pays 58-64 EUR a month in 2016 and 80-89 EUR a month in 2035 depending on scenario, whereas a renovated dwelling of the same type pays 31-35 EUR a month in 2016 and 44-49 EUR a month in 2035, see Table 27 on the following page. Those monthly costs are reduced to 35-43 EUR a month in 2016 and 61-68 EUR a month in 2035 for the former type of consumer and to 19-24 EUR in 2016 and 33-37 EUR a month in 2035 for the latter type, see Table 28 on page 57. Even if these values are 1.53 times higher than for a B type consumer, differences in investment and accumulated balance are not as big as heat demand difference, what is advantageous for a bigger consumer as also observed in the previous section. Once again it is observed installing solar collectors reduces consumers' monthly costs and total accumulated balances (which are 1,600-2,400 EUR (8-11%) lower for a

Table 27: Monthly costs, investment (divided into different components) and total accumulated balances per household of a wood-pellet-fired boiler for 4 types of consumers.

		WOOD-PELLET-FIRED BOILER							
		MONTHLY COSTS [EUR]	INVESTMENT [EUR]						ACCUMULATED BALANCE [EUR]
			Heat production centre		Heat distribution network	Consumer network	Other initial expenses	TOTAL INVESTMENT	
			heat unit + thermal store	building					
Non-renovated *surrounded* B type dwelling (5,880 kWh/year)	S1	38-53	1,000	1,600	1,100	200	500	4,400	15,500
	S2	39-56	1,000	1,600	1,100	200	500	4,400	15,900
	S3	41-58	900	1,600	1,100	200	500	4,300	16,500
	S4	38-52	1,100	900	1,000	200	300	3,500	15,000
	S5	39-54	900	900	900	200	300	3,300	14,600
	S6	42-57	900	900	800	200	300	3,100	15,000
Renovated *surrounded* B type dwelling (3,205 kWh/year)	S1	21-29	600	1,600	1,100	200	500	4,000	9,900
	S2	21-30	500	1,600	1,100	200	500	3,900	10,200
	S3	23-32	500	1,600	1,100	200	500	3,900	10,500
	S4	21-29	600	900	1,000	200	300	3,000	9,000
	S5	21-30	500	900	900	200	300	2,800	9,000
	S6	23-31	500	900	800	200	300	2,700	9,200
Non-renovated *surrounded* D type dwelling (9,000 kWh/year)	S1	58-82	1,600	1,600	1,100	200	500	5,000	21,900
	S2	60-85	1,500	1,600	1,100	200	500	5,000	22,600
	S3	64-89	1,400	1,600	1,100	200	500	4,900	23,500
	S4	58-80	1,600	900	1,000	200	300	4,000	20,900
	S5	60-83	1,400	900	900	200	300	3,700	21,200
	S6	64-87	1,300	900	800	200	300	3,500	21,800
Renovated *surrounded* D type dwelling (4,905 kWh/year)	S1	31-45	900	1,600	1,100	200	500	4,300	13,500
	S2	33-46	800	1,600	1,100	200	500	4,200	13,800
	S3	35-49	800	1,600	1,100	200	500	4,200	14,300
	S4	31-44	900	900	1,000	200	300	3,300	12,500
	S5	33-45	800	900	900	200	300	3,100	12,600
	S6	35-47	700	900	800	200	300	2,900	12,900

Table 28: Monthly costs, investment (divided into different components) and total accumulated balances per household of a wood-pellet-fired boiler with 100% solar for 4 types of consumers.

WOOD-PELLET-FIRED BOILER + 100% SOLAR COLLECTORS										
		MONTHLY COSTS [EUR]	INVESTMENT [EUR]							ACCUMULATED BALANCE [EUR]
			Heat production centre		Heat distribution network	Consumer network	Other initial expenses	TOTAL INVESTMENT		
			heat units + thermal store	building						
Non-renovated *surrounded* B type dwelling (5,880 kWh/year)	S1	24-42	2,200	1,600	1,100	200	500	5,600		14,200
	S2	23-42	2,400	1,600	1,100	200	500	5,800		14,300
	S3	24-45	2,600	1,600	1,100	200	500	6,000		15,000
	S4	27-40	2,500	900	1,000	200	300	4,900		13,400
	S5	28-41	2,500	900	900	200	300	4,800		13,600
	S6	28-41	2,800	900	800	200	300	5,000		13,800
Renovated *surrounded* B type dwelling (3,205 kWh/year)	S1	13-23	1,200	1,600	1,100	200	500	4,600		9,300
	S2	12-23	1,300	1,600	1,100	200	500	4,700		9,300
	S3	13-24	1,400	1,600	1,100	200	500	4,800		9,700
	S4	15-22	1,400	900	1,000	200	300	3,800		8,400
	S5	15-23	1,300	900	900	200	300	3,600		8,400
	S6	15-22	1,500	900	800	200	300	3,700		8,500
Non-renovated *surrounded* D type dwelling (9,000 kWh/year)	S1	36-65	3,400	1,600	1,100	200	500	6,800		20,000
	S2	35-65	3,600	1,600	1,100	200	500	7,000		20,200
	S3	37-68	3,900	1,600	1,100	200	500	7,300		21,300
	S4	42-61	3,800	900	1,000	200	300	6,200		19,300
	S5	43-63	3,800	900	900	200	300	6,100		19,500
	S6	43-63	4,300	900	800	200	300	6,500		20,000
Renovated *surrounded* D type dwelling (4,905 kWh/year)	S1	20-35	1,800	1,600	1,100	200	500	5,200		12,400
	S2	19-35	2,000	1,600	1,100	200	500	5,400		12,500
	S3	20-37	2,100	1,600	1,100	200	500	5,500		13,100
	S4	23-33	2,100	900	1,000	200	300	4,500		11,600
	S5	24-34	2,100	900	900	200	300	4,400		11,700
	S6	24-34	2,300	900	800	200	300	4,500		11,900

non-renovated D type dwelling), despite the need of additional investment, which is 1,800-3,000 EUR (36-85%) for the same type of consumer. These values show the additional investment of installing solar collectors is proportionally higher for a bigger consumer even if proportionally similar reductions in monthly costs are obtained. The reason for this is that the additional investment is divided in relation to specific consumer heat demand unlike some other components of the total investment as already explained before.

6.2.3 Air-to-Water Heat Pump

Table 29 and Table 30 on pages 59 and 60 gather investment, monthly costs and accumulated balances calculated for the analysed four types of consumers when getting connected to a district heating system with an air-to-water heat pump as single producing unit or with an air-to-water heat pump and solar collectors which can cover 100% of summer heat demand in 2026.

When a non-renovated *surrounded* B type dwelling gets connected to a district heating system with a heat pump as unique heat producing unit, monthly costs are 41-52 EUR in 2016 and 62-69 EUR in 2035, both dependent on demand scenario, see Table 29 on the following page. If the same dwelling gets connected to a district heating system consisting of both, a heat pump and solar collectors that may cover 100% of summer heat demand in 2026, depending on scenario, monthly costs are reduced to 33-41 EUR in 2016 and 51-56 EUR in 2035, see Table 30 on page 60. Additional investment for installing solar collectors is 1,100-1,900 EUR, this is, investment increases 24-61% depending on demand scenario. Once again, despite higher investment, lower accumulated balances are obtained due to lower monthly costs. Depending on demand scenario, the reduction in accumulated balances is 700-100 EUR, i.e. 4-6%.

Installing *100% solar collectors* is also more economical than only installing a heat pump for a renovated *surrounded* B type dwelling. Investment increase is 600-1,000 EUR (15-37%) in this case and accumulated balance reduction 400-600 EUR (4-5%) as a result of decreasing monthly costs from 22-28 EUR to 18-22 EUR in 2016 and from 34-38 EUR to 28-30 EUR in 2035 depending on demand scenario.

As for the previously analysed technologies, monthly costs of a *surrounded* D type dwelling are 1.53 higher even though smaller difference is observed for investment and accumulated balances. In a district heating system with an air-to-water heat pump, a non-renovated *surrounded* D type dwelling's monthly costs are 62-80 EUR in 2016 and 94-106 EUR in 2035, its investment is 3,600-5,100 EUR and its accumulated balance 22,800-26,100 EUR, see Table 29 on the following page. If *100% solar collectors* are also installed, monthly costs are reduced to 51-62 EUR in 2016 and 77-85 EUR in 2035. This results in total accumulated balances that are 1,100-1,400 EUR (4-6%) lower and more beneficial for lower demand scenarios as additional investment –1,800-2,900 EUR (36-81%)– is lower in those.

When a *surrounded* D type dwelling that has implemented the proposed energy renovation is connected to a district heating system with a heat pump as only heat producing unit, its monthly costs are 34-42 EUR in 2016 and 51-58 EUR in 2035, which are approximately 46% lower than for a non-renovated *surrounded* D type dwelling. However, investment and accumulated balances are not reduced in the same proportion when implementing the proposed energy renovation as no every investment component is related to consumer heat consumption. As in every other analysed case, a renovated *surrounded* D type dwelling also reduces monthly costs and accumulated balances when solar collectors are also installed. In this case, monthly costs are reduced to 28-34 EUR in 2016 and to 42-47 EUR in 2035 by means of an additional investment of 900-1,600 EUR (21-55%) and which results in accumulated balances that are 600-800 EUR (4-5%) lower.

.

Table 29: Monthly costs, investment (divided into different components) and total accumulated balances per household of an air-to-water heat pump for 4 types of consumers.

		AIR-TO-WATER HEAT PUMP							
		MONTHLY COSTS [EUR]	**INVESTMENT [EUR]**						**ACCUMULATED BALANCE [EUR]**
			Heat production centre		**Heat distribution network**	**Consumer network**	**Other initial expenses**	**TOTAL INVESTMENT**	
			heat unit + thermal store	building					
Non-renovated *surrounded* B type dwelling (5,880 kWh/year)	S1	49-63	1,100	1,600	1,100	200	500	4,500	17,100
	S2	50-65	1,100	1,600	1,100	200	500	4,500	17,600
	S3	52-69	900	1,600	1,100	200	500	4,400	18,200
	S4	41-62	1,200	900	1,000	200	300	3,600	15,800
	S5	42-63	900	900	900	200	300	3,200	15,800
	S6	44-65	900	900	800	200	300	3,100	16,100
Renovated *surrounded* B type dwelling (3,205 kWh/year)	S1	26-34	600	1,600	1,100	200	500	4,000	10,800
	S2	27-36	600	1,600	1,100	200	500	4,000	11,100
	S3	28-38	500	1,600	1,100	200	500	3,900	11,400
	S4	22-34	600	900	1,000	200	300	3,000	9,700
	S5	23-35	500	900	900	200	300	2,800	9,700
	S6	24-36	500	900	800	200	300	2,700	9,800
Non-renovated *surrounded* D type dwelling (9,000 kWh/year)	S1	74-97	1,600	1,600	1,100	200	500	5,000	24,400
	S2	77-100	1,700	1,600	1,100	200	500	5,100	25,100
	S3	80-106	1,400	1,600	1,100	200	500	4,800	26,100
	S4	62-94	1,800	900	1,000	200	300	4,200	22,800
	S5	64-97	1,400	900	900	200	300	3,700	22,900
	S6	67-100	1,400	900	800	200	300	3,600	23,500
Renovated *surrounded* D type dwelling (4,905 kWh/year)	S1	41-53	900	1,600	1,100	200	500	4,300	14,800
	S2	42-54	900	1,600	1,100	200	500	4,300	15,200
	S3	43-58	800	1,600	1,100	200	500	4,200	15,700
	S4	34-51	1,000	900	1,000	200	300	3,400	13,500
	S5	35-53	800	900	900	200	300	3,100	13,600
	S6	36-55	700	900	800	200	300	2,900	13,700

Table 30: Monthly costs, investment (divided into different components) and total accumulated balances per household of an air-to-water heat pump and 100% solar for 4 types of consumers

		AIR-TO-WATER HEAT PUMP + 100% SOLAR COLLECTORS							
		MONTHLY COSTS [EUR]	INVESTMENT [EUR]						ACCUMULATED BALANCE [EUR]
			Heat production centre		Heat distribution network	Consumer network	Other initial expenses	TOTAL INVESTMENT	
			heat units + thermal store	building					
Non-renovated *surrounded* B type dwelling (5,880 kWh/year)	S1	39-53	2,200	1,600	1,100	200	500	5,600	16,300
	S2	40-54	2,400	1,600	1,100	200	500	5,800	16,600
	S3	41-56	2,600	1,600	1,100	200	500	6,000	17,300
	S4	33-51	2,400	900	1,000	200	300	4,800	15,000
	S5	34-51	2,400	900	900	200	300	4,700	15,100
	S6	34-51	2,800	900	800	200	300	5,000	15,300
Renovated *surrounded* B type dwelling (3,205 kWh/year)	S1	21-29	1,200	1,600	1,100	200	500	4,600	10,400
	S2	22-29	1,300	1,600	1,100	200	500	4,700	10,500
	S3	22-30	1,400	1,600	1,100	200	500	4,800	10,900
	S4	18-28	1,300	900	1,000	200	300	3,700	9,300
	S5	19-28	1,300	900	900	200	300	3,600	9,300
	S6	19-28	1,500	900	800	200	300	3,700	9,400
Non-renovated *surrounded* D type dwelling (9,000 kWh/year)	S1	60-81	3,400	1,600	1,100	200	500	6,800	23,100
	S2	61-82	3,600	1,600	1,100	200	500	7,000	23,700
	S3	62-85	3,900	1,600	1,100	200	500	7,300	24,700
	S4	51-77	3,700	900	1,000	200	300	6,100	21,700
	S5	53-79	3,700	900	900	200	300	6,000	21,900
	S6	53-77	4,300	900	800	200	300	6,500	22,300
Renovated *surrounded* D type dwelling (4,905 kWh/year)	S1	33-44	1,800	1,600	1,100	200	500	5,200	14,100
	S2	33-45	2,000	1,600	1,100	200	500	5,400	14,400
	S3	34-47	2,100	1,600	1,100	200	500	5,500	15,000
	S4	28-42	2,000	900	1,000	200	300	4,400	12,900
	S5	29-43	2,000	900	900	200	300	4,300	13,000
	S6	29-42	2,300	900	800	200	300	4,500	13,100

6.2.4 Comparison

The results obtained by analysing accumulated balances of different sizes of heat consumers in different potential heat demand scenarios is in line with those obtained by examining total accumulated balances in Section 6.1 –a wood-chip-fired boiler is the most economical solution, followed by a wood-pellet-fired boiler and an air-to-water heat pump. In every case, adding solar collectors results in lower accumulated balances than only installing a main heat producing unit. The ascendant order of accumulated balances is the following:

1. Wood-chip-fired boiler + 100% solar collectors
2. Wood-chip-fired boiler
3. Wood-pellet-fired boiler + 100% solar collectors
4. Wood-pellet-fired boiler
5. Air-to-water heat pump + 100% solar collectors
6. Air-to-water heat pump

Adding solar collectors entails additional investment, which is proportionally more significant in the case of a wood-pellet-fired boiler and a heat pump as their investment is significantly lower than a wood-chip-fired boiler's. Nevertheless, the higher initial investment is compensated by lower monthly costs for both technologies, wood-chip-fired boiler and solar collectors. It is observed the most attractive case for installing solar collectors is a district heating system with a wood-pellet-fired boiler because additional investment is similar and obtainable reductions in accumulated balance are the highest. The reason why additional investment is similar and not the same is that the it does not only include solar collectors investment, but also difference in investment between *optimum* thermal store size and *1 week* thermal store size. The reason why solar collectors are more beneficial for a system with a wood-pellet-fired boiler than for a system with a heat pump even if running cost of the former is lower than running cost of the latter is that variable running cost of a wood-pellet-fired boiler is bigger than a heat pump's –wood-pellet purchase and O&M cost of wood-pellet-fired boilers are dependent on heat production, see Table 8 on page 38; electricity purchase has a fix component not dependent on electricity consumption, but on hired capacity and O&M cost of heat pumps is fix annual expense, see Table 9 on page 39.

Once again it is important to point out this study does not analyse whether there is enough area for solar collectors installation, which means technical feasibility of this option is not known. Further, as explained when analysis total accumulated balances resulted from entire system economy analysis in Section 6.1.4, financial costs should be added and discounted accumulated balances (NPVs calculated with a discount rate not equal to cero) should be calculated in order to find out whether installing solar collectors is economically beneficial or not.

It is also important to note only that no turning on and shutting down cost is included. This means, *optimum* thermal store size calculated for biomass boilers is not necessarily the most economical. Further, only *1 week* thermal store size is examined when adding solar collectors, but is not affirmed this is the size the thermal store should have if solar collectors were installed. If technical feasibility of installing solar collectors was proven, it was calculated to be economically beneficial and, consequently, it was decided to install solar collectors as supplementary heat producing unit, the size of the store should be defined taking into account the main heat producing technology (a wood-chip-fired boiler is recommended in this study) and the solar collectors.

The way in which costs are divided among consumers supports energy savings since smaller energy consumers' accumulated balance per consumed energy over 20 years is lower than for bigger energy consumers. A renovated *surrounded* B type dwelling (estimated heat demand 3,205 kWh/year) is therefore the type of consumer (among those analysed in this chapter) with the lowest accumulated balances per consumed kWh-heat, followed by renovated *surrounded* D type dwellings (4,905 kWh/year), non-renovated B type dwellings (5,880 kWh/year) and non-renovated *surrounded* D type dwellings (9,000 kWh). It is important to note that implementing the proposed energy renovation results more beneficial for bigger consumers and for energy systems using more expensive energy fuels. The energy renovation proposed by (Maab, 2014 (a)) implies an investment of 9,000-12,000 EUR per household as mentioned in Section 4.2. In a district heating system with an air-to-water heat pump and no solar collectors (i.e. the most expensive of the analysed technology alternatives and, hence, the most attractive for doing the energy renovation), the difference in accumulated balance between a renovated and a non-renovated *surrounded* B type dwelling is 6,800-6,100 EUR, whereas between a renovated and a non-renovated *surrounded* D type dwelling is 9,300-10,400 EUR. In a district heating system with a wood-chip-fired boiler and *100% solar collectors* (i.e. the most economical alternative of those examined in this study and, therefore, the least attractive for doing the energy renovation), the difference in accumulated balance between a renovated and a non-renovated *surrounded* B type dwelling is 4,600-5,100 EUR and between a renovated and a non-renovated *surrounded* D type dwelling 7,000-7,700 EUR. From these values it can be concluded profitability of energy renovation is dependent on the chosen energy technology and demand of each consumer type. Hence, each consumer should consider whether to implement or not the energy renovation by taking into account the future heating system. Before making any decision it is important to add financial costs and deduct increase in real estate value and obtainable subsidies. Furthermore, NPVs with a discount rate applicable to the specific householders should be calculated. Apart from economic parameters, it is also important to value householders comfort and living conditions increase if and reduction of emissions.

It is remarkable scenarios with higher heat demand are the most economical from consumers' perspective, which means the higher the amount consumers connected to the district heating system, the better for system's economy. As a consequence of this conclusion it is recommended to analyse whether adding other existing buildings in the neighbourhood that are not taken into account in this study to the project would be beneficial or not.

Finally, it has to be noted presented monthly cost, total investments and accumulated balances are only valid for a consumer owned district heating system. Alternative ownership models would reduce investment, but monthly costs could be higher if the owner aims for benefits. Hence, as explained in Sections 2.1, it is important to analyse different ownership models and their alternatives in other to choose the most beneficial one for consumers. Apart from that, it is necessary to mention most of the investment and O&M cost values used in the economic analysis of this study are taken from (DEA & energinet.dk, 2012 (a)) and (DEA & energinet.dk, 2012 (b)), meaning differences could be found when assessing monthly costs, investment and accumulated balances per household with Spanish market data. Further, boiler and heat pump investment and O&M values are only applicable for installed capacities higher than 1 MW (DEA & energinet.dk, 2012 (b)) and higher values are expectable for cases with lower capacity heat producing units.

To sum up, a wood-chip-fired boiler in combination with *100% solar collectors* is the most economical alternative for every consumer size and potential heat demand scenario. Investment and running cost distribution is beneficial for households that implement the energy renovation, however, each consumer should further analyse whether implementing it is the right decision for him/her. Finally, it has to be pointed out that the higher the number of connected consumers, the more economical becomes the system for them.

7 Analysis of Similar Initiatives

This chapter gathers description of various district heating initiatives in the Basque Autonomous Community. Some of them are already implemented –Beizama and Abadiño –, some others were cancelled –Bolueta, Zorrozaurre and Leioa– and one is still in planning process –Aramaio. Even if not all of them are directly comparable to the case of San Fausto, all of them provide valuable input for knowledge broadening.

7.1 Beizama

Beizama is a small rural village (kapelbi, n.d.) with approximately 180 inhabitants and located in Gipuzkoa Province (INE, 2014 (c)). In 2009 (Garmendia, 2014) a district heating system that provides heat to 10 dwellings (8 of them newly built), the town hall, a hostel and a nature school was built. The system consists of a 400 kW wood-pellet-fired boiler and 600 m long heat distribution network. It replaced propane- and oil-fired individual boilers, but in the case of the new dwellings. When the project started promoted by Beizama's town council, the target was a more environmentally friendly heating system that would cover town's total heat demand. (kapelbi, n.d.) Biomass was seen as a good fuel alternative (Garmendia, 2014), which in addition could generate employment (kapelbi, n.d.).

Figure 13: Beizama. Picture of the village centre, where the district heating system is installed. (Ganaderia Familiar de Limousin, n.d.)

The town council got into contact with Enerpellet, a project developer, who in turn contacted Kapelbi (engineering firm and distributor of biomass boilers) and Giroa (boiler installer and maintenance service provider) (kapelbi, n.d.). Results obtained from consultants' analysis showed distances were too long and heat demand was too little so that constructing a district heating system for every building in the village would be economically beneficial. However, the same analysis showed it would be so for some buildings located nearby each other in the village centre. Following consultants' advice, some of the consumers (those previously mentioned) located in the area with higher heat demand density decided to go ahead with the project. (Garmendia, 2014) According to (kapelbi, n.d.), a dwelling with estimated annual heat demand of 10,793 kWh would save 342 EUR a year when replacing a propane-fired boiler by the proposed district heating system.

Investment was 273,416 EUR and 188,430 EUR subsidy was obtained from Basque Government as part of "Erein Programa" (kapelbi, n.d.), a programme for promotion and development of rural areas (Govierno Vasco, 2012). It was decided Enerpellet would be the one managing the system (kapelbi, n.d.).

In 2014, the town mayor thinks the project was a complete failure because of many reasons: (1) results from project consultants' analysis were not consulted with other experts, (2) the system is much more expensive than calculated and more expensive than previous system contrary to consultants' estimations and (3) the project developer and system manager was not a trustworthy company –which in addition went bankrupt a few years ago making the problem even bigger. In short, the analysis done before decision-making and project implementation was not deep and accurate enough. The town council pays 12,000 EUR/year more than with the former system, *"we had no experience and we are now paying for a beginner's blunder"* (Garmendia, 2014).

For any potential district heating project, the town mayor advices to carry out a deep technical and economic analysis, whose results should be corroborated by various consultants that are independent from each other. Further, she states it is very important to examine and define who will manage the system once it is built and how management will be done. According to (Garmendia, 2014) detailed analysis and definition of every aspect will lead to less unexpected results and problems.

7.2 Abadiño

Abadiño is one of Durango's neighbouring towns. With 7,458 inhabitants (INE, 2014 (b)), it has an extension of 36.06 km^2 (INE, 2009) where industry, farms and forest are found.

In 2012, the town council built a small district heating system for 7 public buildings in Matiena, the most populated neighbourhood of Abadiño (Fernández, 2014). Those buildings, located very close to each other (within 100-150 m (calculated using Google Maps)), include kindergarten, school, high school and indoor sport facilities. The new heating system has a 500 kW wood-chip-fired boiler and has reduced running expenses down to 50% in comparison with the old oil-fired boilers installed in each building. The boiler is automatically fed and the warehouse for wood chips has space for one week of heat consumption. The warehouse is undersized according to the heating and cooling systems' regulation (*Reglamento de Instalaciones Térmicas de los Edificios* (RITE)), which specifies biomass heat installations have to have a warehouse that may cover 2 weeks of heat consumption. Its small size has in fact created some problems as the system runs out of wood chips sometimes. Nevertheless, old oil-fired boilers where not removed and serve as back-up system. (Fernández, 2014)

When the system was built, wood chips were bought from a sawmill in Elorrio (Fernández, 2014), a town located approximately 6.5 km away from Abadiño (calculated using Google Maps), and wood chips were produced from wood leftovers the sawmill could not use. Later on Abadiño's town council decided to use its own biomass obtained from town's forest cleaning (Fernández, 2014). According to (Fernández, 2014), producing wood chips by means of their own resources results in more expensive biomass than that provided by the sawmill as transportation costs are much higher. Nevertheless, forest cleaning has to be done and the town council wants to use the wood obtained from that activity (Fernández, 2014).

The system has performed properly since it was built and the town council is planning to build a similar system for the school buildings located in Zelaieta, one of the other neighbourhoods of the town. (Fernández, 2014)

7.3 Bilbao

Bilbao is the capital of Biscay Province and the biggest city in the Basque Autonomous Community with almost 350,000 inhabitants (INE, 2014 (b)). Bilbao and its neighbouring towns formed the most industrialised area of the Basque Autonomous Community (Agirre, 1993), but the area has experienced a remarkable transformation during the last decades, as recognised by international prizes such as Lee Kuan Yew World City Prize in 2010 (Ayuntamiento de Bilbao, 2010) (Leen Kuan Yew World City Prize, 2010). The city keeps part of its industry, while culture, services, tourism and other third sector activities continue to strengthen. This way Bilbao is one of the Basque cities with more recent urban development (Aranda, 2014).

Various projects for construction of new buildings in different neighbourhoods of the city included a district heating system (Aranda, 2014), as the two examples –Bolueta and Zorrozaurre– described later on. According to (Aranda, 2014), it may seem to be easier to implement a district heating system for new buildings as future consumers do not have to be convinced by advantages of this type of systems in comparison to conventional ones. However, the interviewee states building a common energy infrastructure implies obstacles as well. First of all, different project developers have to reach an agreement regarding the common energy infrastructure, which according to (Aranda, 2014) may become a problem for implementing a district heating system. Secondly, period for total realisation of a project may reduce profitability of a building district heating system and even prevent it from being economically feasible (Aranda, 2014).

It is important to mention acceptable profitability for investing or not in a specific project is a subjective factor. Public companies and institutions usually invest in projects even if expected profitability in the long term (25-30 years) is low. The reason for this is that public investments' main objective is not to obtain own economic benefits, but social benefits. On the contrary, private companies search for higher profitability investments than public companies and institutions. In spite of differences, most private companies will not invest in a district heating system if its profitability is lower than 12-15% of the internal rate of return in a period of 20 years. (Aranda, 2014)

In the experiences described in the following it was possible to reach an agreement with every project developer, but uncertainty regarding projects' time frame and percentage of its actual realisation entailed such a high risk for profitability that the district heating systems were finally not built (Aranda, 2014).

7.3.1 Bolueta

Bolueta, located by Nervión river, is one of the industrialised areas of Bilbao that is experiencing a transformation. The project called "Bolueta" consisted of 7 new buildings with 1,100 dwellings (EVE, n.d. (c)) and started in 2007-2008 (Aranda, 2014). The objective of the project was to build highly energy efficient and sustainable buildings with low environmental impact (EVE, n.d. (c)).

Figure 14: Bolueta project. A drawing of how it would have looked like. (EVE, n.d. (c))

In other to achieve the goal, it was decided to build a district heating system for the group of buildings. The main energy producing unit of the system was going to be a natural-gas-fired combined heat and power (CHP) plant. (Aranda, 2014) Feasibility of adding supplementary units using renewable energy was also going to be analysed (EVE, n.d. (c)). The energy system, which would have saved 14,300 tonnes of CO_2 emissions annually in comparison to an individual system (EVE, n.d. (c)), was going to be operated and managed by an Energy Service Company aiming for high efficiency and performance. The company was going to be private, but some public participation was also planned so that consumers would not be at the mercy of the Energy Service Company. (Aranda, 2014)

The realisation of the project was expected to take 10-15 years and was going to be done by two project developers: Visesa (a public project developer who was in charge of 60% of the project) and Neinor (a private developer, in charge of 40% of the project) (Aranda, 2014).

Due to the economic crisis it was decided to postpone construction start. In addition, changes in regulation approved in the meanwhile led to examination of biomass-fired boilers as an alternative to the previously planned natural-gas-fired CHP plant. (Aranda, 2014)

In 2011 the public project developer decided to start constructing part of his share. Later on, the private developer decided not to accomplish his part. Finally only 150 dwellings are built by the public project developer. (Aranda, 2014)

Uncertainty on what percentage of the dwelling were going to be built resulted in cancelling the construction of the district heating system as it could have been oversized and profitability was not ensured anymore. (Aranda, 2014)

7.3.2 Zorrozaurre

Zorrozaurre is currently a peninsula in Nervión river, but the project designed by the architect Zaha Hadid for the regeneration of the area will convert it into an island, see Figure 15. The project consists of several buildings for various purposes and 5,000 dwellings (4,000 on the island and 1,000 outside the island). In order to cover buildings' heat demand in an energy efficient way, it was decided to build a district heating system that would provide heat to every new building by means of a natural-gas-fired boiler. (Aranda, 2014)

Figure 15: Zorrozaurre project. A drawing of how it will look like from above. (Gomez, 2012)

Building a district heating system for Zorrozaurre became a highly controversial issue. One of the political parties of the town council was against it and started a campaign to stop it arguing the use of such a big boiler was going to have major impacts on air quality. Afraid of the possibility of high levels of air pollution, residents in the area showed their rejection towards the planned district heating system. The communication campaign started by the town council and EVE (Basque Energy Agency) was not effective enough and it was decided not build a district heating system for the buildings outside the island –already in construction– because of residents' strong resistance. (Aranda, 2014)

Implementing a district heating system for the future buildings on the island is still being analysed, including alternatives to the previously planned natural-gas-fired boiler, such as biomass boilers and waste heat from a nearby waste treatment plant (Aranda, 2014). According to (Aranda, 2014), if the project will go ahead, a good communication and consciousness-raising campaign will be determinant.

7.4 Leioa

Leioa, a town located in Biscay Province and where one of the Basque University's campuses is located, was the town chosen for placing Basque University's science park. The objectives of the project are to create an space for excellence and innovation, promote university-enterprise relationships, generate high qualification jobs and encourage new technology based enterprise emergence (Euskadido Parke Teknologikoak, n.d.). 19 buildings were planned to be built for that aim and the project got broad support from public institutions due to its innovative character (Aranda, 2014).

It was analysed the possibility of implementing a district heating and cooling system and using cogeneration and renewable energies. An Energy Service Company (a public company in this case) was going to cover the investment and be in charge of operating and managing the system. (Aranda, 2014)

The investment required to build the district heating and cooling system was 7.5 million EUR. A conventional heating and cooling system would need a lower investment –5.2 million EUR–, but this was expected to be counteracted in the long term due to the district heating and cooling system's higher efficiency. In addition, the system would prevent 21% of polluting emissions in comparison to conventional alternatives. (EVE, 2011)

Building a district heating and cooling system and using cogeneration and renewable energies was going to be beneficial for every stakeholder: construction companies would have saves space and lower their investment as no heating and cooling system had to be installed in each building (EVE, 2011); consumers would have had lower bills as a result of more efficient and cheaper energy sources and they would not have had to care about system management as it would have been done by the Energy Service Company; finally, society would have benefited from lower fuel consumption and emissions (EVE, 2011).

The project, born from an agreement between Technology Park of Biscay and EVE, was meant to be a pilot project (EVE, 2011). However, the project was partly postponed as a consequence of the economic crisis and reduced public budgets. This means only 3 buildings have been built for the moment and building a district heating and cooling system was dismissed after some investment and work had already been done. (Aranda, 2014)

As already mentioned before, constructing a district heating system for new buildings involves problems related to reaching agreements with the different project developers taking part in the project –an obstacle that had been overcome in this specific project. In this case, district heating and cooling system profitability was not as determinant factor as in other examined projects –which was an advantage. The reason for it was that low profitability (or even not losing money on the long run) was acceptable as the Energy Service Company was going to be public and the project was a pilot project that aimed for district heating and cooling systems' promotion. Nevertheless, uncertainty regarding buildings' construction implied a high risk and public institutions decided not to take it. (Aranda, 2014)

7.5 Aramaio

Aramaio is a small rural town with approximately 1,500 inhabitants located in Araba Province. The town has an area of 73.3 km^2 and is divided into different neighbourhoods. Ibarra is the biggest of them and the main urban area with approximately 900 inhabitants. (Ajuria & Beitia, 2014)

Even if it is only 8 km away from Mondragon (calculated using Google Maps), the biggest town of Debagoiena, one of the main industrial areas of the Basque Autonomous Community (Agirre, 1993), the main economic activities of Aramaio are related to the first sector –i.e. farming and forestry (Ajuria & Beitia, 2014). The town owns its electricity distribution grid, which belongs to Aramaio Argindar Banatzailea (AAB), a public company owned by the town council. Apart from that, increasing leisure offer and tourism related to nature is one of the objectives of the town. (Ajuria & Beitia, 2014)

Figure 16: Ibarra. The most populated neighbourhood of Aramaio. (Unknown, 2011)

In this context, the town defined its target: food-, energy- and leisure/tourism-sovereignty. Different work teams were created for this purpose (some of them are independent from town council, but count on its support) and some work has already been done with high participation of local residents. (Ajuria & Beitia, 2014)

Regarding energy-sovereignty goal, the first step was to analyse local energy resources –solar, geothermal, wind, fluvial hydro and biomass. The former two are not considered feasible alternatives as conditions for using solar energy are not very good in the town and local experience with geothermal energy proved it to be too expensive. On the contrary, good wind conditions were observed, especially in the area known as Aixola. However, installing wind turbines has been postponed for the moment as they will have a big impact on nature and landscape. Small scale hydro plants (below 1 MW) were very common in Aramaio before oil price went down and all plants closed because of lessened profitability. Some of those plants are very damaged, but two of them could be fixed and there is a water fall where a new one could be installed. Finally, forestry biomass is the most abundant energy source in the town, with approximately 60 km^2 of easily accessible wood. (Ajuria & Beitia, 2014)

After this initial step, it was decided the first work to be done was to replace the current heating system, which is based on propane-fired boilers. Ibarra, the main urban area in the town, is going to be the first one doing so by building a district heating system with biomass boilers. Later on, smaller district heating systems are planned to be built for other neighbourhoods and individual biomass boilers will be installed for farms and houses that are too far from those district heating systems. (Ajuria & Beitia, 2014)

After analysing different types of forestry biomass, such as wood-peg, wood-chip and wood-pellet, it was decided to use wood-chips as they enable controlled combustion and require little transformation, which can be done by local wood producers. Wood is going to be obtained from forest cleaning, a work that has to be done in order to increase production and reduce fire risk. Nowadays pruning, which should be done at least once every 16 years, implies a cost for wood producers, who only make money when trees are cut, this is, 40 years after tree planting when speaking about species such as pine. Using wood obtained from tree pruning in local forests will be beneficial for wood producers (who will get a remuneration for it), for residents security and for consumers (who will reduce their bills). This means, using biomass for heating is attractive for every stakeholder in the town. (Ajuria & Beitia, 2014)

Since the study to build a district heating system with biomass boilers as heat producing units for Ibarra started in 2007, several consultants have analysed technical and economic feasibility of the project. After obtaining very different results from different consultants, which were based on very different heat demand calculations, the town council decided to carry out a thorough analysis of Ibarra's heat demand by examining each building's demand with the help of a new consultant. The analysis concluded aggregated annual heat demand of buildings in the neighbourhood plus system's heat loss would be 6.22 GWh. Later on it was decided to take into account only the already existing 394 dwellings (141 buildings) and the 7 municipal buildings and to exclude 200 dwellings that are planned to be built in the neighbourhood as their construction start year is uncertain. Those buildings accounted for 40% of the calculated heat demand. This way, it was calculated a boiler with a capacity of 3,077 kW is required to cover Ibarra's heat demand and the distribution network is going to be 9.3 km long in total. (Ajuria & Beitia, 2014)

Regarding system operation and management as well as ownership, various alternatives were examined. Calculations showed the option with lowest expenses for consumers was the system to be operated by a team of local residents. However, this option implied total investment had to be covered by local people or/and by the town council. Hence, it was decided system operation and management is going to be done by a private Energy Service Company. Many companies of this kind also provide biomass themselves, but it was decided local producers (who may create a company, a cooperative or an association) will do it so that the project would keep attractive for every stakeholder in the town. In order to be able to control biomass price and kWh-heat price, AAB is going to be the intermediary between wood-chip producers and the Service Energy Company and also between the Energy Service Company and heat consumers. (Ajuria & Beitia, 2014)

Required investment is approximately 3.8 million EUR. Heat producing units and heat distribution network are going to be covered by an Energy Service Company (who will be in charge of system operation and management), whereas connection to the network and required equipment and its installation in each building will have to be paid by consumers. Approximately 1.1 million EUR will have to be covered by private consumers (i.e. residents in Ibarra who get connected to the system), this is in average 2,800 EUR per dwelling. Residents, unlike companies or public institutions, cannot get a subsidy for this project. Those householders who needed financing, will be able to obtain it either from their bank (estimated average interest rate 6%) or from AAB (interest rate 6%+VAT). It is expected subsidies will cover 65% of the remaining 2.7 million EUR. (Ajuria & Beitia, 2014)

System's annual running costs are expected to be 290,000 EUR lower than the current system's. This reduction is possible mainly due to the fact that wood-chip is a cheaper fuel than propane gas –the former costs 41 EUR/MWh and the latter 105 EUR/MWh (both including VAT). This way, consumers will save 15% when financing 100% of the investment with a loan given by AAB, 19% when financing 100% of the investment with a loan given by a bank and 43% when no financing is needed. At the same time, benefits of the Energy Service Company will be 50,000 EUR/year during 200 months (almost 17 years). If the demand happened to be lower or higher than estimated, the period will be shortened or prolonged so that the company may obtain arranged benefits. At the end of that period, the system will become public property owned by the town council. (Ajuria & Beitia, 2014)

Town council's approach regarding biomass provision, system operation and management, ownership and achievable benefits were not attractive for many consulted Energy Service Companies. In fact, during the whole process many Energy Service Companies said they were not interested, some who had seen the project positively for their business retracted when the project was about to be implemented in 2011 and even EVE said it was not economically feasible at a certain point. In spite of this, the town council never lost his faith on the project, he got into contact with Avebiom (the Spanish Association for Biomass Energy Valuation) and presented the district heating system project during a fair called EXPOBIOMASA held in Valladolid and organised by the association. 12 Energy Service Companies attended the presentation and some of them showed their interest in taking part in the project. (Ajuria & Beitia, 2014)

Currently a team formed by 14 people who represent diverse interests is working on a Forest-Biomass Management Plan whose purpose is that forests are exploited in an optimised and sustainable way. (Ajuria & Beitia, 2014)

Apart from that, it will soon start the town council's communication campaign, which will include a standing presentation in the town square, informative leaflets that will be sent to every consumer, various presentations, videos and participative processes in each neighbourhood (the latter is already in progress). The objective is to inform consumers about the benefits of getting connected to the system. After so many years analysing the possibility of implementing a district heating system, many inhabitants know the project and seem to be positive as they are aware of the benefits of being self-sufficient because there was a sudden rise in bills (which almost doubled) when lower calorific value propane gas was injected in the network some years ago. In addition, forest owners are very much interested in the project. Therefore, no resistance against the project is foreseen. Nevertheless, 280 dwellings out of the 314 have to get connected to the system so that the project results beneficial, meaning the campaign will be determinant for project implementation. If no unexpected obstacle appears, a tendering processes will start in the very near future. (Ajuria & Beitia, 2014)

The mayor states it has been a long process, with ups and downs, but affirms the town council is happy with the result so far. When being asked about advice for similar projects, he answered the following: every project should start by examining local energy resources; town council's lack of knowledge can be expected, so experts involvement and a knowledge gaining process are very important; do not only consult one expert or rely 100% on one expert's conclusions; and involve citizens in the process, make it participative. *"This is a project born from people in the town and meant to be beneficial for residents in the town, that was our key factor"*. (Ajuria & Beitia, 2014)

7.6 Considerations

Experiences described in the previous section lead to various considerations to be taken into account for any district heating development project in the Basque Autonomous Community:

- It important to carry out a thorough analysis of project's technical and economic feasibility. For this purpose it is recommendable to ask various experts and to check whether they obtain similar results and conclusions from their studies or not. If significant difference is observed among consultants' results, it should be find out where the difference comes from and decide how to proceed in order to obtain reliable results.
- Even if technical feasibility is an objective parameter, economic feasibility or profitability is a subjective parameter that may vary from one investor to another as explained in Sections 7.3 and 7.4. This means a district heating project could be unattractive for some investors, but attractive for others. Few investors denial does

not necessarily imply a specific district heating project is not profitable, it does not mean the project should be cancelled, but other alternatives need to be examined, e.g. other investors, other ownership models and other financing sources.

- District heating projects' profitability is not only influenced by heat demand density of the analysed area, but it is also affected by when consumers get connected to the system. The shorter the period between system implementation and consumers' connection, the higher system's profitability. This is because higher expenses per produced MWh-heat result of an oversized system. If the system was consumer owned and monthly payments were calculated based on both, specific consumer's demand and system's annual expenses (as done in the economic analysis of this study), longer connection periods would result in longer investment pay-off periods (assuming the district heating system was more economical than conventional alternatives). If consumers paid a fix price related only to their consumption and not to system's annual expenses (this would be the case of a district heating system owned and operated by an Energy Service Company, for example), benefit per produced MWh-heat would be lower during connection period than once 100% of expected consumers get connected to the system.
- In addition to technical and economic feasibility, it is essential to examine other aspects such as fuel and technology providers, system operators and managers, ownership models and so on. Several alternatives exist for each of those aspects and it is important to analyse each of them in order to be able to choose the most appropriate for each specific case.
- Involving householders in district heating (or any other energy project) planning process is of great relevance. Communication and awareness-raising campaigns are indispensable tools, but their effectiveness is not ensured. Communicating a project once it is fully designed may not be enough to convince householders about project's advantages and it may generate residents' rejection and resistance reaction instead, as it happened in Zorrozaurre, see Section 7.3.1.
- Taking into account every single stakeholder during a district heating project planning process makes it possible to design a project that satisfies everyone's interests, resulting in easier project implementation, lower uncertainty and higher probability of convincing consumers of district heating systems' benefits.
- Participative processes and communication and awareness-raising campaigns are two methods for convincing consumers and other stakeholders about district heating systems' advantages and, in combination, they may provide very positive results. However, according to (Aranda, 2014) it might happen not to obtain desired results only applying them in some cases and other methods such as city ordinances that promote consumers' connection to the system should be analysed, e.g. municipality tax deduction for consumers connected to a district heating system.

8 Conclusions

This chapter summarises results and conclusions obtained from carried out analysis by going through each of the three sub-questions that enable to answer this study's research question.

This study belongs to the initial stage of analysis of the possibility of implementing a district heating system in San Fausto, a low income neighbourhood with poor energy performance residential buildings located in Durango (Maab, 2014 (a)), a town in northern Spain. The study has two objectives. The first one is to obtain a preliminary idea about investment and monthly costs to be covered by householders, as this is a determinant parameter for project implementation, and the second one is to gain knowledge from similar initiatives developed in the area in order to define an effective guideline for future stages of analysis. This means results and conclusions obtained in this study will serve as the basis for next stages of the planning process.

The research question is defined in order to meet specified objectives:

What are investment and monthly costs to be covered by householders of San Fausto when building a district heating system for the neighbourhood and what aspects should be taken into account so that the project is successfully developed?

Sub-question 1 and 2 answer the first part of the research question and sub-question 3 the second one. Every sub-question is answered in the following.

Sub-question 1: ***What is heat demand to be covered by the district heating system, what heat producing technologies are applicable and what is their technical and economic data?***

The energy demand to be covered by the district heating system depends on how many buildings decide to get connected to the system, on when they do it and on how many of them carry out the energy renovation proposed in (Maab, 2014 (a)) as part of the project "Berritu San Fausto". This implies the need for examining neighbourhood's current heat demand as well as its potential evolution.

The neighbourhood is formed by 53 buildings of 5 storeys, but in the case of building which only have 4 storeys. Most buildings have two dwellings per storey, but some of them have trade premises at ground floor level instead. This way, dwellings sum 508 and trade premises 24.

Table 31: Buildings in San Fausto grouped according to their dwellings' heated area. (*) Trade premises do not have the same heated area as dwellings.

Building type	Buildings	Dwellings	Trade premises (*)	Heated area [m^2/dwelling]
A	10	96	4	39
B	37	361	3	49
C	3	24	8	65
D	3	24	9	75

Four type of buildings –A, B, C and D– and six types of space heating demand – *Surrounded, Ground floor (GF), Roof, Exterior (Ext), Exterior Ground Floor (Ext GF)* and E*xterior Roof (Ext Roof)*– can be found in San Fausto. Building type is related to the heated area of its dwellings, see Table 31 and space heating demand type to dwelling (or trade premises) location within buildings, see Figure 17. Trade premises area is different from dwellings', however, no data on their heated area has been accessed. Therefore, it is assumed trade premises have the same heated area as dwellings they replace (if two trade premises replace a dwelling, their heated area is assumed to be half of the dwellings') and that their space heating consumption is also the same. Space heating consumption according to dwellings' or trade premises' position within buildings is shown on Table 31 on the previous page, where Add Ext is the additional space heating demand to be added to *GF* and *Roof* in order to calculate *Ext GF* and *Ext Roof*. It is important to note values shown on the table do not represent real heat demand, but heat demand calculated by means of thermography analysis (Maab, 2014 (a)).

Real heat demand, calculated based on consumers' bills, is much lower –53 kWh/m^2/year for a *surrounded* dwelling– because many households do not use heating as much as necessary to keep acceptable indoor temperatures in winter time (Maab, 2014 (a)). In this study values based on thermography analysis are the only ones taken into account aiming for a system dimensioning that can supply enough heat for good living conditions.

Figure 17: Types of dwelling according to their location within buildings.

Table 32: Annual space heating demand per dwelling in kWh per heated area. Values calculated based on thermography analysis. (Maab, 2014 (a))

Space heating demand per dwelling [kWh/m^2 /year]	
Surrounded	84
GF	145
Roof	138
Ext	127
Add Ext	43

DHW demand is 36 kWh/m^2/year for every dwelling type, based on real consumption analysis (Maab, 2014 (a)), and trade premises' is 11% of their space heating demand, based on (IDAE, 2011 (d)). This way, neighbourhood's current total heat demand is calculated to be 4,091,596 kWh/year, see Table 33 on the following page.

Table 33: San Fausto's current annual total heat demand in kWh. Space heating demand values are calculated based on data obtained from thermography analysis and not on householders' energy bills.

	Dwellings	Trade premises	TOTAL DEMAND
Space heating demand [kWh/year]	2,990,062	187,773	3,178,393
DHW demand [kWh/year]	892,548	20,655	913,203
TOTAL DEMAND [kWh/year]	3,883,168	208,428	**4,091,596**

If householders decided to implement the energy renovation proposed in (Maab, 2014 (a)), their space heating consumption would be reduced to 35% of the current space heating demand and DHW demand would remain the same. It is assumed the same reduction is applicable to trade premises.

Currently there is a high uncertainty regarding how many householders will decide to do the energy renovation because surveys show other proposals included in the project "Berritu San Fausto" are more urgent and important for them and because the investment needed is 9,000-12,000 EUR/household (Maab, 2014 (a)). In addition, there is uncertainty also regarding amount of householders that will decide to connect to the system and regarding when they will do it. As energy demand to be covered by a heating system conditions its dimensioning and, hence, it has a direct effect on investment and O&M cost, it is essential to analyse how different demand scenarios could influence system's economy. 6 demand scenarios are defined for this study, as shown in Table 34, which result in the demand curves shown in Figure 18 on the following page.

Table 34: Potential heat demand scenarios to be analysed. These scenarios arise from combining options regarding connection to DH system and energy renovation implementation presented in Table 6 on page 33.

	Potential heat demand scenarios
S1	Connection to DH system: 20% (from beginning)+ 40% (in 10 years) = 60% Energy renovation implementation: 25%
S2	Connection to DH system: 20% (from beginning)+ 40% (in 10 years) = 60% Energy renovation implementation: 50%
S3	Connection to DH system: 20% (from beginning)+ 40% (in 10 years) = 60% Energy renovation implementation: 75%
S4	Connection to DH system: 60% (from beginning)+ 40% (in 10 years) = 100% Energy renovation implementation: 25%
S5	Connection to DH system: 60% (from beginning)+ 40% (in 10 years) = 100% Energy renovation implementation: 50%
S6	Connection to DH system: 60% (from beginning)+ 40% (in 10 years) = 100% Energy renovation implementation: 75%

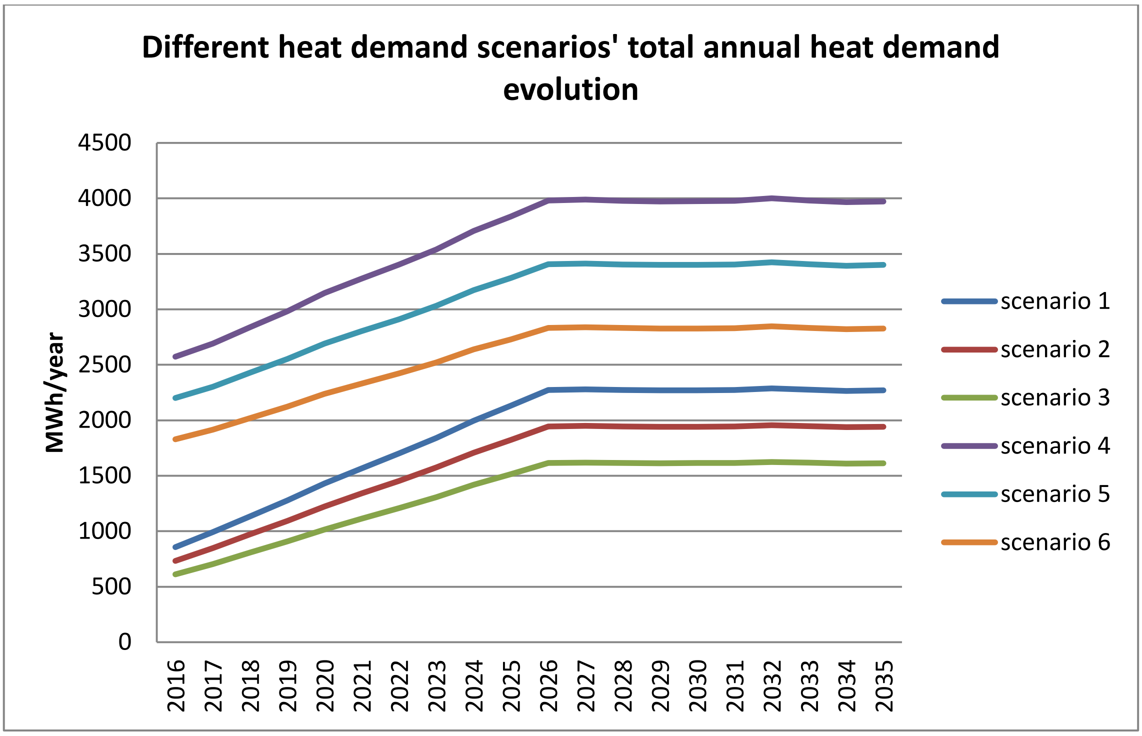

Figure 18: Different heat demand scenarios' annual heat demand evolution, including heating demand, DHW demand and system's losses.

Regarding applicable heat producing technologies, it has to be mentioned only technologies that would increase the share of renewable energy used in the neighbourhood are decided to be analysed. This way, 5 different alternatives are taken into account: biomass-fired boiler, biomass-fired CHP plant, heat pump, electric boiler and solar collectors. Biomass-fired CHP plant and electric boiler were dismissed for further analysis, the former because of the current unstable situation of the Spanish electricity market and the latter because no consumption units but hydro-pumping stations can take part in power network balancing markets (REE, 2014).

Table 35: Investment, O&M cost and efficiencies of wood-chip-fired boilers and wood-pellet-fired boilers in 2015. Investment and O&M cost exclude VAT. (DEA & energinet.dk, 2012 (b))

	Wood-chip-fired boiler	Wood-pellet-fired boiler
Investment [million EUR/MW]	0.8	0.4
O&M cost [EUR/MWh]	6.68	3.34
Efficiency [%]	108	108

Forestry biomass is the most abundant type of biomass in the Basque Autonomous Community (EVE, 2012). Therefore wood-chip-fired and wood-pellet-fired boilers are two of the main heat producing technologies selected for the economic analysis. Their economic and technical data is shown in Table 35. Wood-chip price in 2013 was 112 EUR/ton (including transportation and excluding VAT) (Enciso, 2013) and it is assumed it will increase 15% plus inflation from 2012 to 2020 and only as much as inflation from 2021 on. Wood-pellet price in 2013 was 225 EUR/ton (including transportation and excluding VAT) (Enciso, 2013) and it is assumed it will increase

12% plus inflation from 2012 to 2020 and 3% plus inflation from 2021 on. Wood chip's calorific value is 14.226 GJ/ton and wood pellets' 18.828 GJ/ton (Enciso, 2013).

Air-to-water heat pump is the chosen type of heat pump for analysis. Its technical and economic data is shown in Table 36. The analysis of this technology is done taking into account a 3-period electricity tariff offered by ENDESA in 2014 and valid for installed capacities lower than 450 kW, see Table 37 and Table 38. To electricity prices shown in Table 37 electricity tax (5.1%) and VAT have to be added (EVE, 2014 (a)). Regarding electricity price projection, it is assumed hired capacity element will increase 4.41% (including inflation) annually and consumed electricity 4.29% (including inflation) annually.

Table 36: Investment, O&M cost and COP of an air-to-water heat pump in 2015. Investment and O&M cost exclude VAT. (DEA & energinet.dk, 2012 (b))

Air-to-water heat pump	
Investment [million EUR/MJ/s]	0.4
O&M cost Cost 1 [EUR/year] Cost 2 [EUR/MJ/s out/year]	 2,500 1,500
COP	2.8

Table 37: Retailer prices for a 3-period high voltage tariff in 2014. Prices exclude electricity tax and VAT. (ENDESA, 2014 (a))

	Period 1 (Punta)	**Period 2 (Llano)**	**Period 3 (Valle)**
Hired capacity [EUR/(kW /year)]	59.475288	36.676813	8.410411
Consumed electricity [EUR/kWh]	0.123310	0.106111	0.077121

Table 38: Electricity tariff's periods delimitation over a year and over a day. Period 1 (Punta) in red, Period 2 (Llano) in white and Period 3 (Valle) in green. (ENDESA, 2014 (b))

Hours	**0-1**	**1-8**	**8-9**	**9-10**	**10-16**	**16-17**	**17-18**	**18-23**	**23-24**
Winter weekdays									
Summer weekdays									
Weekends and national holidays									

Finally, flat solar collectors are also chosen for further analysis as supplementary heat producing units that have to be examined in combination with a main heat producing technology. Economic and technical data used for system modelling and economic analysis are shown in Table 39 on the following page.

Thermal store investment in 2010 was 230 EUR/m^3 excluding VAT (DEA & energinet.dk, 2012 (a)). Investment required for the rest of the components that form a district heating system is shown in Table 40, values on the table are for 2015 and include VAT. O&M cost of the heat distribution network in 2015 is 900 EUR/GWh and of the consumer network 1,250 EUR/building/year (both values exclude VAT) (DEA & energinet.dk, 2012 (b)).

Table 39: Solar collectors' investment and O&M cost in 2015 (excluding VAT) (DEA & energinet.dk, 2012 (b)) and technical data (TÜV Rheinland DIN CERTCO, 2013) used for economic analysis.

Flat-Plate Solar Collector	
Investment [EUR/m^2]	227
O&M cost [EUR/MWh]	0.57
Collector's area [m^2/collector]	2.51
Start efficiency (η_0)	0.79
Loss coefficient 1 (a_1)	3.721
Loss coefficient 2 (a_2)	0.016
Incidence angle modifier (K_θ), 50 °	0.9

Table 40: Building, heat distribution network and consumer network investment and other initial expenses depending on demand scenario. Values are for year 2015 and include VAT.

	Investment of other components of the district heating system [million EUR]					
	S1	**S2**	**S3**	**S4**	**S5**	**S6**
Building	0.5	0.5	0.5	0.5	0.5	0.5
Heat distribution network	0.335	0.335	0.335	0.556	0.480	0.402
Consumer network	0.06	0.06	0.06	0.1	0.1	0.1
Other initial expenses	0.15	0.15	0.15	0.15	0.15	0.15

Sub-question 2:*What is the economy of applicable heat producing technologies in relation to potential heat demand scenarios?*

Table 41 on the following page shows total accumulated balances of every examined main heat production technology, either as systems single heat production unit or in combination with solar collectors.

Results show a wood-chip-fired boiler is the most economical main heat producing technology of those analysed, followed by a wood-pellet-fired boiler and an air-to-water heat pump, respectively. It is important to mention values shown in the table are those obtained for the most economical combination of boiler or heat pump capacity and thermal store volume examined in this study. However, it does not mean they are the most economical because no turning on and shutting down costs are added as it has not been possible to access them. Following stages should include this cost and recalculate heat producing unit capacity and thermal store size so that their investment and O&M cost sum results in the lowest possible.

Total accumulated balances are lower when main heat producing technologies are combined with solar collectors, especially with *100% solar collectors*. However, it should be analysed whether the reduction in accumulated balance compensates additional investment or not by adding financial costs and by calculating NPVs with a discount rate which is not equal to cero.

Table 41: Total accumulated balances of wood-chip-fired boiler, wood-pellet-fired boiler and air-to-water heat pump as single heat producing unit of the system and in combination with *100%* and *50% solar collectors*. WBC: wood-chip-fired boiler, WPB: wood-pellet-fired boiler, HP: air-to-water heat pump, S (100): 100% solar collectors, S (50): 50% solar collectors.

	Total Accumulated Balance [million EUR]					
	S1	S2	S3	S4	S5	S6
WBC	4.69	4.26	3.83	8.00	7.11	6.22
WPB	5.10	4.63	4.15	8.79	7.78	6.82
HP	5.61	5.08	4.56	9.61	8.41	7.31
WCB + S (100)	4.57	4.18	3.78	7.88	6.95	6.12
WPB + S (100)	4.80	4.31	3.93	8.25	7.31	6.38
HP + S (100)	5.43	4.90	4.41	9.23	8.14	7.05
WCB + S (50)	4.59	4.20	3.81	7.94	7.04	6.17
WPB + S (50)	4.91	4.43	4.03	8.49	7.57	6.58
HP + S (50)	5.48	4.95	4.48	9.35	8.28	7.15

Sensitivity analysis concludes a wood-chip-fired boiler is the most secure of the three main heat producing technologies examined in this study. When none of them are combined with solar collectors, a wood-chip-fired boiler is the most economical alternative even when wood-pellet and electricity price increase only as much as inflation and wood-chip price twice the expected projection plus inflation. When analysing main heat producing technologies in combination with solar collectors, there is only one case in which a wood-chip-fired boiler combined with 100% solar collectors is not the most economical alternative –this is when wood-pellet price increases only as much as inflation and wood-chip price twice the expected plus inflation. Nevertheless, this is a very improbable scenario because both are forestry biomass and will probably follow similar price tendencies.

Table 42 on the following page shows distribution of monthly costs, investment and total accumulated balances per household for four types of consumers. It is important to note monthly costs and investment shown in that table would correspond to a consumer ownership, i.e. monthly costs do not include any type of benefit and investment is the sum of every investment component (values for each investment component are presented in Tables 25-30 in Section 6.2). Other ownership models would probably result in higher monthly costs and lower investment. The way in which monthly cost and investment is distributed among consumers benefits consumers with lower demands and support energy renovation.

As when analysing entire system's economy, a wood-chip-fired boiler is the most economical main heat producing unit from a consumer perspective. A wood-pellet-fired boiler and a heat pump (which imply almost the same initial investment) require lower investment than a wood-chip-fired boiler, but their running cost is higher, resulting in higher accumulated balances. Installing solar collectors reduces monthly costs in every case and, in spite of implying additional investment, obtained accumulated balances are lower. However, taking into account it is a 20 year period and the additional investment needed for solar collectors installation, the difference in accumulated balances is rather small, especially in the case of a wood-chip-fired boiler and *100% solar collectors*. As already mentioned before, financial costs should be added and NPVs with a discount rate that is not equal to cero should be calculated to find out whether installing solar collectors is in fact economically beneficial or not. It is important to do the calculation not only for the expected energy price projection scenario, but also for lower and higher energy price scenarios, as solar collectors are less attractive in lower energy price scenarios and more attractive when energy prices are higher. Apart from that, householders should also consider other parameters such as reduction of emissions and higher heat supply security before making any decision on installing solar collectors or not. Finally, it is important to remind this study does not analyse whether sufficient ground or roof area is available for installing required solar collector area, this means feasibility is not ensured and should be examined.

Based on the results obtained from the carried out economic analysis, wood-chip-fired boiler and solar collectors are both chosen for further analysis in following stages of analysis.

Table 42: Monthly costs, total investment and total accumulated balance per household. Monthly costs and investment shown in this table correspond to a consumer ownership, i.e. monthly costs do not include any type of benefit and investment is the sum of every investment component. WBC: wood-chip-fired boiler, WPB: wood-pellet-fired boiler, HP: air-to-water heat pump, S (100): 100% solar collectors, S (50): 50% solar collectors.

	Monthly costs, total investment and accumulated balance per household			
	Monthly costs in 2016 [EUR]	Monthly costs in 2035 [EUR]	Total investment [EUR]	Total accumulated balance [EUR]
Non-renovated *surrounded* B type dwelling without energy renovation (5,880 kWh/year)				
WCB	31-34	41-47	3,800-5,200	13,100-14,500
WCB + S (100)	20-25	32-37	5,500-6,700	12,800-14,400
WPB	38-42	52-58	3,000-4,400	14,500-16,500
WPB + S (100)	23-28	40-45	4,800-6,000	13,400-15,000
HP	41-50	62-69	3,100-4,400	15,800-18,200
HP + S (100)	33-41	51-56	4,800-6,000	15,000-17,300
Renovated *surrounded* B type dwelling with energy renovation (3,205 kWh/year)				
WCB	17-19	23-26	3,100-4,400	8,300-9,700
WCB + S (100)	11-13	18-20	4,000-5,200	8,000-9,300
WPB	21-23	29-31	2,700-4,000	9,000-10,500
WPB + S (100)	13-15	22-24	3,600-4,800	8,400-9,700
HP	22-28	34-38	2,700-4,000	9,700-11,400
HP + S (100)	18-22	28-30	3,600-4,800	9,300-10,900
Non-renovated *surrounded* D type dwelling without energy renovation (9,000 kWh/year)				
WCB	47-53	63-72	4,600-6,200	18,800-20,400
WCB + S (100)	31-38	50-57	7,200-8,400	18,300-20,200
WPB	58-64	80-89	3,500-5,000	20,900-23,000
WPB + S (100)	35-43	61-68	6,000-7,300	19,300-21,300
HP	62-80	94-106	3,500-5,000	22,800-26,100
HP + S (100)	51-62	77-85	6,100-7,300	21,700-24,700
Renovated *surrounded* B type dwelling with energy renovation (4,905 kWh/year)				
WCB	26-29	34-40	3,500-4,900	11,400-13,000
WCB + S (100)	17-20	27-31	5,000-6,100	11,000-12,500
WPB	31-35	44-49	2,900-4,300	12,000-14,300
WPB + S (100)	19-24	35-37	4,400-5,500	11,600-13,100
HP	34-43	51-58	2,900-4,300	13,500-15,700
HP + S (100)	28-34	42-47	4,300-5,500	13,000-15,000

Sub-question 3: ***What aspects should be taken into account so that the district heating project is successfully developed?***

District heating systems and their development projects are new for consumers, town councils and project developers in Spain. Learning from other similar initiatives in the region will facilitate the process, reduce problems and obstacles and increase chances for achieving aimed objectives. Therefore, interviews are held with agents involved in some of the district heating projects that are operating, cancelled or in planning process in the Basque Autonomous Community. The reason for analysing only project of this region is that they share 3 out of the 4 levels in which the context of this study is divided, see Figure 5 on page 11. Examined district heating projects are those developed for Beizama, Abadiño, Bilbao, Leioa and Aramaio.

Beizama is a small rural town located in Gipuzkoa Province. In 2009 (Garmendia, 2014) a wood-pellet-fired boiler was installed to provide heat to 10 households, the town hall, a hostel and a nature school. The district heating system replaced oil- and propane-fired individual boilers, but in the case of 8 newly built households. The project started with the aim of reducing town's environmental impact and, according to project consultants, it would also reduce consumers' bills (a consumer with an estimated annual demand of 10,793 kWh would save 342 EUR/year in comparison to using a propane-fired individual boiler). (kapelbi, n.d.) On the contrary, after project implementation and operation start it was proven the system is more expensive than the one it replaced. Apart from that, other problems related to system management have been experienced with the company in charge of it. Lack of awareness, not having asked independent consultants for result corroboration and not having defined every single aspect of the project in detail are the reasons why consumer are now paying for a bad decision according to Begoña Garmendia, town mayor.

Abadiño is one of Durango's neighbouring towns. Here a small district heating system was built to supply heat to 7 public buildings located very close to each other. Oil-fired boilers installed in each building were replaced by a central wood-chip-fired boiler. The system has run properly since it was built and users are happy with its performance. The only problem is that the system runs out of wood chips sometimes because the warehouse is too small. Nevertheless, some of the oil-fired boilers were not decommissioned and serve as back-up system for such situations. (Fernández, 2014)

The two projects developed for Bilbao (for two residential neighbourhoods named Bolueta and Zorrozaurre) and the project developed for the Basque University's science park were all cancelled. All of them were planned to cover heat demand of new buildings, but delays in construction start, uncertainty regarding future demand and resistance from residents in the area, resulted in lessened profitability, increased investment risk and pressure on politicians. When a district heating system is meant to supply heat to a group of new buildings, the first difficulty is to reach an agreement among every project developer on a common energy system, the second is the projects time span (i.e. when will first buildings be built and when will the last one be) as this will influence project's profitability. Apart from that, it is important to take into account residents who already live in the area and to design an effective awareness-raising and communication campaign for them in order to avoid resistance. (Aranda, 2014)

Aramaio is a small town located in Araba Province. One of town's objectives is reaching energy-sovereignty and that is why the analysis of the possibility of implementing a district heating system started. Before that, a thorough analysis of town's energy resources was made and biomass was found out to be the most abundant and sufficient to cover towns heat demand in a sustainable way. For many years economic and technical feasibility of installing a wood-chip-fired boiler has been examined. Even if technical feasibility is possible according to every consultant, diverse opinions have been expressed regarding economic feasibility. The main reason for it was differences in annual heat demand estimations done by different consultants. Hence, another consultant was hired in order to do an analysis of the energy demand of every building in the town. Later on, potential investors and system operators and managers showed their disapproval towards obtainable benefits and town councils' approach, which consists in the following: wood chips will be provided by local wood producers, an energy service company is going to own and run the system for the first 200 month, the public company in charge of the local power distribution grid that belongs to the town council is going to be the intermediary between wood-chip suppliers and the energy service company and between the company and end consumer, and after the 200-month period the district heating system is going to be publicly owned. In order to find other energy service companies that could be interested in investing in this project and managing the system under the conditions established by the town council, the project was presented in a biomass faire in Valladolid in front of a dozen of companies. Some of the attendants affirmed they were interested and next steps of the project are related to tendering process and communication campaign for citizens. No resistance reaction is expected as the project is designed so that it is beneficial for every stakeholder in the town, but the campaign will be decisive to reach the minimum amount of consumers that is necessary to make the system profitable. (Ajuria & Beitia, 2014)

From described experiences it is concluded following considerations should be taken into account when developing a district heating project:

- It important to carry out a thorough analysis of project's technical and economic feasibility. For this purpose it is recommendable to ask various experts and to check whether they obtain similar results and conclusions from their studies or not.
- Even if technical feasibility is an objective parameter, economic feasibility or profitability is a subjective parameter that may vary from one investor to another as explained in Sections 7.3 and 7.4. This means a district heating project could be unattractive for some investors, but attractive for others.
- District heating projects' profitability is not only influenced by heat demand density of the analysed area, but it is also affected by when consumers are connected to the system. The shorter the period between system implementation and consumers' connection, the higher system's profitability.
- In addition to technical and economic feasibility, it is essential to examine other aspects such as fuel and technology providers, system operators and managers, ownership models and so on. Several alternatives exist for each of those aspects and it is important to analyse each of them in order to be able to choose the most appropriate for each specific case.
- Involving citizens in district heating (or any other energy project) planning process is of great relevance. Communication and awareness-raising campaigns are indispensable tools, but their effectiveness is not ensured. Communicating a project once it is fully designed may not be enough to convince householders about project's advantages and it may generate residents' rejection and resistance reaction instead.
- Taking into account every single stakeholder during a district heating project planning process makes it possible to design a project that satisfies everyone's interests, resulting in easier project implementation, lower uncertainty and higher probability of convincing consumers of district heating systems' benefits.
- Participative processes and communication and awareness-raising campaigns may not be effective enough to obtain aimed results. In those cases other methods such as city ordinances that promote consumers' connection to the system should be analysed, e.g. municipality tax deduction for consumers connected to a district heating system.

9 Perspectives

This study belongs to the initial stage of analysis of the possibility of implementing a district heating system in San Fausto. As explained in Section 2.3, this means obtained results and conclusions are the basis for following stages of analysis, where scope of analysis will be expanded and limitations will be lessened with the objective of more accurate examination and results.

Apart from the work to be done for the implementation of the district heating project in San Fausto, there is also research to be done regarding citizens' acceptance of and involvement in energy projects and policy changes.

9.1 Following Stages of Analysis

9.1.1 Intermediate Stage

The intermediate stage will provide a clear picture of the economy and social characteristics of the project and amount of potential consumers interested in getting involved in the project.

Wood-chip-fired boilers and flat-plate solar collectors are the chosen technologies for further analysis. The initial stage of analysis does not examine whether there is enough area for installing required solar collectors or not. That is why this should be the first task to be done in the intermediate stage before going ahead with solar collectors analysis. If it was found out it is possible to install solar collectors either on ground or roofs, advantages and disadvantages of both possibilities should be analysed in order to make a decision.

Heat demand estimation should be thoroughly checked. As in other district heating projects developed for the Basque Autonomous Community, differences exist in consultants heat demand estimation. Visesa estimates annual heat demand in a demand scenario with 100% connection and 0% renovation is 2.21 GWh. Another consultant, whose report is confidential, estimates annual heat demand in the same scenario is 3.03 GWh. The estimation done in this report for that scenario is 4.09 GWh –almost double Visesa's estimation. The method utilised by Visesa to calculate aggregated heat demand is not known, whereas the other consultant assumes every dwelling is a *surrounded* B type dwelling and uses real space heating demand instead of space heating demand calculated based on thermography data. Demand is one of the most important factors of a district heating system as it conditions system dimensioning, investment and O&M cost and profitability. Therefore it is essential to reach a realistic estimation corroborated by more than one independent consultant. Apart from that, it could be interesting to analyse whether including other nearby buildings in the project would reduce accumulated balances of consumers because demand scenarios with the highest demands are the most economical for householders according to conclusions drawn from initial stage of analysis.

Once technical feasibility of installing solar collectors is known and a more precise aggregated demand is estimated, boiler capacity, solar collector area (if installation was proven to be feasible) and thermal store volume should be adjusted to newly calculated aggregated heat demand. Further, investment and O&M cost values correspondent to the Danish market and obtained from (DEA & energinet.dk, 2012 (a)) and (DEA & energinet.dk, 2012 (b)) should be replaced by Spanish market values. Apart from a biomass boiler and thermal store, biomass heating systems require warehouses, biomass handling and boiler feeding mechanisms, control devices, ash extraction facilities and chimneys (FOREST, n.d.). Investment and O&M cost of all those components (which is not included in the economic analysis done in the initial stage of analysis) should be added in the economic analysis of the intermediate stage. In the same way, cost of installing radiators in dwellings should be found out and average cost of cancelling contracts with current energy suppliers should be estimated.

Searching for more accurate economic results, obtainable subsidies, financial costs and ownership models will be analysed. Those three aspects are dependent on each other and, therefore, economic results will be calculated and presented in relation to different ownership models. Further, the economy of the current individual heating system will be compared to the district heating systems. Discounted accumulated balances (NPV calculated with a discount rate not equal to cero) will be included as an extra parameter. Discount rate is dependent on investor and, hence, different discount rates will be applied for each ownership model.

Economic results obtained from the explained analysis will be presented to householders of San Fausto in a public meeting. During the meeting householders will have the chance to make comments and suggestions for improvements and to clarify any doubt they could have. The meeting will also be used to gather information on household economies, householders interest in the project and their opinion. If the district heating system's economy resulted in more economical than the current individual heating system, but a significant percentage of householders were not interested in building and getting connected to such a system, reasons should be found out and a solution designed.

Based on the list of considerations defined after examining other similar initiatives developed in the Basque Autonomous Community, it is also thought to be important to analyse how other local stakeholders (wood-chip providers, blacksmiths...) could get involved in the project.

9.1.2 Final Stage

If project's economy was affordable and residents were positive to build a district heating system, the final stage of analysis would start. At this stage various experts on biomass heating system design should be contacted for system design, as recommended by (FOREST, n.d.) and extremely accurate economic analysis. This should include a comparison of installing a single biomass boiler or various smaller boilers in order to find out whether the additional investment would be compensated by expected reduction in O&M and turning on and shutting down costs. If solar collectors were also decided to be installed, the optimum boiler capacity, solar collector area and thermal store size should be found out.

Apart from that, it will be necessary to contact technology, energy and service providers and energy service companies (if they should be the owners or be in charge of system managament) to find out whether they could be interested in getting involved in the project. Following some interviewees piece of advice it is important that every single aspect of the project is defined before project implementation, including issues such as who the biomass provider will be, who will manage and operate the system and under which conditions and how payments will be done.

New results will be presented to residents again and they will have to make a decision on building the district heating system or not. If the project was approved, a preliminary stage of the implementation process would start afterwards, contracts would be signed with every provider, applications for permits and subsidies would be processed, etcetera.

9.2 Further Research on Citizens Involvement and Acceptance

Analysis of similar initiatives developed in the Basque Autonomous Community reveals none of the projects was promoted by citizens, neither by private companies –they were all started by public institutions. Projects were (or are going to be) communicated to citizens once they are completely designed and only one of them takes into account every local stakeholder. This shows actual situation –citizens are not involved in energy project not even when the project may affect them directly as potential consumers. Some organisations and associations are working on how to build a participative society aiming for a sustainable future that is designed taken into account everyone's interests and wills. Studying the work done by those groups could be helpful for involving citizens in district heating project development.

A case of project cancelation because of citizens resistance has been found out and others could appear in the future if reasons for potential resistance are not analysed and the way to achieve acceptance is not found. This analysis will probably be very much link to involving citizens in energy projects.

9.3 Investigation for Policy Changes and Development

As explained in the introduction, energy poverty has increased in Spain in the last year and, in spite of EU directives that oblige Member Countries to develop plans to address this issue, Spain has not defined an strategy to mitigate the problem yet. Research on what measures should be adopted and what their economic and social impact would be is essential and urgent.

Last modifications of the electricity sector law and access fee to be paid by consumers are barriers to renewable energy development and energy savings because subsidies for renewable energies were reduced and the fix component of the access fee was significantly increased whereas the variable part (dependent on consumed electricity) was reduced. These measures go against national and European energy targets and should be reconsidered.

Integration of heat and power systems is essential in order to be able to increase the share of fluctuating renewable energies in the electricity system and making the most of them. Currently hydro pumping stations are the only consumption units that are allowed to take part in power balancing markets. It should be analysed how regulation should be changed so that electric boilers and heat pumps could be used to absorb excess electricity when necessary.

Policies for promotion of district heating and cooling systems in Spain should be defined. Technical, economic and social effects of various potential policies should be analysed in order to chose the most beneficial one.

References

ADHAC, 2013. *ADHAC - Asociación de Empresas de Redes de Calor y Frío. Censo de Redes.* [Online]
Available at: http://www.adhac.es/Priv/ClientsImages/AsociacionPerso8_1390845164.pdf
[Accessed 10 July 2014].

Agirre, I., 1993. El fenómeno industrial en Euskadi. *Lurralde: investigación y espacio,* Issue 16, pp. 75-86.

Ajuria, R. & Beitia, I., 2014. Ramon Ajuria is the Mayor of Aramaio and Idoia Beitia the town environment councillor [Interview] (10 June 2014).

Andersen, I., 2008. *Den skinbarlige virkelighed. vidensproduktion inden for samfundsvidenskaberne.* 4 ed. s.l.:Samfundslitteratur.

Aranda, I., 2014. Ismael Aranda is the Head of Industry Area at the Basque Energy Agency (EVE) [Interview] (12 June 2014).

Ayuntamiento de Bilbao, 2010. *Bilbao.net - Web del Ayuntamiento de Bilbao. Reconocimientos y premios de la ciudad de Bilbao y de su Ayuntamiento. 2010.* [Online]
Available at:
http://www.bilbao.net/cs/Satellite?c=Page&cid=1279098019452&language=es&pageid=1279098019452&pagename=Bilbaonet%2FPage%2FBIO_contenidoFinal
[Accessed 30 June 2014].

Barciela, C., 2014. *El Pais: el periódico global. Economía. Los años del hambre..* [Online]
Available at:
http://economia.elpais.com/economia/2012/02/03/actualidad/1328294324_702765.html
[Accessed 6 March 2014].

Baxter, P. & Jack, S., 2008. Qualitative case study methodology: Study design and implementation for novice researchers. *The Qualitative Report,* December, 13(4), pp. 544-559.

Biomass Energy Centre, n.d. (a). *Biomass Energy Centre. Sources of biomass. Wood pellets and briquettes.* [Online]
Available at:
http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,18519&_dad=portal&_schema=PORTAL
[Accessed 13 March 2014].

Biomass Energy Centre, n.d. (b). *Website of the Biomass Energy Centre. What is biomass?.* [Online]
Available at:
http://www.biomassenergycentre.org.uk/portal/page?_pageid=76,15049&_dad=portal
[Accessed 27 March 2014].

Brookins, M., n.d.. *Chron. Small Business. Human Resources. Change in Organizations. What Causes Resistance to Change in an Organization?.* [Online]
Available at: http://smallbusiness.chron.com/causes-resistance-change-organization-347.html
[Accessed 28 May 2014].

Casanova, J. & Gil, C., 2012. *Breve Historia de España en el Siglo XX.* Ariel.

CE NEWS, 2013. *CE NEWS. Política. Todos contra la Ley del Sector Eléctrico de Soria.* [Online]
Available at: http://www.cenews.es/index.php/politica/251-todos-contra-soria
[Accessed 15 April 2014].

de Vaus, D., 2006. *SAGE Benchmarks in Social Research Methods: Research design.* London: SAGE Publications Ltd.

DEA & energinet.dk, 2012 (a). *energinet.dk.* [Online]
Available at:
http://www.energinet.dk/SiteCollectionDocuments/Danske%20dokumenter/Forskning/Technology_data_for_individual_heating_plants_and%20energy_transport.pdf
[Accessed 16 May 2014].

DEA & energinet.dk, 2012 (b). *energinet.dk.* [Online]
Available at:
http://www.energinet.dk/SiteCollectionDocuments/Danske%20dokumenter/Forskning/Technology_data_for_energy_plants.pdf
[Accessed 1 April 2014].

Departamento de Industria, Comercio y Turismo del Gobierno Vasco, 2008. *BOPV - Boletín Oficial de País Vasco. ORDEN de 22 de julio de 2008, de la Consejera de Industria, Comercio y Turismo, por la que se dictan normas en relación con el Reglamento de instalaciones térmicas en los edificios (RITE).* [Online]
Available at: http://www.euskadi.net/cgi-bin_k54/ver_c?CMD=VERDOC&BASE=B03A&DOCN=000085502&CONF=/config/k54/bopv_c.cnf
[Accessed 11 July 2014].

Department of Development and Planning, Aalborg University, n.d.. *EnergyPLAN. Advanced energy system analysis computer model. Introduction. EnergyPLAN compared to other models.* [Online]
Available at: http://www.energyplan.eu/training/introduction/
[Accessed 15 May 2014].

Díaz, M., 2014. *El Correo.com - Noticias Vizcaya - Noticias Duranguesado. Un desembolso de 30.000 euros es imposible para la mayoría de los vecinos.* [Online]
Available at: http://www.elcorreo.com/vizcaya/v/20140426/duranguesado/desembolso-euros-imposible-para-20140426.html
[Accessed 1 June 2014].

El Observatorio Crítico de la Energía, 2012. *Observa el Mercado Eléctrico*. [Online]
Available at:
http://www.observaelmercadoelectrico.net/Descargas/Entiende_el_mercado_electrico.pdf
[Accessed 26 February 2014].

EMD, 2013. *EMD International A/S. energyPRO. Downloads.* [Online]
Available at: http://www.emd.dk/files/energypro/energyproHlpEng-master.pdf
[Accessed 20 February 2014].

Enciso, E., 2013. *ForoBiomasa - FórumBiomassa. Ponencias de Foro Biomasa.* [Online]
Available at: http://forobiomasa.cavatrans.com/documentacion/TAvebiom/avabiom-enrique-enciso.pdf
[Accessed 27 March 2014].

ENDESA, 2014 (a). *ENDESA. Empresas. Electricidad. Tarifa Óptima. Precios.* [Online]
Available at:
http://www.endesaonline.com/ES/empresas/luz/tarifas_electricas_empresas_alta_tension/op

tima/precios/index.asp
[Accessed 3 April 2014].

ENDESA, 2014 (b). *ENDESA. Empresas. Electricidad. Tarifa Óptima. Periodos horarios.* [Online]
Available at:
http://www.endesaonline.com/ES/empresas/luz/tarifas_electricas_empresas_alta_tension/optima/horas/index.asp
[Accessed 3 April 2014].

Euskadido Parke Teknologikoak, n.d.. *Euskadido Parke Teknologikoak. Parque Científico de UPV/EHU.* [Online]
Available at: http://www.parque-tecnologico.es/?page_id=2339
[Accessed 15 June 2014].

EUSTAT, n.d.. *EUSTAT. Instituto Vasco de la Estadística. Definiciones. Índice de confort.* [Online]
Available at:
http://www.eustat.es/documentos/opt_0/tema_443/elem_1757/definicion.html#axzz2vmfTzWqv
[Accessed 11 March 2014].

EVE, 2011. *EVE - Ente Vasco de la Energía. Noticias. El futuro Parque Científico de Leioa tendrá un sistema energético que ahorrará 5,2 millones.* [Online]
Available at: http://www.eve.es/Noticias/El-futuro-Parque-Cientifico-de-Leioa-tendra-un-sis.aspx
[Accessed 15 June 2014].

EVE, 2012. *EVE - Ente Vasco de la Energía. Estrategia 2020.* [Online]
Available at: http://www2.eve.es/web/Eve/files/53/53a00585-04b0-42e1-99e6-0543852d23cc.pdf

EVE, 2014 (a). Email from Felipe Perez, Research and Planning Department of EVE. *(9 April 2014).*

EVE, 2014 (b). Phone conversation with Felipe Perez, Research and Planning Department of EVE. (9 April 2014).

EVE, n.d. (a). *EVE - Ente Vasco de la Energía. La energía. Diccioario. Biomasa.* [Online]
Available at: http://www.eve.es/Aula-didactica/Hiztegia.aspx?id=I12637&term=biomass&terminoEstado=biomasa&fuzzyEstado=True&idiomaEstado=es&arloaEstado=biomasaren-energia&busquedaTerminoEstado=True&tipoBusqueda=terminoak#tabs-1
[Accessed 27 Mach 2014].

EVE, n.d. (b). *EVE - Ente Vasco de la Energía. La energía. Diccionario. Energía Solar.* [Online]
Available at: http://www.eve.es/Aula-didactica/Hiztegia.aspx?terminoEstado=energ%C3%ADa%20solar&idiomaEstado=es&arloaEstado=cualquiera&fuzzyEstado=True&busquedaTerminoEstado=True&tipoBusqueda=terminoak&id=G08314&term=energ%C3%ADa%20solar#tabs-1
[Accessed 6 April 2014].

EVE, n.d. (c). *EVE - Entre Vasco de la Energía. Proyectos en desarrollo. Proyectos energéticos. DH Bolueta.* [Online]
Available at: http://www.eve.es/Proyectos-energeticos/Proyectos-en-desarrollo/DH-Bolueta.aspx
[Accessed 15 June 2014].

EVE, n.d. (d). *EVE - Ente Vasco de la Energía. About us.* [Online]
Available at: http://www.eve.es/Quienes-somos.aspx?lang=en-GB
[Accessed 6 March 2014].

Expansión, 2013. *Expansión.com. Portada. Empresas. Energía. El Congreso aprueba la nueva Ley Eléctrica y la oposición promete derogarla.* [Online]
Available at: http://www.expansion.com/2013/12/19/empresas/energia/1387473644.html
[Accessed 15 April 2014].

Fernández, A., 2014. *Andrés Fernández is a building engineer of Abadiño's town council* [Interview] (12 June 2014).

FOREST, n.d.. *Tipperary Energy Agency.* [Online]
Available at: http://tea.ie/wp-content/uploads/2010/11/Forest-Specifiers-Guide_Ireland-Annexe-v11.pdf
[Accessed 20 March 2014].

Francescato, V., Antonini, E. & Bergomi, L. Z., 2008. *AEBIOM - European Biomass Association.* [Online]
Available at: http://www.aebiom.org/IMG/pdf/WOOD_FUELS_HANDBOOK_BTC_EN.pdf
[Accessed 2 July 2014].

Fundación FOESSA & Cáritas, 2013. *Cáritas Española. Publicaciones. Análisis y perspectivas.* [Online]
Available at:
http://www.caritas.es/imagesrepository/CapitulosPublicaciones/4551/Desigualdad%20y%20derechos%20sociales.%20Versi%C3%B3n%20digital.pdf
[Accessed 16 July 2014].

Ganaderia Familiar de Limousin, n.d.. *Beizama Abrupta.* [Online]
Available at: http://arruti.galeon.com/productos738899.html
[Accessed 19 July 2014].

Garmendia, B., 2014. Begoña Garmendia is the Mayor of Beizama. [Interview] (11 June 2014).

Gomez, B., 2012. *Bilbao en construcción! Masterplan de Zorrozaurre: Aprobado el Plan Espcial Definitivo.* [Online]
Available at: http://bilbaoenconstruccion.com/2012/01/26/masterplan-de-zorrozaurre-aprobado-el-plan-especial-definitivo/
[Accessed 15 June 2014].

Gonzalez Perez, A., 2012. Especial biomasa forestal: Las tendencias solidas de la biomasa sólida de aquí a 2020. *Foresta,* 5 July, Issue 53, pp. 8-11.

Govierno Vasco, 2012. *euskadi.net - El portal de las administraciones vascas. Ayudas a la promoción y desarrollo de las zonas rurales (Programa Erein).* [Online]
Available at: http://www.euskadi.net/r33-2288/es/contenidos/ayuda_subvencion/2563/es_4840/erein2.html
[Accessed 9 June 2014].

Grualba, O. & Pennese, C., 2014. *Presentation. Arquitectura, calidad de vida y participación..* Ekoliderrak 2013/2014. Donostia.

Grundahl, L. et al., 2013. *Aalborg Universitet. The Project Library.* [Online]
Available at: http://projekter.aau.dk/projekter/files/72409676/Group_B2_8_final.pdf
[Accessed 11 July 2014].

Hargassner, n.d.. *Hargassner. Preguntas frecuentes. ¿Cuándo es necesario un depósito de inercia?* [Online]

Available at: http://www.hargassner.es/faqcategories/
[Accessed 12 July 2014].

IDAE & MINETUR, 2010. *Ministerio de Industria, Energía y Turismo. Energías Renovables.* [Online]
Available at:
http://www.minetur.gob.es/energia/desarrollo/EnergiaRenovable/Documents/20100630_PANER_Espanaversion_final.pdf
[Accessed 28 March 2014].

IDAE, 2011 (a). *IDAE - Instituto para la Diversificación y Ahorro de la Energía. Noticias.* [Online]
Available at:
http://www.idae.es/index.php/mod.documentos/mem.descarga?file=/documentos_Informe_SPAHOUSEC_ACC_f68291a3.pdf
[Accessed 16 March 2014].

IDAE, 2011 (b). *IDAE - Instituto para la Diversificación y Ahorro de la Energía. Energías Renovables.* [Online]
Available at: http://www.idae.es/uploads/documentos/documentos_11227_PER_2011-2020_def_93c624ab.pdf
[Accessed 28 March 2014].

IDAE, 2011 (c). *IDAE - Instituto para la Diversificación y Ahorro de la Energía.* [En línea]
Available at:
http://www.idae.es/index.php/mod.documentos/mem.descarga?file=/documentos_11905_PAEE_2011_2020._A2011_A_a1e6383b.pdf
[Último acceso: 11 March 2014].

IDAE, 2011 (d). *IDAE - Instituto para la Diversificación y Ahorro de la Energía.* [Online]
Available at:
http://www.idae.es/index.php/mod.documentos/mem.descarga?file=/documentos_11905_PAEE_2011_2020._A2011_A_a1e6383b.pdf
[Accessed 11 March 2014].

IDAE, 2014. *IDAE - Instituto para la Diversificación y el Ahorro de la Energía. Publicaciones. Precios energéticos.* [Online]
Available at:
http://www.idae.es/uploads/documentos/documentos_Tarifas_Reguladas_2ecbeac0.pdf
[Accessed 28 March 2014].

IEA & Danish Technological Institue, 2012. *Danish Energy Agency.* [Online]
Available at: http://www.ens.dk/sites/ens.dk/files/undergrund-forsyning/vedvarende-energi/bioenergi/analyse-bioenergi-danmark/temamoeder/Market%20and%20Price%20Projection%20for%20Wood%20Pellets_Wolfgang_Stelte_DTI.pdf
[Accessed 16 March 2014].

IGN, n.d.. *IGN - Instituto Geográfico Nacional.* [Online]
Available at:
http://www.ign.es/espmap/figuras_industria_bach/pdf/Industria_Fig_01_texto.pdf
[Accessed 6 March 2014].

INE, 2009. *INE - Instituto Nacional de Estadística. Población, superficie y densidad por municipios. Vizcaya.* [Online]
Available at:
http://www.ine.es/jaxi/tabla.do?path=/t43/a011/a1998/densidad/a2009/l0/&file=t10081.px&

type=pcaxis&L=0
[Accessed 15 June 2014].

INE, 2014 (a). *INE - Instituta Nacional de Estadística.* [En línea]
Available at: http://www.ine.es/daco/daco42/daco4211/epa0413.pdf
[Último acceso: March 2014].

INE, 2014 (b). *INE - Instituto Nacional de Estadística. Demografía y población. Padrón. Población por municipios.Cifras oficiales de población resultantes de la revisión del Padrón municipal a 1 de enero de 2013. Bizkaia.* [Online]
Available at:
http://www.ine.es/jaxi/tabla.do?path=/t20/e260/a2013/l0/&file=mun48.px&type=pcaxis&L=0
[Accessed 11 March 2014].

INE, 2014 (c). *INE - Instituto Nacional de Estadística. Demografía y población. Padrón. Población por municipios. Cifras oficiales de población resultantes de la revisión del Padrón municipal a 1 de enero de 2013. Gipuzkoa.* [Online]
Available at:
http://www.ine.es/jaxi/tabla.do?path=/t20/e260/a2013/l0/&file=mun20.px&type=pcaxis&L=0
[Accessed 15 June 2014].

INE, 2014 (d). *INE - Instituto Nacional de Estadística. Cálculo de variaciones del Indice de Precios de Consumo (sistema IPC base 2011).* [Online]
Available at:
http://www.ine.es/varipc/verVariaciones.do?idmesini=2&anyoini=2005&idmesfin=2&anyofin=2014&ntipo=1&enviar=Calcular
[Accessed 1 March 2014].

INE, n.d.. *INE - Instituto Nacional de Estadística. Cifras de población y censos demográficos. Series históricas de población.* [Online]
Available at: http://www.ine.es
[Accessed 5 March 2014].

Jefatura de Estado, 2013 (a). *BOE - Agencia Estatal Boletín Oficial del Estado.* [Online]
Available at: https://www.boe.es/boe/dias/2013/12/27/pdfs/BOE-A-2013-13645.pdf
[Accessed 27 March 2014].

Jefatura de Estado, 2013 (b). *BOE - Agencia Estatal Boletín Oficial del Estado.* [Online]
Available at: https://www.boe.es/boe/dias/2013/07/13/pdfs/BOE-A-2013-7705.pdf
[Accessed 01 April 2014].

kapelbi, n.d.. *EVE - Ente Vasco de la Energía.* [Online]
Available at: http://www.eve.es/CMSPages/GetFile.aspx?guid=452fe37b-fb77-4f04-bce2-11cf223b1f45
[Accessed 9 June 2014].

Laws, K. & McLeod, R., n.d.. *System Dynamics Society.* [Online]
Available at:
http://www.systemdynamics.org/conferences/2004/SDS_2004/PAPERS/220MCLEO.pdf
[Accessed 15 June 2014].

Ledec, R., 1987. Neoclassical economics and principles of sustainable development. *Ecological Modelling,* 38(1987), pp. 19-46.

Leen Kuan Yew World City Prize, 2010. *Leen Kuan Yew World City Prize. Laureates. Prize Laureates. 2010 Prize Laureate: Bilbao City Hall.* [Online]
Available at: http://www.leekuanyewworldcityprize.com.sg/laureate_bilbao.htm
[Accessed 30 June 2014].

Lefcovich, M., 2006. *deGerencia.com. Superando la resistencia al cambio.* [Online]
Available at: http://www.degerencia.com/articulo/superando_la_resistencia_al_cambio
[Accessed 28 May 2014].

Maab, 2014 (a). *Durangoko Udala. Urbanismo y medio ambiente.* [Online]
Available at: http://www.durango-udala.net/portalDurango/RecursosWeb/DOCUMENTOS/1/1_6576_3.pdf
[Accessed 4 February 2014].

Maab, 2014 (b). Meeting with Ángel M. Cea Suberviola (Maab). Bilbao. (25 February 2014)

Martí Scharfhausen, F., 2009. *ANEEL - Agencia Nacional de Energía Eléctrica.* [Online]
Available at:
http://www.aneel.gov.br/arquivos/PDF/Fernando%20Marti_Jun09_AneelSeminar.pdf
[Accessed 15 April 2014].

Microsoft Office, n.d.. *Microsoft Office. Soporte. ¿Qué es Excel?* [Online]
Available at: http://office.microsoft.com/es-es/excel-help/que-es-excel-HA010265948.aspx
[Accessed 19 May 2014].

MINETUR, 2008. *BOE - Agencia Estatal Boletín Oficial del Estado.* [Online]
Available at: http://www.boe.es/boe/dias/2008/12/31/pdfs/A52672-52685.pdf
[Accessed 27 March 2014].

MINETUR, 2012. *BOE - Agencia Estatal Boletín Oficial del Estado.* [Online]
Available at: https://www.boe.es/boe/dias/2012/04/26/pdfs/BOE-A-2012-5527.pdf
[Accessed 2 April 2014].

MINETUR, 2013. *BOE - Agencia Estatal Boletín Oficial del Estado.* [Online]
Available at: http://www.boe.es/boe/dias/2013/08/03/pdfs/BOE-A-2013-8561.pdf
[Accessed 16 July 2014].

MINETUR, 2014 (a). *Ministerio de Industria, Energía y Turismo. Energía.* [Online]
Available at: http://www.minetur.gob.es/energia/es-ES/Documents/Energia_en_Espana.pdf
[Accessed 26 March 2014].

Ministerio de Vivienda, 1977. *BOE - Agencia Estatal Boletín Oficial del Estado.* [Online]
Available at: http://www.boe.es/boe/dias/1977/07/09/pdfs/A15443-15444.pdf
[Accessed 10 March 2014].

Mosquera, P., 2013. *Energías Renovables - El periodismo de las energías limpias. Panorama. La mayoría de la oposición se compromete a derogar la reforma eléctrica.* [Online]
Available at: http://www.energias-renovables.com/articulo/la-mayoria-de-la-oposicion-se-compromete-20131219
[Accessed 15 April 2014].

NVI Solar, n.d.. *NVI Solar. Catalog. Articles. Which type of solar collector is best for me?* [Online]
Available at: http://www.nvisolar.com/catalog/article_info.php/which-type-of-solar-collector-is-best-for-me-a-2
[Accessed 5 July 2014].

Observa el Mercado Eléctrico, 2014. Email from Observa el Mercado Eléctrico. (26 February 2014)

OMIE, 2014. *OMIE. Resultados del mercado.* [Online]
Available at: http://www.omie.es/files/flash/ResultadosMercado.swf
[Accessed 20 March 2014].

OPEN DATA EUSKADI, 2014. *OPEN DATA EUSKADI. Catálogo de datos. Meterología.* [Online]
Available at: http://opendata.euskadi.net/w79-resformx/es?r01kQry=tC:euskadi;tF:opendata;tT:ds_ayudas_subvenciones,ds_contrataciones,ds_anuncios_contratacion,ds_arbitrajes_denuncias_reclamaciones,ds_premios_concursos,ds_multas_sanciones,ds_procedimientos_otros,ds_autor
[Accessed 3 February 2014].

Ortega, E. & Peñalosa, J., 2012. *Banco de España.* [Online]
Available at:
http://www.bde.es/f/webbde/SES/Secciones/Publicaciones/PublicacionesSeriadas/DocumentosOcasionales/12/Fich/do1201.pdf
[Accessed 10 March 2014].

Oxford Economics, Biomass Energy Centre, Forest Research, 2011. *GOV.UK.* [Online]
Available at:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48059/1464-aea-2010-uk-and-global-bioenergy-report.pdf
[Accessed 28 March 2014].

Perez de Lema, M., 2012. Desarrollo de los District heating en España. *Energética XXI,* Sept 2012(124), pp. 60-62.

Photovolcatic Solar Panels, 2013. *How to find the best solar panel angle or tilt angle.* [Online]
Available at: http://solarpanelsphotovoltaic.net/find-best-solar-panel-angle-tilt-angle/
[Accessed 16 July 2014].

PRC Bouwcentrum International, 2011. *European Commission. Enterprise and Industry. The Lead Market Initiative (LMI) and sustainable construction: Screening of national building regulations.* [Online]
Available at: http://ec.europa.eu/enterprise/sectors/construction/studies/national-building-regulations_en.htm
[Accessed 10 March 2014].

REE, 2014. Email from Red Eléctrica Española (REE), TSO. (2 April 2014)

Romero, C., 2014. *Presentation. Platafaforma por un nuevo modelo energético..* Berdeago 2014. Durango. Cote Romero is one of the representatives of the Spanish platform for a new energy model and the director of Ecooo.

Ruesga, S. M., 2013. Para entender la crisis económica en España. El círculo vicioso de la moneda única y la carencia de un modelo productivo eficiente.. *Economía Unam,* 10(28), pp. 70-94.

Ruiz Luna, R., 2011. *Universidad Carlos III de Madrid.* [Online]
Available at: http://e-archivo.uc3m.es/bitstream/handle/10016/12118/PFC_Raul_Ruiz_Luna.pdf?sequence=1
[Accessed 26 March 2014].

Skogerbø, E., 2011. *UIO - Universitetet i Oslo.* [Online]
Available at:
http://www.uio.no/studier/emner/hf/imk/MEVIT4800/h11/undervisningsmateriale/MEVIT4800%202011_2_250811.ppt.pdf
[Accessed 11 July 2014].

Spanish Goverment, 1978. *BOE - Agencia Estatal Boletón Oficial del Estado.* [Online]
Available at: https://www.boe.es/boe/dias/1978/12/29/pdfs/A29313-29424.pdf
[Accessed 11 July 2014].

Tirado Herrero, S., López Fernández, J. & Martín García, P., 2012. *Pobreza Energética en España. Potencial de generación de empleo derivado de la rehabilitación energética de viviendas,* Madrid: Asociación de Ciencias Ambientales.

Town council & Maab, 2014 (a). Meeting with Igor Zorrakin (town council), Jorge Mallagarai (Maab) and Ángel M. Cea Suberviola (Maab). Durango (4 February 2014)

Town council & Maab, 2014 (b). Meeting with Igor Zorrakin (town council), Aitor Larruzea (town council) and Jorge Mallagarai (Maab). Durango (9 May 2014)

Trier, D., 2012. *SDH - Solar District Heating.* [Online]
Available at: http://www.solar-district-heating.eu/Portals/0/Factsheets/SDH-WP3_FS-7-1_SolarCollectors_version3.pdf
[Accessed 20 April 2014].

TÜV Rheinland DIN CERTCO, 2013. *The Solar Keymark Database. Collector Certificates.* [Online]
Available at: http://www.dincertco.de/logos/011-7S516%20F.pdf
[Accessed 15 April 2014].

Udalsarea 21, n.d.. *Udalsarea 21 - Red vasca de municipios hacia la sostenibilidad. ¿Qué es Udalsarea 21?* [Online]
Available at: http://www.udalsarea21.net/paginas/ficha.aspx?IdMenu=17d05e9d-8396-438d-9530-d4a94ea60184
[Accessed 6 March 2014].

University of Wisconsin, n.d.. *University of Wisconsin - Milwaukee. Resistance to Change.* [Online]
Available at: https://www4.uwm.edu/cuts/bench/change.htm
[Accessed 28 May 2014].

Unknown, 2010. *wikipedia. Aramaio. Ibarra elurtuta.* [Online]
Available at: http://eu.wikipedia.org/wiki/Aramaio
[Accessed 19 July2014].

Urresti, A., 2014. *Mugatik - Desde la frontera. El mercado eléctrico, empieza el truco del trilero.* Aitor Urresti teaches at Basque University. He is an engineer spesialized in renewable energies and energy efficiency.
[Online]
Available at: http://mugatik.wordpress.com/2014/01/10/el-mercado-electrico-empieza-el-truco-del-trilero/
[Accessed 24 March 2014].

Visesa, 2014. Email from Visesa. (3 June 2014)

Appendix

Appendix A - Interview model

GENERAL DESCRIPTION

Town name: Inhabitants:
Analysed area name: Inhabitants:

The district heating system...

 replaces former/current heating system is built for new buildings

If replacement project,

what heating system does it replace: individual or collective?
what technology and energy source is/was used in the former/current system?

What are main local energy resources?

TECHNICAL AND ECONOMIC ASPECTS OF THE DISTRICT HEATING SYSTEM

Technical data:

- Area [m2] or amount of buildings
- Consumer types
- Amount of consumers
- Approximate annual heat demand
- Energy source and technology
- Network length

Economic data:

- Investment
- Running costs/Annual expenses
- Savings in comparison to replaced system

PROJECT MOTIVATION AND PROMOTERS
When did the project start?
Who was the project initiator?
What are the reasons that motivated this project?

PROJECT DEVELOPMENT
What alternatives are analysed in terms of technology, economy, ownership model...? Which are approved and which dismissed? Why?
When did other stakeholders get involved in the project? (experts, town council, town residents...)
Did you face any problem during project development?

RESIDENTS' PARTICIPATION AND POINT OF VIEW
What is residents' role in the project and level of participation?
What decisions have been made or will be made by householders?
What is householders' point of view? What are their fairs and concerns? What do they value positively of the project?
Have you found any resistance from householders? What kind and why? How did you solve it?

MADE DECISION *(only for cases where a decision has already been made)*

When was final decision made?
What was the final decision?
If implementation was decided,

- what technology and energy source was chosen?
- who manages the system?
- who has to cover investment? and running costs?
- did you or householders get any subsidies? if so, from whom and what percentage of the investment did it account for?
- what ownership model is applied?
- when did construction work finished?

SYSTEM PERFORMANCE AND CONSUMERS OPINION AFTER IMPLEMENTATION *(only for cases where implementation was decided and has already been done)*

How does the system perform technically, in terms of management, etc?
What is consumers' opinion? What is town council's? And what is other residents' opinion?
Are there any plans for future expansion of the district heating system?

RECOMMENDATIONS
Based on your experience, what would be your advice for similar project developments in the Basque Autonomous Community?