Linköping University | Department of Management and Engineering
Bachelor's thesis, 12 credits| Bachelor's programme
Spring 2020| LIU-IEI-TEK-G--20/01837—SE

District Heating and Cooling, analysis and comparison with traditional methods

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Abstract

One of the main reasons for the damage that humans are causing to the environment is the energy production sector. Thus, society should find manners to develop its life with lower energy use and the energy generation should be carried out respectfully.

This project aims to compare the heating and cooling methods used in Sweden and Spain, focusing on the situation in Linköping, where a District Heating and Cooling network is used.

Swedish situation will be studied by District Heating and Cooling technology integrated with the Combined Heat and Power method, using municipal waste as fuel, as it happens in Linköping. For the Spanish situation, the most used methods according to the national statics will be analyzed. The aim of this report is to determine whether using large-scale heat and cool production methods leads to better energy efficiencies and less environmental impact.

The District Heating and Cooling system will be analyzed using the information in the book by Frederiksen and Werner and the data that Tekniska Verken has kindly provided by individual communication. For the heating and cooling systems used in Spain, different sources have been used.

In this project, the exigent emission's limits and the control measures of the large-scale production methods are pointed out. Besides, the noticeable power losses in the District Heating and Cooling networks are estimated, although the efficiency advantages of using Combined Heat and Power in the generation process are also determined.

The large-scale heat and cool production systems raise as a wise way to harness the energy and to have reduced and controlled emission levels.

Acknowledgment

First of all, I would like to thank my supervisor Mariana Andrei for her support and advice for accomplishing the goals of this project, and my examiner Shahnaz Amiri for her final advice. Besides, I also would like to thank both University of Cantabria and Linköping's University, for their help so I can complete my studies at a foreign university.

Moreover, I would like to thank Tekniska Verken for its goodwill, providing me the information I asked them for, and solving the doubts I had.

Lastly, I would like to thank my family and friends, who have always been there to help me.

This project, and everything I will finally reach in my life, is thanks to you. Thank you very much.

Contents

1. Introduction

Heat and power energy supply are key for human life as we know it nowadays. The need for light and heating pushed humans to manage fire many years ago. Since then, power and heat generation have turned much more sophisticated and the demand grows bigger day by day. In fact, big energy use is tightly related to human development. Unluckily, not only both power and heat require complex infrastructure so humans can use them, but many harmful pollutants are produced during the generation, transport and consumption processes. Thus, it is a must for humanity to develop more efficient and respectful ways of dealing with the energy demanded. Despite big efforts are being carried out in the energy sector to reduce environmental impact, humanity is running out of time to save the only planet where we can live in. Luckily, society is getting more concerned and many governments are pushing green technologies.

In this context, many new technologies have been born during the last years. The different alternatives that exist to generate electricity in a more environmentally friendly way such as wind, solar, tidal, geothermal, etc. are popularly known. Nevertheless, society seems to be less concerned about how it is produced the heat we consume, even though it exists a big daily demand. Actually, there exist technologies that work for having a reliable, affordable and environmentally respectful heat consumption.

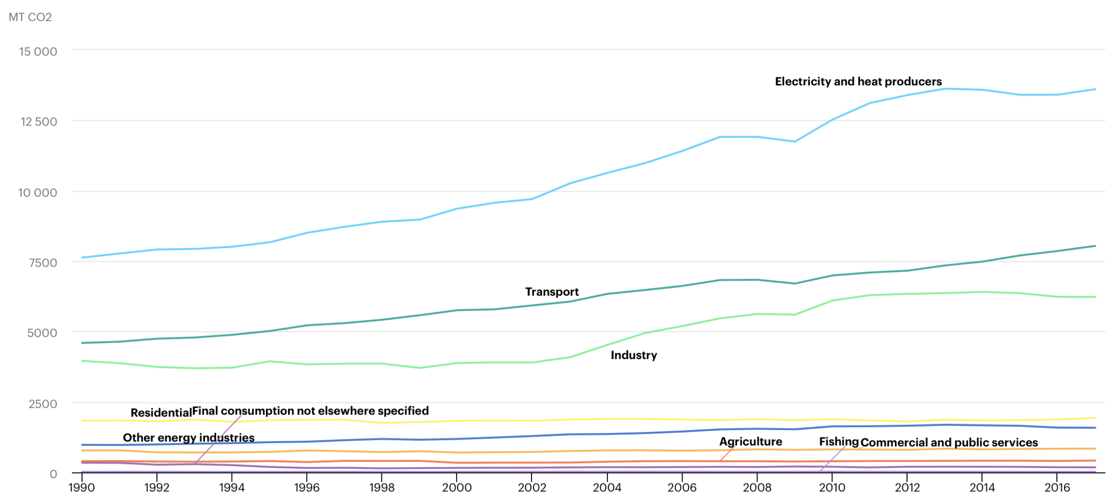

Figure 1: CO_2 in millions of tons emission by each sector for the entire world. Chart from the International Energy Agency. [1]

Assuming that CO_2 emissions is the main cause for greenhouse effect, the remarkable importance of the electricity and heat production sector on this phenomenon can be clearly appreciated in the figure 1. Consequently, the energy production sector must make an effort to reduce its increasing impact. The volume of greenhouse effect gases emitted to the atmosphere because of the energy sector depends on the amount of energy used. Thus, the less energy is produced, the fewer pollutants are emitted. Hence, it is key for environmental sustainability to reduce the enormous amounts of energy lost in form of heat during the whole process, since the more energy is harnessed, the less is needed to be supplied. In this regard, the two following figures are presented, where the difference between the energy supply and the energy use can be appreciated for the European Union.

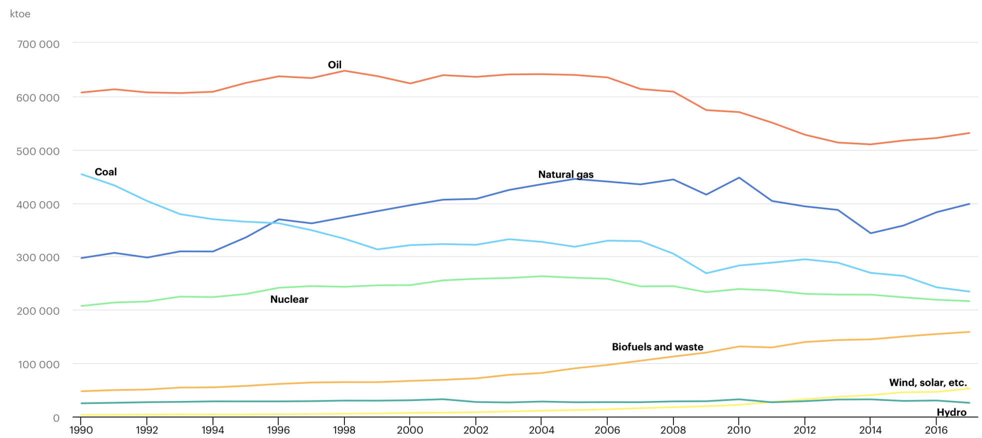

Figure 2: Energy generated by source, in equivalent tons of petrol for European Union. Chart from the International Energy Agency. [2]

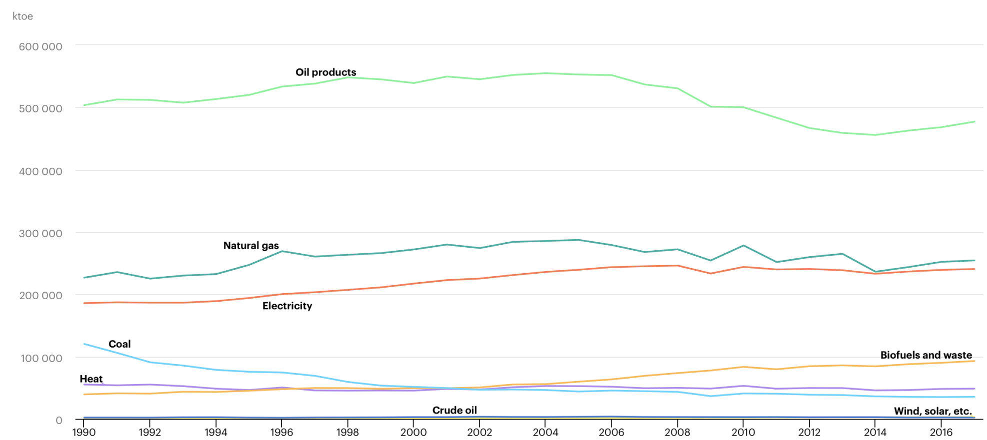

Figure 3: Energy used by source, in equivalent tons of petrol for European Union. Chart from the International Energy Agency. [3]

For instance, in 2017 the energy supply for the oil products is 531,133 ktoe [2] and the final use is

477,236 ktoe [3]. For natural gas the situation is very similar, as 398,384 ktoe are supplied [2] while 254,386 ktoe are used [3]. Moreover, according to the estimations by Frederiksen and Werner [4, p. 32] the real final use is less than half of the energy generated, due to other losses in the consumption process. In this context, using heat leftovers at any stage of the energy supply might be a good choice, so the whole process becomes more efficient.

Considering the cases of Spain and Sweden, the role of the electricity and heat producers in the gas emissions differs considerably, when compared with the global situation (figure 1). In Spain and Sweden, the energy sector is not as dominant in greenhouse emissions, although other differences can be appreciated between both countries.

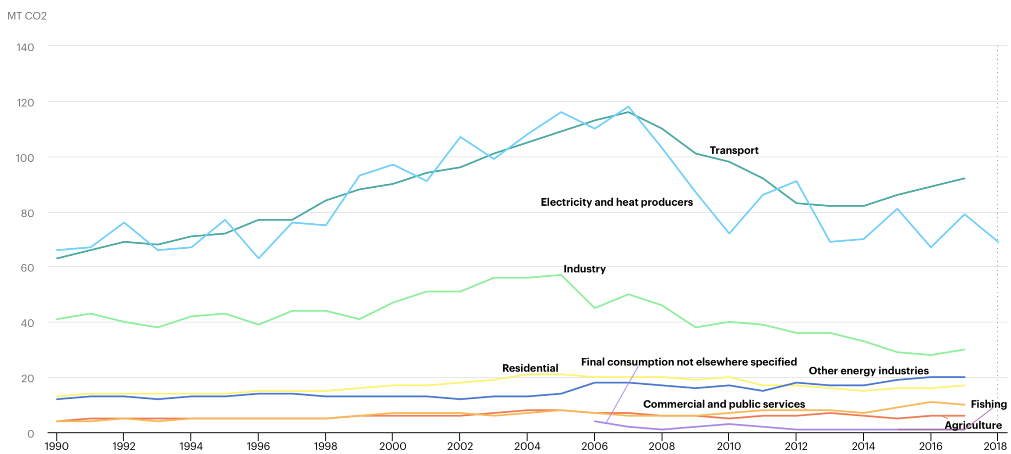

Figure 4: CO_2 in millions of tons emission by each sector in Spain. Chart from the International Energy Agency. [5]

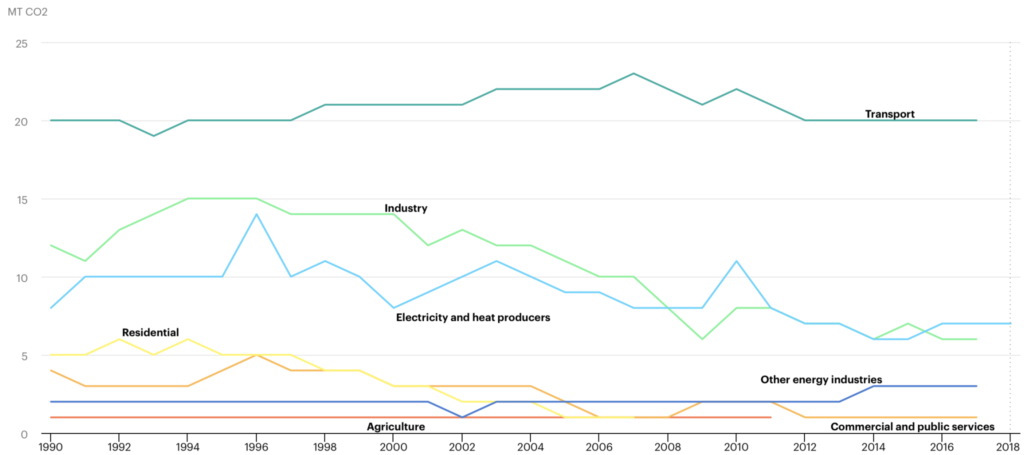

Figure 5: CO_2 in millions of tons emission by each sector in Sweden. Chart from the International Energy Agency. [6]

CO_2 emissions are growing neither in Spain nor in Sweden. Nevertheless, Sweden has achieved a better ratio of CO_2 emissions because of electricity and heat generation per capita:

Country	Population (millions)	CO_2 emissions (millions of tons) 2018	CO_2 tons per capita
Spain	47.1	69	1.46
Sweden	10.3	7	0.68

Table 1: CO_2 emission comparison for both countries. [5][6][7][8]

As the information in the chart includes data about electricity and heat generation, many different factors have been taken into account. Electricity generation has a major role in the emissions and it is key to understand the differences between both countries. In 2016 in Sweden, 90.25% of the electricity generation was carried out in nuclear, wind power and hydroelectric plants [9]. None of these methods produce any kind of greenhouse effect gases. In 2019 in Spain, 58.6% of the electricity generated was by methods that do not emit CO_2 to the atmosphere [10].

On the other hand, there is another characteristic that must be noted. The CO_2 emissions in the residential sector in Sweden (the yellow line in figure 5) are considerably lower than in Spain. CO_2 emissions in the residential sector are mainly because of the combustion of fossil fuels to generate heat [11]. In Spain in 2017, it was the reason for 8% of the total greenhouse effect emissions. If the intensive greenhouse effect gases producers are not considered, the residential sector involves 14% of the emissions of greenhouse effect to the atmosphere [12]. This difference between both countries is conditioned by a technology that is widely spread in Sweden, but which is barely know in southern countries such as Spain.

District Heating and Cooling (DHC) is a technology that seeks to provide heat and cooling supply to the consumer in a more efficient way compared to using the own production systems. Besides, resources that otherwise would be wasted or heat leftovers from the industry are used, so waste emissions are avoided and energy is more efficiently used. This DHC method has been used for more than 100 years and it is widely spread in Northern European countries, North America and Russia. It is an interdisciplinary technology, as it requires knowledge in combustion, thermodynamics, piping, marketing, and billing. Nowadays, there are around 8000 District Heating networks in Europe, North America, Russia, China, Korea, and Japan. As a result, around 600000 kilometers of pipes have been installed. However, District Cooling (DC) is not as common as District Heating (DH), it is mainly found in Europe, North America, and the Far East [4].

Several kinds of sources are used in the DHC process. Fortunately, those sources are able to produce 200 the nowadays DHC energy deliveries [13]. Moreover, heat and cooling demand will always be a reality, so there is no doubt that there is room for improving and spreading this technology.

Despite all the positive consequences that DHC can bring to our society, there are also some disadvantages that will be explained afterwards. In this introduction, the fact that this kind of technology requires a long-term way of thinking should be stood out. DHC systems need a big initial investment, so the complex infrastructure is built. Also, if waste incineration is used as source for generating heat, a very sophisticated recycling system is a must too. All in all, I find that countries that are struggling in economic difficulties or other kinds of problems will not be facing this kind of project in the short term.

The aim of this project is to compare the District Heating and Cooling system used in Sweden with with the commonly used own heating systems used in Spain by environmental impact and energy efficiency criteria. For that purpose, data from the different sources will be gathered and analyzed.

2. Background

2.1. Concept

District Heating and Cooling (DHC) is a technology to distribute heat and cool to a determined area from a particular place where they are generated. In DHC systems, local fuel and heat resources that otherwise would be wasted are used. This service seeks to satisfy the demand by better use of the energy sources that are already available. Due to the fact that DHC networks are limited to a relatively small land, a local heat and cooling supply market are created.

In other words, DHC distributes heat and cool preferably extracted from heat recycling processes or by burning non-fossil fuels, although fossil fuels might also be used. Thus, the goal of this technology is to obtain energy in a more environmentally friendly way than the methods that are commonly used nowadays, especially in southern countries, seeking to supply energy with lower primary energy input, by using local sources and avoiding dioxide carbon and other pollutant emissions. Moreover, energy producers and consumers are linked by a piping system.

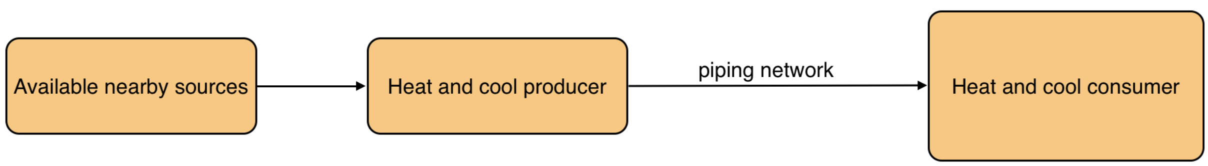

Figure 6: Simplified scheme of the agents taking part in District Heating and Cooling.

Both heat and cooling systems work in a similar way. As cool can be generated from heat by thermodynamic processes, they both have the same sources to be produced. However, differences may be appreciated since heat may be extracted from geothermal sources, meanwhile cold might be obtained from the deep of the cold seas, lakes or rivers.

Roughly explained, there are three main factors that appear in the DHC service. First of all, a heat and cool producer is needed. In these plants, fuel is burned, or heat leftovers are collected. On the other hand, consumers create a heat and cooling demand which must be fulfilled. These consumers might be private houses, public buildings or low temperature heating demand in the industry. However, this demand variates enormously depending on the place, the season of the year or the moment of the day. Lastly, there is a complex piping network that links the other two agents. Inside those pipes, heat and cool is widespread all over the area where DHC is working.

Regarding the heat and cool producer, the first requirement for DHC is to be able to extract heat from cheap sources. If this would not be possible, other methods would be economically a better choice for the consumer, since DHC requires an expensive piping installation. Thus, the source's costs must remain low, so this method is still competitive. There are five main ways to obtain heat for DHC networks [4]:

- Collecting heat from power plants: when heating a liquid to create steam to generate electricity, great amounts of heat used. This hot steam is used to heat the liquid which would be used for DHC. This method is called Combined Heat and Power (CHP) or cogeneration.
- Burning waste: this has multiple benefits for the environment, for instance, landfilling is partially avoided. This method takes place in Waste-to-Energy plants. This source might be also used as fuel for a Combined Heat and Power plant, as it happens in Linköping.
- Using heat leftovers from the industry.
- Obtaining heat from geothermal sources.
- Burning another kind of renewable sources or another kind of sources that are difficult to manage in small quantities such as wood, for example.

2.2. Market

Since energy is a commodity that may be generated, transported and consumed, a complex market is created in its surroundings so it can be commercialized. In this chapter, the heat and cool market will be analyzed.

For every kind of energy supplied, there are four factors which appear in the process. First of all, the primary sources where the energy will be extracted from. These sources are coal, wood, waste, nuclear sources, etc. Then, these sources are used in the energy industry in the central conversion plants. There, electricity or heat are generated or fuel is refined from the primary sources. Afterwards, the electricity is released to the electrical grid, heat is conducted by the piping network and fuels are distributed. Besides, energy might be also transformed in local conversion installations, where primary sources are used or energy from the energy industry is converted. Finally, the end consumer uses the energy that comes from the local conversion installation or from the central conversion plant [4, p. 30]. All these factors and their connection are represented in the following figure.

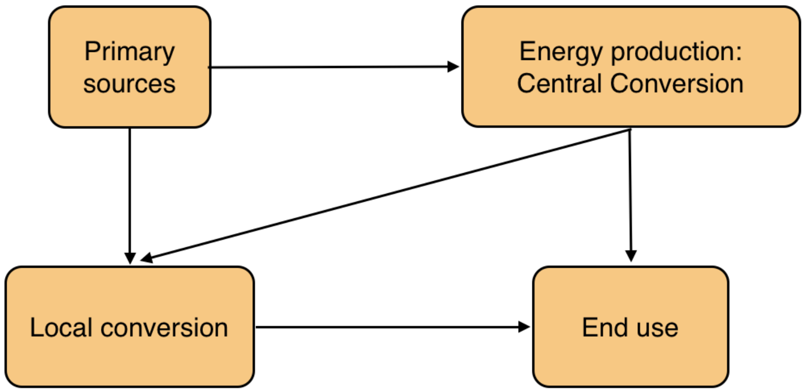

Figure 7: Agents in the energy sector.

As noted in the introduction of this project, several heat losses appear during the consumption process, since energy generation until its final use, and as a consequence, considerable amounts of money are lost. These heat losses are carried out by the agents that take place in the energy market. In order to obtain a better usage of the energy to reduce impact and to save money, DHC systems may be a good option to use the heat leftovers, so they can provide benefits. Furthermore, the fewer steps there are between the primary sources to the final use the less energy will be wasted. As a result, since DHC does not need local conversion, it seems to be a better option than other sources that have to be treated and then burned in a local conversion installation.

Nowadays heat generation in Europe is mostly carried out by fossil fuels in nearby boilers and most of the cool supply is covered with electric devices. However, it is remarkable the increasing tendency of use of renewables and biofuels sources. About the DHC share in European countries, in France, for instance, the share in the heat and the cool market is a 17% [14], and in Germany the share for residential sector reaches the 13.8% [15]. Nevertheless, DHC technology seems, in the first place, an economically efficient way to harness energy. However, the drawback that this technology has regarding energy losses is the fact that heat is lost in the piping systems when distributed.

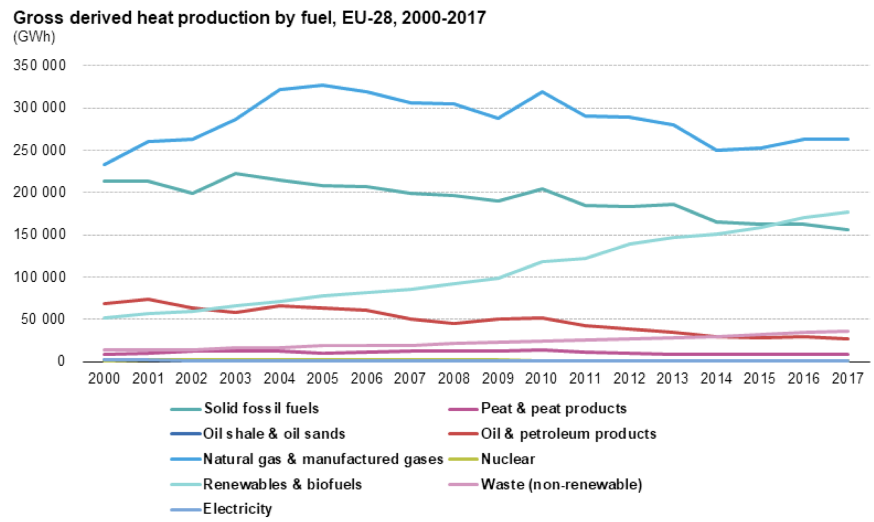

Figure 8: Heat generation by source in Europe. Chart from Eurostat. [16]

There are some countries located in northern Europe with a relatively high share of District Heating deliveries, such as Iceland (92%), Latvia (65%), Denmark (63%), Estonia (62%) and Lithuania (57%) [17]. Sweden also has a considerable District Heating share, as shown in the chart below.

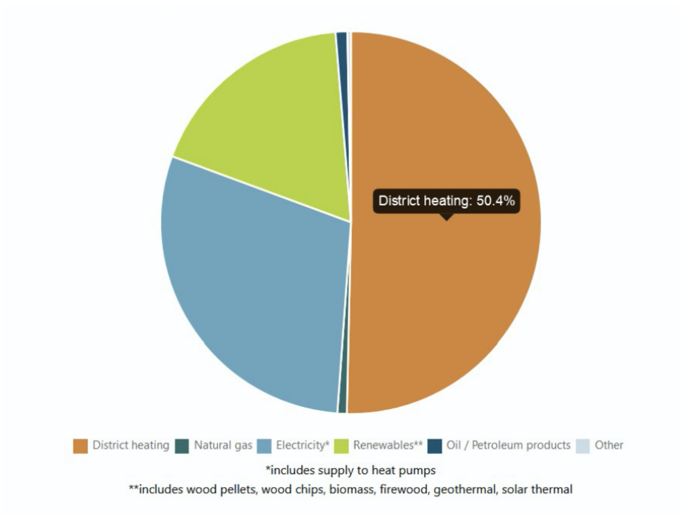

Figure 9: Share of energy sources used to fulfill the residential sector's demand in Sweden. Chart from euroheat.org. [18]

In Spain, as in other southern countries, DHC is a rare technology. Nowadays, 117,550 citizens are served by DH in Spain [19] (0.25% of the Spanish population). However, DHC is a rising technology in Spain, as it can be concluded from the increasing length of the piping system. In 2017, the piping length is Spain was about 600 kilometers, meanwhile in 2014 in Sweden, the distribution pipelines was 23,400 kilometers.

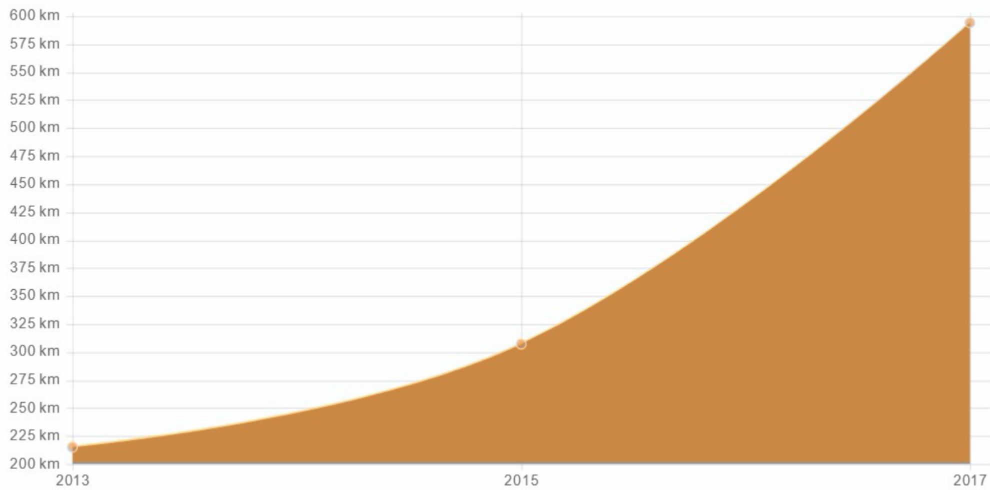

Figure 10: Piping system development in Spain from 2013 to 2017. Chart from euroheat.org. [19]

2.2.1. Heat demand

The heat supply must fulfill the existing demand, which can be divided into four different groups: residential, industrial, service sector and agricultural demand. In this section, the situations where DHC may be an alternative will be pointed out.

Maybe the most common use of District Heating is for having a warm ambient to live, to work, to study, etc. Space heating is about supplying heat so people can develop their life in comfortable conditions. To achieve this, heat must be added to a particular place, so the desired temperature is reached, without regarding the outdoors' weather conditions. Moreover, the heat losses that occur in any kind of building have to be compensated too. The heat balance in a building is [4, p. 32]:

$$Q_{demanded} = Q_{leaving} + Q_{ventilation} - Q_{generated} \quad (J) \tag{1}$$

$\mathbf{Q}_{demanded}$ is the amount of heat that balances the ingoing and outgoing heat flows. If the balance is null, the temperature will remain constant.

$\mathbf{Q}_{leaving}$ is the heat that flows out of the building. It is tightly related to the walls, doors and windows insulation.

$\mathbf{Q}_{ventilation}$ is the heat that leaves the building when a door or window is opened to change the polluted air in a chamber for new fresh air from outdoors.

$\mathbf{Q}_{generated}$ is the involuntary heat generation as a result of electricity utilisation or generated by humans because of their metabolism. For instance, incandescent bulbs emit considerable amounts of heat while working because of their low efficiency, or the heat released by the oven when taking out the food may be considered as well. All this heat generated is a heat that does not have to be supply by the heating system.

Balance temperature is an important factor to define not only in space heating but in space cooling too. It is the outdoors temperature that produces the heat equilibrium between the heat flow leaking out the building and flow generated inside, so the heat balance is zero. Thus, there is no need neither to add nor extract heat. Besides, the comfort temperature must be noted too. These parameters depend on each part of the world and each person's criteria. However, the average value in Spain for comfort temperature is 23-25 C in summer and 21-23 C during winter. [20]

Another heat demand which is typically fulfilled by DHC systems is the domestic hot water supply. This water is used for human consumption as it is drinking water, but it is also used for other domestic uses such as personal hygiene uses, in sinks, toilets, or the shower, for instance. The heat power demanded to fulfill the demand can be determined as it follows [4, p. 54]:

$$P_{demanded} = \dot{m} \cdot c_{H_2O} \cdot (T_h - T_c) \quad (W) \tag{2}$$

$P_{demanded}$ is the heating power demanded by the domestic water supply.

$\dot{m}$ is the water mass flow required.

c_{H_2O} is the specific heat capacity of water.

$T_h - T_c$ is the difference of temperatures between the desired final temperature (which is typically 55º) and the temperature of the water where it is obtained. These temperatures tend to remain constant all over the year.

The domestic hot water supply varies during the day. Since it is used for cooking, the peak hours are before meals. During the rest of the day, the demand is constant, except for the nights, when the demand is significantly low. These abrupt changes on the demand imply a challenge for the heating system, as it must be able to face them almost immediately.

Another important agent in heat energy use is the industry. The demand can be divided into three groups, regarding the temperature needed. Firstly, some industries demand a very high temperature (more than 400º) for their processes. This happens for the metal or the ceramic industry, and they are normally supplied by themselves using hot flue gases, electrical induction, etc. Secondly, other industries demand heat at 100º-400º for evaporation in drying processes, for instance. In this case, the heat supply can be carried out using hot steam or heat from Combined Heat and Power plants. Finally, temperatures lower than 100º are commonly used in the alimentary sector, or for space heating in the industry environment. In this case, the heat can be supply by the DHC system or Combined Heat and Power plants, and the heat leftovers can be harnessed as well. For the other two groups, heat can be recovered so it is used in DHC [4, p. 60].

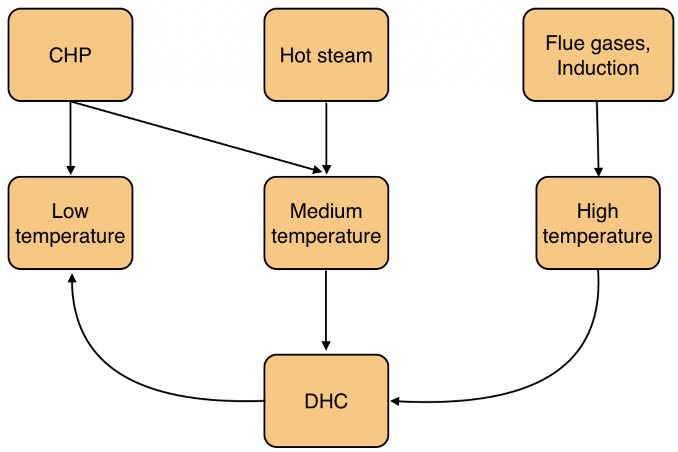

Figure 11: Scheme of the heat industry market regarding to temperature demanded.

Apart from the demands already noted, there are others that also require a significant consumption. Heating supply is also needed in outdoor places, such as sports stadiums, bus stops, or in streets or railways to avoid freezing. Heat is also used in the agricultural sector in the greenhouses. Besides, cold can be generated using heat as input for large absorption chillers. Moreover, DHC seeks to be an alternative to heating devices using electricity such as drying machines, as they also involve heat consumption [4, p. 62].

2.2.2. Cool demand

The cool demand is referred to the heat that is needed to extract from a chamber or a building so particular ambient conditions are achieved inside. The main cool demand is for space cooling in residential and service sector. Besides, its use is widely extended in the alimentary sector, as it is used to preserve food, in industrial processes as in cooling systems in computer rooms, and in other particular applications as in super cooling applications in laboratories. Most of the cooling supply is carried out by electric devices, which are only able to cool a particular room, they involve a considerable energy use as a result of their low efficiency, but their cost is relatively low. DC systems have a low operation costs although the initial inversion required is considerably high. These kinds of systems are recommended when there is a significant demand, for multiple chambers or big rooms. Northern and East European countries do not tend to have high cool demands specially in the residential sector because of the climate in these zones. Nevertheless, China, United States of America and Mediterranean countries demand significant cool supply for the residential and the service sector.

2.3. Cool generation

The procedure for generating heat is by combustion of nearby fuels or heat collecting from industrial processes, as it has already been pointed out. Nevertheless, the methods used from generating cool for District Cooling must be marked too.

For extracting heat from a cold body and sending it to a hot body energy is needed. There are several cooling processes regarding its working principles, but here attention will be paid on the three different processes used in Linköping. These processes are compression, absorption and free cooling.

Both compression and absorption processes are based on physical methods, where smartly using the changes of state (vaporization), cool is achieved without the need to constantly adding more refrigerant since it works in a closed system. Besides, they both require some kind of energy supply.

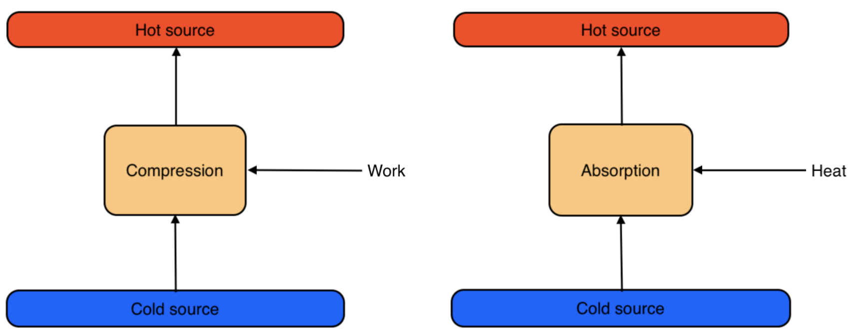

Figure 12: Energy flows in compression and absorption processes. Work is added to the system for compression and heat is added for absorption. Heat flows from the cold to the hot sources.

The compression method has the following thermodynamic scheme:

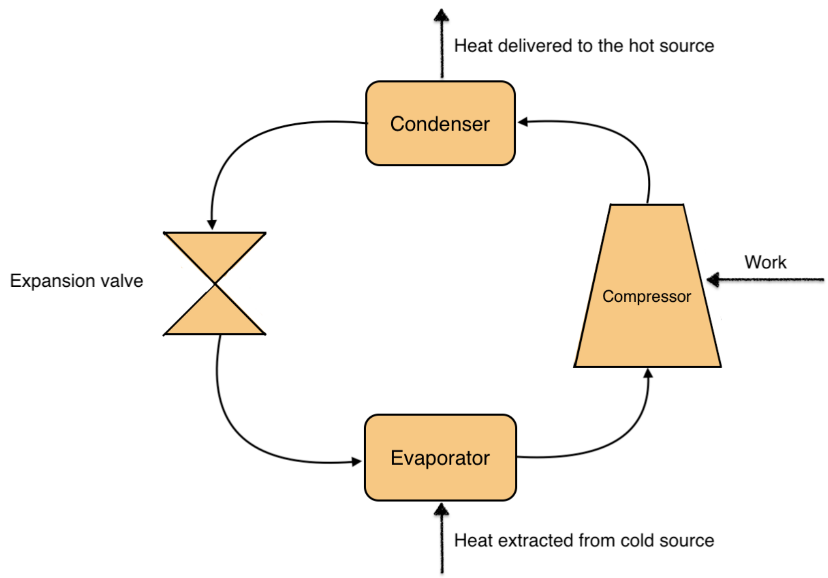

Figure 13: Compression method thermodynamic scheme.

This method is composed of four steps: compression, condensation, expansion, and evaporation. The refrigerant in gas state leaves the evaporator and gets to the compressor where its pressure and temperature increase. In the condenser, the gas turns into liquid, releasing heat during the process and reducing its temperature. Then, in the expansion valve, the liquid's pressure drops, and as a consequence, it turns into vapor by collecting heat from the evaporator's environment. For achieving better efficiencies some variations may be added, like using two compressors in a row with refrigeration in between, or using two evaporators, for instance. It must be noted that this method requires electric supply in the compressor. [21]

The thermodynamic cycle done by the refrigerant is represented in the following Molliere chart, where the horizontal axis represents the enthalpy in kJ/kmol and the vertical axis represents the pressure in bar.

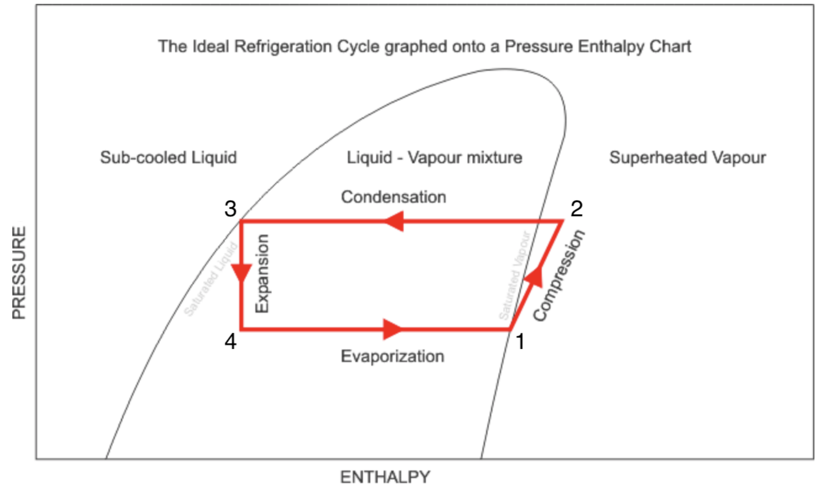

Figure 14: Mollier diagram where the compression process is represented. Chart from https://www.novar.com [22]

The heat and energy fluxes are represented by the changes of enthalpy on the Mollier diagram. The heat extracted from the camera where cool is being generated is the difference of enthalpy between situations 1 and 4. The energy supplied to the compressor is the enthalpy difference between 2 and 1. Lastly, the heat delivered is given by the change of enthalpy between 2 and 3. Knowing the energy flows, the performance of the cooling process can be determined by the COP (Coefficient of Performance).

$$COP = \frac{heat\,extracted}{energy\,supplied} = \frac{h_1 - h_4}{h_2 - h_1} \tag{3}$$

The maximum efficiency that can be achieved is given by the COP of the reversible Carnot cycle operating between the same temperatures.

$$COP_{max} = 1 - \frac{T_{cold}}{T_{hot}} \tag{4}$$

On the other hand, the absorption cooling has the following scheme:

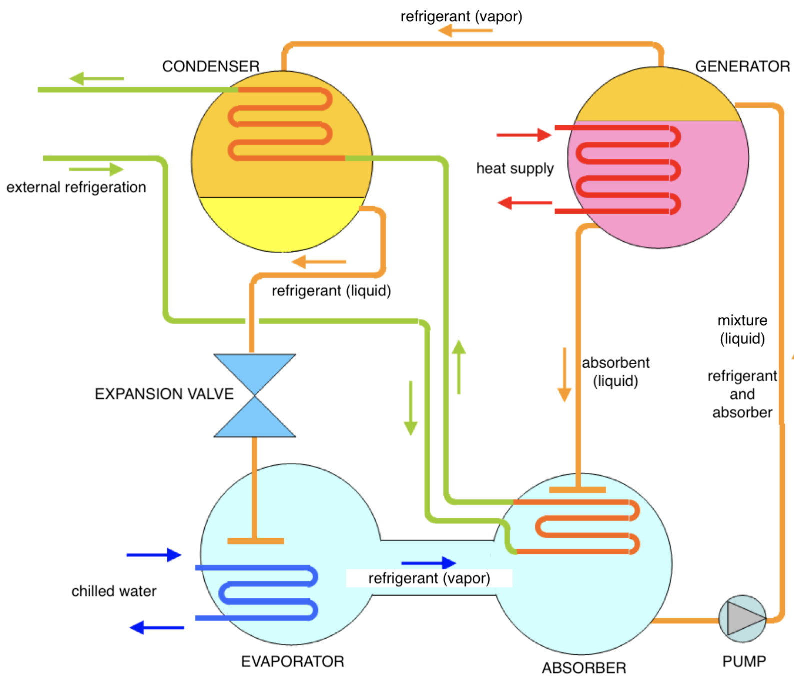

Figure 15: Absorption method thermodynamic scheme. Figure extracted from http://personales.unican.es. [21]

As it was stated before, heat supply is needed in the absorption cooling method. Besides, heat at an intermediate temperature (between the hot supply and the cold result) is released as leftover. The operational costs of the process are low as long as the heat source is cheaply obtained. As there few mobile parts, it does not involve problems with noise nor vibrations, and its maintenance costs are low. Two different fluids are required in this method: a refrigerant and an absorbent. In the past, harmful compounds for the ozone layer were used (HFC), and now the most common options are $NH_3 - H_2O$ and $LiBr - H_20$.

The process works as follows: the mixture of absorber and refrigerant gets in a liquid state to the generator, where heat is used to turn the refrigerant into vapor and send it to the condenser, while the absorbent (liquid) turns back to the absorber. In the condenser, the refrigerant is turned to liquid by applying external cooling. Then, the liquid refrigerant is expanded and turned into gas, so its pressure and temperature drop, and cold is generated. This cold is collected in the evaporator by the fluid aimed to chill. The refrigerant in a vapor state gets to the absorber, where it is cooled by the external cooling and mixed with the liquid absorbent. Lastly, the mixture is pumped back to the generator.

As a result, the only mobile part that requires energy supply is the pump that moves the mixture to the generator.

The COP in this refrigeration method is determined by taking into account the heat input required and the cold extracted from the liquid aimed to cool. Typical COP for commercial $LiBr - H_20$ is 0.7 meanwhile for $NH_3 - H_2O$ is 0.5. [21]

These kinds of installations are expensive and of considerable size. Thus, they are a good investment when they are supposed to work many hours a year and the heat source is achieved at a low cost.

Finally, the last cooling production method is free cooling. Unlike the other methods, there is no need to supply energy to achieve results. Instead, it is enough with an installation that allows the heat transfer between the liquid aimed to cool and the cold outside environment. Thus, this kind of system is installed in rivers, seas or beneath the earth, where cold water reservoirs are available. In order to obtain lower temperatures, it is common to build the installation in the depth of seas or lakes, where the water temperature is lower.

Examples of free cooling are found all over the world. In Stockholm, for instance, cool is collected for the District Cooling system from the sea or the cold outside air [23]. Another example is found in Cornell University, in the United States of America, where cool is extracted from the lake in the nearby of the campus, providing cool supply for 80 buildings, so the demand for space cooling, air conditioning for laboratories or computer rooms is fulfilled [24]. Moreover, free cooling can also be carried out by the storage of snow and then deliver its cooling potential, as it happens in the hospital of Sundsvall, in Sweden. [25]

Free cooling is a cool production method that does not require energy input, so it does not produce emissions of harmful particles to the environment at any stage. Nevertheless, it might involve negative consequences in the environment where cold is extracted as it involves a change of temperature of the place, and it may affect the living systems there. Besides, this kind of production is not reliable on its own, as the demand could be bigger than the extracting capacity, as it is limited by the medium's temperature. Hence, a compression or absorption chiller might be installed to reduce the temperature until the desired one. [4, p. 217]

2.4. Combined Heat and Power

Among the different alternatives that there exist to produce heat and cold for the District Heating and Cooling networks, Combined Heat and Power plants are a direct consequence of this technology's philosophy of harnessing the energy to the most. The already generated heat that otherwise would be wasted, is conducted so it can be used afterwards.

Combined Heat and Power is the method used in some power plants where the heat supplied to heat steam to move the turbine is also harnessed so it can be spread in the District Heating network. Of course, the heat obtained might be also used for other purposes in the same plant, or in other industries, for instance. This method is also called cogeneration.

Although it is a common technology in Sweden, it has a limited market share in the overall electricity production in the country.

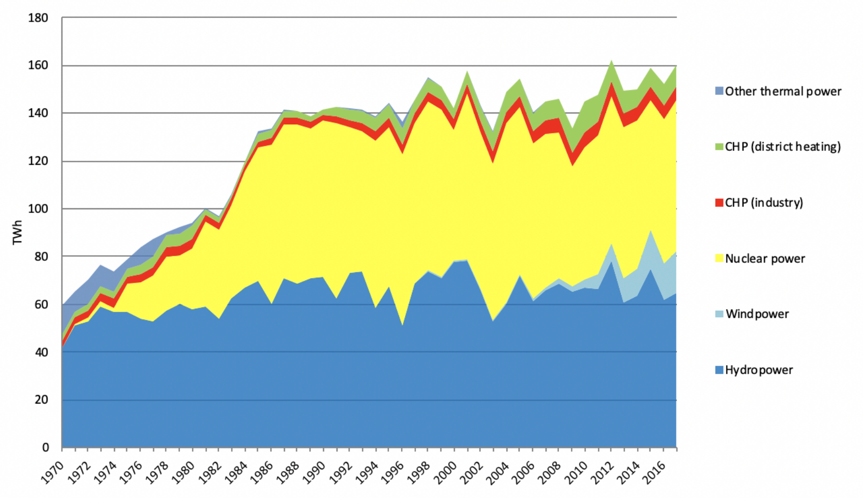

Figure 16: Net electricity generation in Sweden from 2017. Chart from the Swedish Energy Agency, Energy in Sweden, facts and figures (Excel) 2019. [26]

According to Frederiksen and Werner [4] the reason why Combined Heat and Power plants have a limited contribution in the overall electric supply is that nuclear and hydroelectrical generation are considerably settled in the country. As a result, these methods offer low prices for electricity, and in this context, it has been difficult for CHP generation to take place in this competitive market. Nevertheless, this technology has a remarkable importance in some cities, as it happens in Linköping.

2.4.1. Linköping

Linköping is located in southern Sweden and it is the capital of the region of Östergötland. Its population is growing each year and nowadays Linköping is the fifth largest city in Sweden with a population of 157,000 inhabitants [27]. As any developed city, there exists a considerable demand for electricity for the residential and industrial sectors that must be fulfilled. Moreover, because of its cold climate, remarkable heat supply is demanded especially during winters, and cold is required all over the year.

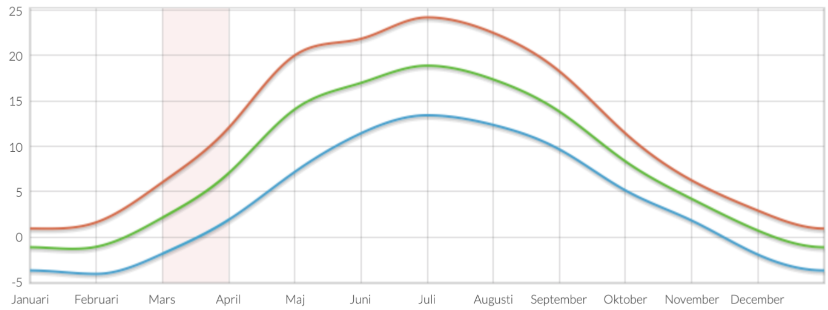

Figure 17: Average maximum temperature (red), average temperature (green) and average minimum temperature (blue) for each month in Linköping. Chart from www.vackertvader.se. [28]

To deal with these energy requirements, Linköping is making efforts for doing it in the most environmentally friendly way. To achieve this goal, Linköping and its associated enterprise Tekniska Verken have advocated for producing heat and power simultaneously in several CHP plants. Besides, among the different fuels that can be used, waste from human processes has been their main choice. As a result, a complex recycling system has been designed, where biomass waste is collected in green bags, which can be automatedly separated from other kinds of waste, so then it is carried by trucks and delivered to the different incineration plants in Linköping. Moreover, apart from supplying energy, biomass is used to produce biogas fuel and biofertilizer. In fact, public buses in Linköping are fed by biogas fuel. [29]

There are two incineration plants in Linköping. The largest one is Gärstadverket, in the north-east of the city, which supplies heat and power all over the year, and Kraftvärmeverket, in the east part of the city, near the train station.

Gärstadverket, consisting of five different chimneys, is the most modern one. This plant deals with 600,000 tons of waste each year as input fuel and it is able to supply heat by the District Heating network to 70,000 houses, and electricity to 15,000 houses [30]. Each chimney is connected to the different production installations in the plant, so each of them deals with a different amount of energy. The most recent installations built are 4 (2004) and 5 (2015) so the energy supply capacity has increased during the recent last years.

Chimney	1	2	3	4	5
Power (MW)	10	10	10	19	20
Steam (MW)	75	75	75	65	80

Table 2: Electric and steam power for District Heating and Cooling in MW for each chimney in Gärstadverket. Data provided by Tekniska Verken. [30]

Figure 18: Gärstadverket plant. Figure from www.wistbo.com. [31]

The Kraftvärmeverket incineration plant produces heat when the demand is bigger, so it gets to work when the temperature in Linköping is below 5^{o} C. Besides, it has a power capacity production from 10 up to 65 MW. Unlike the Gärstadverket's plant, other kinds of fuels are being burned in Kraftvärmeverket's plant. These fuels are renewable as wood waste and non-renewable, as oil. Each production installation using each type of fuel is linked to one of the three different chimneys in the plant [30].

Chimney	1	2	3
Steam (MW)	63	154	60
Fuel used	Wood waste	Oil	Wood waste, plastic reject and bark

Table 3: Steam power capacity used for District Heating and Cooling for each chimney, and the fuel used in Kraftvärmeverket. Data provided by Tekniska Verken. [30]

Figure 19: Kraftvärmeverket plant. Figure from Tekniska Verken 2020's presentation. [30]

About the second chimney, it is remarkable in the first place the considerable capacity it has. Nevertheless, it must be taken into account that oil has approximately 4 times the heating value of waste or 5 times the heating value of wood [30]. Moreover, as oil is a non-renewable source, research is being carried out in order to use bio-oil instead of oil. Bio-oil is a promising liquid fuel obtained from the pyrolysis fraction of biomass, a renewable source that Tekniska Verken is used to work with [32]. Moreover, Kraftvärmeverket's plant has a water heat storage tank with a capacity of up to 20,000 m3, and as a result, 1,000 MWh of heat can be stored.

Both plants collect heat that is spread in Linköping and some urban areas in the nearby in a piping system that nowadays is 500 kilometers long.

As a result of this production strategy, Linköping is now able to supply the heat enough for District Heating only with their own waste when the temperature is above 5^{o}, which is approximately from the second half of April until the end of September (figure 20). If the temperature is lower, renewable biomass sources are burned, and only when is needed because of lower temperatures, non-renewable sources are used. Besides, the total amount of electricity production in 2018 was 570 GWh.

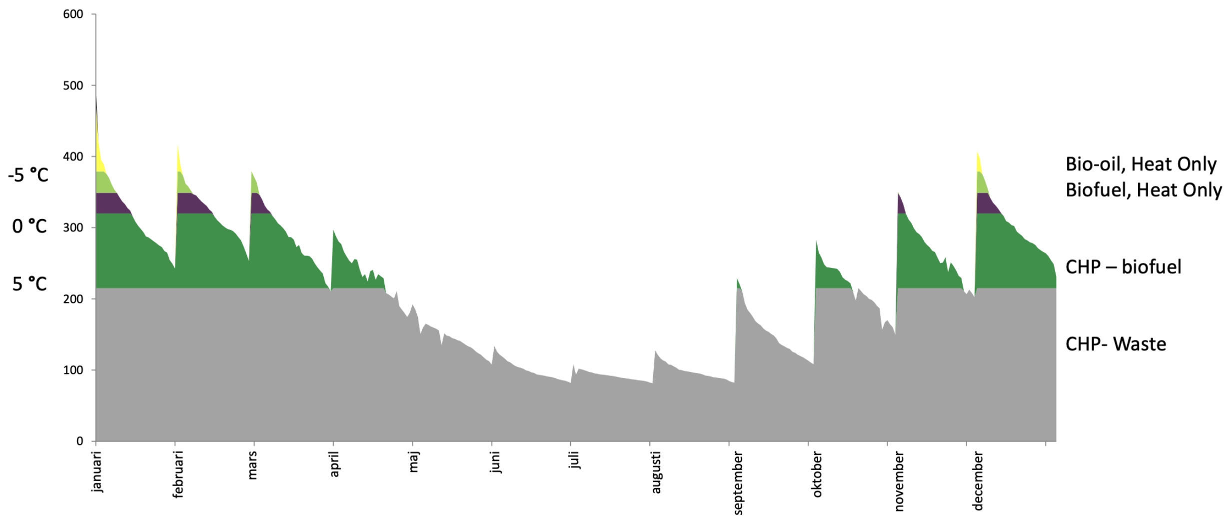

Figure 20: Production in MW of heat for each source in the CHP plants in Linköping. Chart from Tekniska Verken. [30]

On the other hand, District Cooling in Linköping began in 1997 at the University Campus. Later, in 2000 the cooling network spread in the city center, and today the piping length is 100 kilometers.

In Linköping three different alternatives for producing cool are used. The absorption process uses heat from the Waste-to-Energy production in Tekniska Verken's plants and it has 53% of the cooling generation share in the city. On the other side, 21% is produced by compression chillers using ammonia as refrigerant and demanding electrical power. Moreover, cool is also produced in Linköping by free cooling in outdoor conditions. In this case, no refrigerant nor electrical power is needed. By using these high-scale cool production systems, Linköping has achieved not to use hydrofluorocarbons (HFC) because of its enormous impact on the greenhouse effect and the depilation of the ozone layer. In fact, it is a must since the Kigali Agreement in 2016 stipulated that the developed countries (as it is Sweden) are forbidden to use HFC from January 1st, 2019 [34]. Instead, compressor chillers in Linköping use ammonia, although carbon dioxide is another option too [33].

All in all, the District Heating system in Linköping began to be built in 1954. Tekniska Verken's goal is that this system is fed only by only either renewable or recycled sources for 2021, turning the traditional linear economy into a circular economy, as a consequence of their aim to make Linköping become carbon neutral for 2025. As their own slogan says: 'We are building the world's most resource-efficient region' [35].

2.5. Own production methods in Spain

Whether DHC technology wants to extend its use, it must be shown as a reliable and affordable energy supply to the consumer, and it must involve other benefits, such as a lower environmental impact, so governments and public institutions are interested in empowering its importance in the market. If a future spreading of this technology is desired, it has to appear as a better choice than the own producing traditional methods. These nowadays competitors and their contribution to the Spanish energy supply are noted in the following table. The Spanish situation is going to be used as a representative example of the heating and cooling market in southern European countries.

		Spain
Heating	Electricity	46.3%
	Natural gas	32.0%
	LPG	4.5%
	Diesel fuel	14.3%
	Coal	0.9%
	Renewable sources	1.9%
Domestic hot water	Electricity	21.5%
	Natural gas	40.3%
	LPG	25.9%
	Diesel fuel	10.1%
	Coal	0.1%
	Renewable sources	1.7%
Cooling	Electricity	99.7%
	Renewable sources	0.3%

Table 4: Energy supply sources in Spain for heating, domestic hot water and cooling. Table extracted from Spanish Institute for Diversification and Energy Saving (idae.es). [36]

As seen in the chart, electric heaters are the most common devices used for heating and it is widely used to heat domestic water. These devices work because of the Joule principle, which says that when the electric current is flowing by a material that has an electric resistance, energy is liberated in the form of heat. Hence, these devices are connected to the electric network and they involve electric energy demand. The heat released by the resistances is used to heat water which is pumped by the piping system inside the house. In order to control the energy required by the device, a programmer is installed to constantly check the temperature, so the water is not heated more than necessary and energy can be saved.

It is remarkable how electric heating systems are more used in the Mediterranean part of the country.

	Spain	Atlantic zone	Continental zone	Mediterranean zone
Electricity	46.3%	35.7%	21.0%	66.8%
Natural gas	32.0%	39.3%	45.7%	20.4%
LPG	4.5%	6.0%	4.7%	4.0%
Diesel fuel	14.3%	16.1%	26.0%	5.7%
Coal	0.9%	0.6%	1.5%	0.6%
Renewable sources	1.9%	2.2%	1.0%	2.5%

Table 5: Heating sources depending on the part of Spain. Table extracted from Spanish Institute for Diversification and Energy Saving (idae.es). [36]

Lastly, electric devices are almost the only way to generate cool in Spain (table 4). These devices are mainly present in the Continental and the Atlantic zone, because of its higher temperatures, especially during summer.

Nevertheless, electric heating is the most used source in the kitchen throughout the whole country.

	Spain	Atlantic zone	Continental zone	Mediterranean zone
Electricity	63%	68.1%	72.4%	55.8%
Natural gas	17.9%	8.8%	15.8%	21.4%
LPG	18.9%	22.7%	11.5%	22.7%
Coal	0.0%	0.0%	0.0%	0.0%
Renewable sources	0.2%	0.2%	0.3%	0.1%

Table 6: Heating sources in the kitchen for the whole country, and the Atlantic, Continental and Mediterranean zones. Table extracted from Spanish Institute for Diversification and Energy Saving (idae.es). [36]

On the other hand, natural gas is the second most used option in the heating systems in Spain. Natural gas is a mixture of gases which mainly contains methane. In lower proportions, ethane, butane, propane, nitrogen, carbon dioxide are present [37]. This gas tends to be found in deep reservoirs on the surface or below the seas. It is generated as a result of the decomposition of natural and animal matter in conditions of high pressure and temperature. In these reservoirs, natural gas may be whether pure or in a mixture with other compounds. Since it takes millions of years to methane to be formed, it is considered a fossil fuel, so its availability is limited. [38]

The natural gas main component is methane, a molecule formed by 4 atoms of hydrogen and one atom of carbon. In the natural gas combustion, it works as the fuel which burns in the presence of oxygen, which works as the oxidizing agent. The heat released in the combustion reaction is transferred to the water that circulates by the heaters in the installation by a heat exchanger placed inside the combustion chamber. The mixture of natural gas and air can have different proportions where the combustion can be carried out. The minimum concentration of methane is 4.4% while the maximum is 17%. Hence, for a determined amount of methane, the amount of air used can be chosen for each boiler with a certain freedom. [39]

Depending on the combustion system used, two kinds of boilers can be differentiated. First, the atmospheric boilers, which do the combustion in an open environment taking air from the chamber where it is placed. This type of boilers are highly dangerous because of the emissions of gases to the chamber, so they are banned by the Spanish government from 2007 (Real Decreto R.D. 1027/2007 B.O.E.). [40]

On the other hand, the airtight boilers, where the combustion occurs in a closed enclosure and the air for the process is taken from outside the chamber which is aimed to heat. Thus, the combustion gases are delivered outside the local where human activities are developed. There are different kinds of closed airtight boilers, but the most important one is the condensation boilers, since the European Union has advocated for its use, as they are found to be the most efficient type of boiler. Thus, other boilers such as the low NO_x emission boilers are not anymore produced, although they still can be installed. [41]

The goal of the condensation boilers is to increase the efficiency, as the water vapor that appears as a result of the combustion of methane (4.1.2) is used to preheat the water that comes back to the boiler from the piping system that feeds the heaters. This gas is led throw a heat exchanger where it condensates, and it liberates the latent heat corresponding to water when it turns to liquid from gas. As a consequence, the temperatures used in this kind of boilers are considerably lower than the boilers that do not use condensation. The energy saving is evident, as before the boiler emitted hot gases to the atmosphere and now the energy carried by these gases is harnessed. Besides, the fewer the temperature of the returning gases is, the more energy will be extracted in the condensation process. Hence, these boilers must be constructed with materials that are not harmed because of condensation. Moreover, a liquid extraction system must be installed to collect the condensed water. [42]

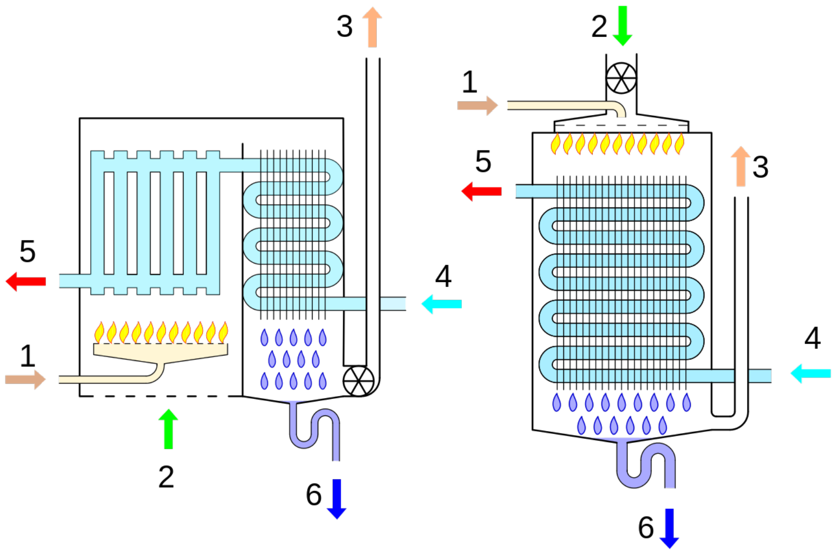

Figure 21: Condensation boiler. 1-Gas input, 2-Air input, 3-Combustion gases output, 4-Returned water from heaters, 5-Heated water to heaters, 6-Condensed water. Figure from gasnature.com. [43]

3. Method

As it has been stated in the previous background, the heating and cooling markets differ considerably between Sweden and Spain. In the following sections, the consequences of both models will be studied, in order to compare them according to emissions and energy efficiency criteria.

In Spain, most heating supply is carried out by electricity (46.3%), natural gas (32.0%), and diesel (14.3%) (Table 4). Thus, the impact of these methods will be analyzed in the following section.

For the electric heat production, attention will be paid only in the consequences that it involves to the consumer's electrical consumption, as this method does not produce direct pollutants. To do this, calculations will be carried out, analyzing the impact of using an electric boiler, for a house where a remarkable heating consumption is carried out. The reference data to obtain numerical information will be extracted from the invoices in the Appendix (6).

For the combustion processes, attention will be paid to natural gas boilers. Using the chemical characteristics of methane combustion, and information from a study about methane combustion [52], the emissions of this method will be determined. The invoices in the Appendix (6) from the reference house will be used to obtain numerical reference too. Although other fuels are used nowadays in Spain, natural gas has been selected to be analyzed, since it is the least harmful to the environment 5.1.

On the other hand, Sweden's main option for heat generation is District Heating, with a market share of 50.4% (figure 9). Besides, the use of electric heaters is widely extended and renewable sources have a noticeable share too. In this project, the Swedish situation will be studied by the DHC method, in a CHP plant, using municipal waste as fuel. To study this method, an environmental and efficiency analysis will be carried out.

For the pollutants emitted, the European law for emissions in big waste-to-energy plants will be analyzed. In this file, the limit amount of pollutants that can be emitted to the atmosphere and the water is determined. These requirements are to be fulfilled in 2023, but they are already followed by Tekniska Verken in Linköping. Thus, the emissions in Linköping are limited by the regulations established in the BAT (Best Available Technology) reference article referred to waste incineration. These articles are public domain and they have been provided to me by Tekniska Verken's workforce by individual communication.

For the efficiency concerns as a result of the transportation of the heat, the losses in the piping system will be studied. To calculate the losses in a piping system, the formulas presented in the book by Frederiksen and Werner (2013) will be used. Moreover, there is another fact that must be stood out, as its use is widely extended in Sweden and it involves appreciable improvements in energy harnessing. Combined Heat and Power has a 46% share of the heat production for District Heating in Sweden [18]. Using the information by Tekniska Verken and the United States Environmental Protection Agency, the energy saving thanks to this technology can be determined.

For large-scale cooling production, the possible emissions may be created because of the refrigerants used, and the efficiency of the process is determined by the Coefficient of Performance (COP) of the process, which differ considerably from the COP in individual cooling devices. The information about the COP of the cooling processes in Linköping is provided by Tekniska Verken.

To analyze the characteristics of both countries, the data analysis section is structured into two sections, one for each country.

4. Data analysis

4.1. Spain

In order to establish some reference data to make the calculations, information has been extracted from the invoices and other files in the final appendixes. This data refers to the consumption in a flat (residential sector) in the north of Spain, where the need of heating is remarkable during winters. In the following chart, the most important data is gathered.

House in northern Spain	
People living	5
Area	$90\,m^2$
Electric power installed	$5.5\,kW$
Boiler's power capacity	$23\,kW$
Boiler's kind	Non-condensing natural gas combustion
Boiler's efficiency	0.924
Electric consumption	
December 2019 (December 4th to January 4th)	$263\,kWh$
January 2020 (January 4th to February 4th)	$250\,kWh$
Gas consumption	
December 2019 (December 5th to 31st)	$601\,kWh$
January 2020 (January 1st to February 7th)	$846\,kWh$

4.1.1. Electric Boiler

Electric boilers work by heating the water that is fed to the heating system by Joule's effect. Thus, if a determined amount of heat is needed to be generated, the electrical energy required is the same, because ideally, the total amount of energy supplied turns in to heat in the resistive element, and all that heat gets to the water that is aimed to be heated. Thus, in this kind of installation, the energy consumption for heating is tightly related to electric consumption. On the other hand, since there is no combustion process, there are no emissions to the environment of any kind during the utilization process itself. Nevertheless, the emissions when generating the electrical energy could be taken into account in an overall analysis.

There is no doubt that electrical energy use grows enormously as a consequence of using electricity for heating. Besides, the electrical power demanded by the consumer also increases remarkably. This power demand is agreed between the consumer and the supplier enterprise. In Spain, according to the electrical regulations (ITC-BT-10 [44]), there are two different electrification levels for the residential sector, regarding the power capacity installed. When a house is bigger than 160 m^2 or when an especial electric receptor is installed, it is a must to install the higher electrification level. Electric heaters, air cooling systems are two examples where it is mandatory by law, as they are considered to be non-basic receptors for a house. Besides, the power demanded by the lower electrification level will never excess 7360 W, as it is specified in the Spanish regulation (ITC-BT-25). [45]

As there are no emissions during the consumption process, attention will be paid on the economic consequences for the consumer of this type of technology. The monthly costs in the electric invoices will increase as a result of the higher electrification level because of the higher power installed capacity, and the higher amount of energy required by the boiler to work. Considering the consumption carried out in the studied house, the maximum electrical demand is 5.5 kW (as there is no especial electrical receptors or any other characteristic that forces it to install the higher electrification level) meanwhile the maximum power that the boiler can demand is 23 kW (6). As a result, it would be compulsory to increase the power demand contract. Besides, the heating demand in kWh tends to be a considerably high value compared with the average electrical consumption in the residential sector. Comparing the invoices for December 2019 and January 2020, the impact that introducing the kWh for heating in the electrical consumption can be determined. For January, it would involve an increase of 238.4% more electrical consumption. For December, the increase turns to be 128.52% more than it was before.

From the invoices of the reference house estimations can be made to determine the consequences on the consumer's payment as a result of the use of an electric boiler, considering the month of January. If an electrical boiler is to be considered, the maximum power demand must be redefined too. In this calculation, a 8 kW boiler from the Domusa products [46] is going to be used (a considerable lower power capacity, so as not to excess the maximum electrical power limit). The total electrical power demand would be the sum of the electrical power already considered (5,5 kW) and the boiler's demand. Hence, the maximum power demand for residential sector is required (14,490 kW) [44]. This calculations are done following the procedure in the electrical invoices for January. The prices may change for each month and for each enterprise. Besides, the fact that 2020 is a leap year is considered as well.

$Input\, data:$

$Electrical\, consumption\, for\, January\, 4th\, to\, February\, 4th\, (31\, days): 250\, kWh$

$Gas\, consumption\, for\, January\, 1st\, to\, February\, 7th\, (37\, days): 846\, kWh,\ so\ \frac{31}{37}\cdot 846\, kWh = 708.8\, kWh$ $will\, be\, considered.$

$Electrical\, costs:$

$Payment\ because\, of\, power\, installed:\ 14,490\, kW\cdot(38.043426+3.113)€/kW year\cdot\frac{31}{366} year = 50.51€$

$Payment\ because\, of\, energy\, used:\ (250+708.8)\, kWh\cdot(0.044027+0.0592)€/kWh = 98.97€$

$Tax\, because\, of\, geographical\, location:\ 1.08€$

$To\, the\, sum\, of\, this\, expenses\, the\, electrical\, tax\, (5.11269632\%)\, is\, applied:\ 150.56\cdot 1.0511269632 = 158.26€$

$Other\, costs:$

$Measure\, equipment\, renting:\ 0.026€/day\cdot 31\, days =\ 0.81€$

$159.07\, is\, the\, total\, amount\, before\, the\, VAT\ (21\%)\, is\, applied.$

$The\, final\, amount\, to\, pay\, is:\ 192.47$ €

For the studied dates (January 4th to February 4th), the electrical invoice in the reference house for the electric consumption only is 59.57 €. From the natural gas invoices, it can be estimated that the amount to pay for those dates is 41.2 €. The total amount to pay in that case is 100.77 €.

$43.96 \cdot \frac{32}{38} + 0.129872 \cdot 32 \cdot 0.8 + 1.23 \cdot \frac{32}{65} = 100.77$ €

The enormous increase in the energy use when this method is utilized involves a considerable higher price to pay each month.

4.1.2. Natural Gas

Natural gas boilers generate heat as a result of the combustion of the methane molecule. As it is an exothermic process, the chemical energy stored is released during the combustion reaction in the presence of oxygen. This non-reversible chemical reaction works as follows:

$$\mathrm{CH_4(g)} + 2\,\mathrm{O_2(g)} \longrightarrow CO_2(g) + 2\,\mathrm{H_2O(g)} + \Delta H_\mathrm{c}$$

The amount of heat released in the ideal reaction can be determined if the formation enthalpy is known, applying the Hess' Law:

$$Formation\, equations:$$

$$\mathrm{C(graphite)} + 2\,\mathrm{H_2(g)} \longrightarrow CH_4(g) \qquad \Delta \mathrm{H}_f = \text{-74.8 kJ/mol [47]}$$
$$\mathrm{C(graphite)} + 2\,\mathrm{O_2(g)} \longrightarrow CO_2(g) \qquad \Delta \mathrm{H}_f = \text{-393.5 kJ/mol [47]}$$
$$\mathrm{H_2(g)} + \tfrac{1}{2}\,\mathrm{O_2(g)} \longrightarrow H_2O(g) \qquad \Delta \mathrm{H}_f = \text{-241.8 kJ/mol [47]}$$

$$Hess'\,Law:$$

$$\Delta \mathrm{H}_c(CH_4) = \Delta \mathrm{H}_f(CO_2) + 2\Delta \mathrm{H}_f(H_2O) \text{ - } (\Delta \mathrm{H}_f(CH_4) + 2\Delta \mathrm{H}_f(O_2))$$
$$\Delta \mathrm{H}_c(CH_4) = -393.5\,kJ + 2\,molH_2O \cdot (-241.8\,kJ/molH_2O) - (-74.8\,kJ + 2\,molO_2 \cdot 0\,kJ/molO_2)$$

$$\Delta \mathrm{H}_c(CH_4) = -802.3kJ/molCH_4$$

This is the amount of heat released by methane during its combustion. It is a negative value because it is an exothermic reaction. Natural gas is the most environmentally respectful fossil fuel because it produces less harmful pollutants for the same amount of heat generated (section 5.1). Thus, attention will be paid on this fuel although many others can be used.

Knowing the heat released in the ideal combustion of methane by the Hess' Law, the amount of reactants and products can be calculated for a determined heat generated. This situation refers to the perfect mixing and combustion of natural gas only formed by methane, with oxygen. Natural gas might have considerably high levels of purity which can be achieved, (typically the composition of methane is about 90% [48]) but considering that air main component is O2 is an excessive simplification. In fact, other components appear in the real reaction that are not considered in this first stage.

Considering the invoices of January (until February 7th), the emissions for the energy supplied can be determined:

$$846\,kWh \cdot \frac{3600\,kJ}{1\,kWh} \cdot \frac{molCH_4}{802.3\,kJ} = 3796.09\,molCH_4$$

According to the stoichiometry of the reaction, the amount of CO_2 is the same as CH_4.

$$3796.09\,molCO_2 \cdot \frac{44.01\,g}{1\,molCO_2} = 167065.76\,gCO_2 = 167.07\,kgCO_2$$

If non-ideal characteristics are to be considered, the performance of the boiler where heat is produced is a dominant factor in the study. The traditional concept of performance of a boiler refers to the ratio between the heat produced and the total heat that can be extracted from the combustion reaction. Hence, if a determined amount of heat has been extracted, the previous calculations are appropriate to determine the ideal emissions, and the performance of the boiler is used to calculate the real emissions (for the ideal combustion).

The data in the technical report (6) shows that the boiler analyzed has a performance of 92.40%, so 8.22% more of reactants must be fed to the reaction, and 8.22% more of products will be generated.

$$Efficiency = \ 92.40\% \longrightarrow \eta = 0.9240$$
$$Emissions\,considering\,boiler's\,efficiency = \frac{167.07}{0.924} = \ 180.81\,kg\,CO_2$$

In order to achieve better performance in the boilers to reduce emissions and fuel consumption, innovations have appeared over the years, and nowadays there is one method that is considered to be the most efficient, by the European Union [49]. This method is the condensation boilers, as it was mentioned in the section 2.5. Due to these boilers, the definition of performance of the boiler has been changed. In the traditional boilers, the maximum amount of heat that can be extracted is the heat released by the ideal combustion, and the performance was determined by this value. However, the condensation boilers are able to harness the heat stored in the combustion gases and that is released in the condensation process. Hence, according to the previous concept of performance, efficiencies higher than 100% can be achieved. As a result, the performance concept has been redefined as the ratio between the heat produced for the heating system and the sum of the heat extracted and the heat that may be extracted if the condensation process is completed, so the performance is limited to 100%. However, the previous performance criteria is still used by the seller enterprises maybe as a commercial tool to catch the attention of the consumer.

As a consequence of this distinction, two concepts that can be used to quantify the impact of this technology are defined. Lower Heating Value (LHV) is the heat that can be extracted only from the combustion process, and Higher Heating Value (HHV) is the Lower Heating Value and the maximum heat that can be extracted from the condensation.

The ratio between the HHV and LHV for natural gas is 110.7% [50], so from the ideal combustion process, it would be possible to extract a 10.7% more heat than with only the combustion. The condensation process takes place when the gas is below its dew point, which is 55º for natural gas [50]. In fact, the lower is the environment where the condensation is carried out, the more energy will be extracted from the combustion gases, and the overall efficiency will be better. Hence, it is desirable that the temperatures of the return water from the piping system are the lower as possible (section 2.5). The relation between the temperature and the condensed water produced and its consequence on the performance of the boiler are represented in the following figure.

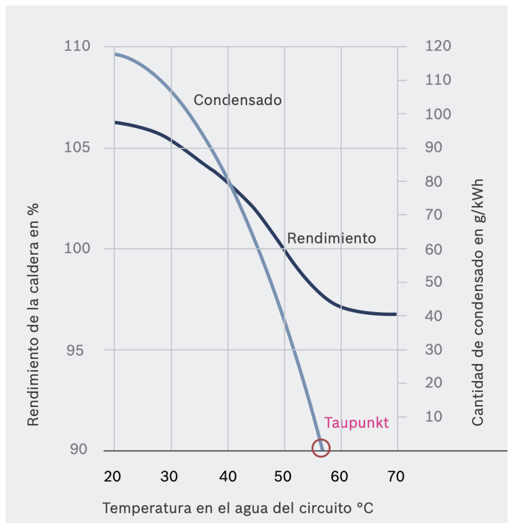

Figure 22: Condensed water (condensado) in g/kWh of heat produced and the performance (rendimiento) of the boiler for the water's temperature in the piping circuit for natural gas with an air excess of 10%. Chart extracted form www.bosch-industrial.com. [50]

All in all, condensation boilers tend to work with lower temperatures than traditional boilers, as they are able to harness better the energy in the process. This fact has several consequences. First, as the temperature of the heating substances is lower, it is needed a bigger contact surface, so the same amount of heat is transferred. Besides, the materials that the boiler is made of must be stainless so the corrosion does not affect them. Moreover, since the hot water supply temperature is lower, the losses in the piping system will also be lower. In fact, the supply temperature for traditional boilers is about 80-90 C meanwhile for consending boilers is about 40-60 C. [51].

As it was mentioned in the section 2.5, there is an interval of concentration of air and natural gas where the combustion takes place. In the following chart, how harnessed the heat is, regarding the gases of the combustion temperature and the concentration of air in the mixture.

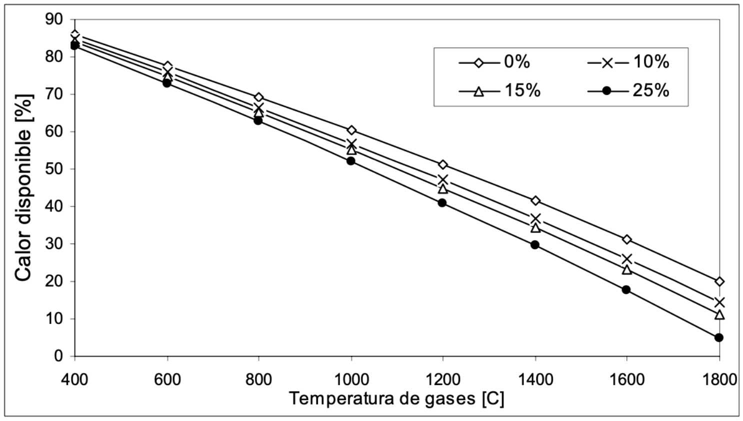

Figure 23: Available heat (calor disponible) in relation to the temperature of the combustion gases and the excess air for the combustion. Chart from [52]

For a determined air-natural gas mixture, the harnessed heat decreases with the temperature, as a higher amount of heat leaves with the hot combustion gases. This figure clearly states that condensation boilers can achieve better efficiencies since they work with lower temperatures. On the other hand, for a determined temperature, the higher concentration of air involves a worse heat use, as a part of the heat is used to raise the temperature of the incoming air.

The percentage of excess or defect air is also important when the emissions that the combustion process involves are analyzed, even those that are not present in the stoichiometric formula, as a result of the components of air itself and the impurities that natural gas may carry.

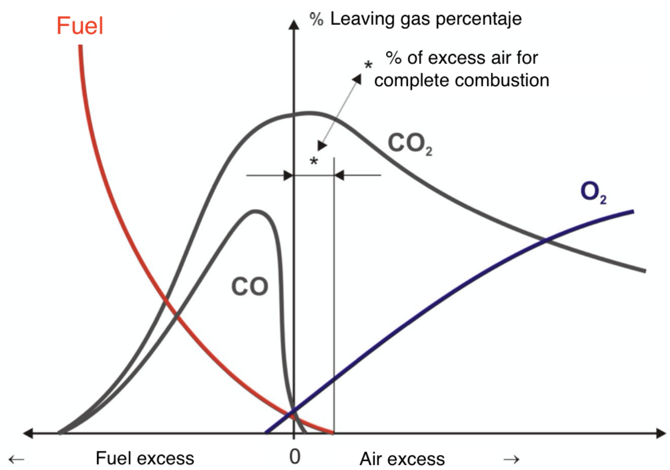

Figure 24: Percentage of leaving gases regarding on the composition of the mixture. Chart from www.tiemporeal.es [53]

As can be appreciated in the figure, the complete combustion is achieved when there is a determine the excess of air. The reason is that a mixture with more air than the stoichiometric reaction requires is more likely to completely mix. Working with this concentration, CO emissions are avoided and O_2 emissions remain relatively low. CO is formed by an endothermic reaction, so heat would be wasted in the formation process and the performance would fall. Besides, it is a very dangerous compound for humans. [52]

The excess air typically used in gas boilers is 15%, as it is recommended by the boiler's producers [52]. In the following figures, emissions for the non-excess air reaction and the typical excess air reaction are presented.

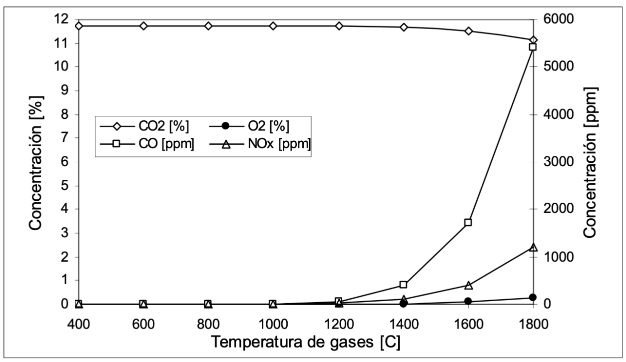

Figure 25: Concentration of the products in the reaction for the temperature of the combustion gases for a 0% air excess in the reaction. Chart from Serrano & Carranza (2005) [52]

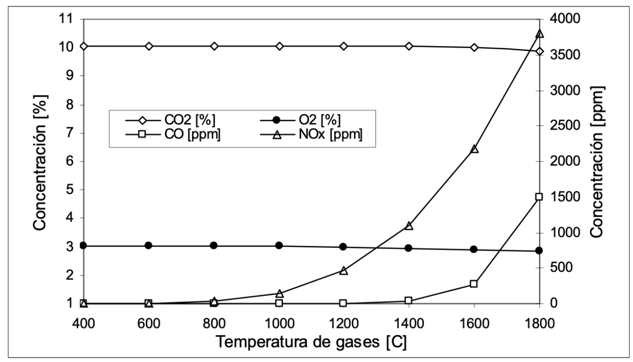

Figure 26: Concentration of the products in the reaction for the temperature of the combustion gases for a 15% air excess in the reaction. Chart from Serrano & Carranza (2005) [52]

The higher the air proportion is, the more pollutants are emitted. Nevertheless, these substances are created when the combustion occurs at high temperatures, which mainly appears in the industrial sector. Due to the fact that condensation boilers require low temperatures, emissions apart from CO_2 and O_2 remain in the background. O_2 emissions appear in the 15% excess air process, as a part of the air does not take part in the combustion. In the 0% excess combustion, methane emissions may be considered, since some reactants are not burned. As long as the combustion temperatures remain relatively low, NO_x emissions can be dispensed, as the N_2 in the air does not get to react with oxygen.

In the case of the 15% excess air reaction, the reactants and products in the combustion process are the following ones, considering air composition of 78% N_2, 21% O_2, 0.03% CO_2 and 0.94% Ar [54]. Complete combustion and low temperatures are considered as well.

$$\begin{array}{ccc}
Reactants: & & Products: \\
1\,mol\,CH_4 & & 1\,mol\,CO_2 \\
2\,mol\,O_2 & & 2\,mol\,H_2O \\
0.3\,mol\,O_2 & \longrightarrow & 0.3\,mol\,O_2 \\
7.99\,mol\,N_2 & \longrightarrow & 7.99\,mol\,N_2 \\
0.003\,mol\,CO_2 & \longrightarrow & 0.003\,mol\,CO_2 \\
0.096\,mol\,Ar & \longrightarrow & 0.096\,mol\,Ar
\end{array}$$

CO_2 concentration according to this calculations is 8.81%. O_2 concentration is 2.63%. Both values match with the data shown in the figure 26 about 15% excess air combustion products. As calculated before, 1 mol of CH_4 generates 802.3 kJ. Considering the condensation method with a performance of 110%, 882.53 kJ might be produced with emitting the mixture already pointed out.

4.2. Sweden

For analyzing the Swedish situation, attention will be paid on the waste-to-energy Combined Heat and Power plants in Linköping. These plants generate and distribute heat and cool by District Heating and Cooling and electricity by burning municipal waste and other fuels, when it is required. Tekniska Verken's plant has the following design.

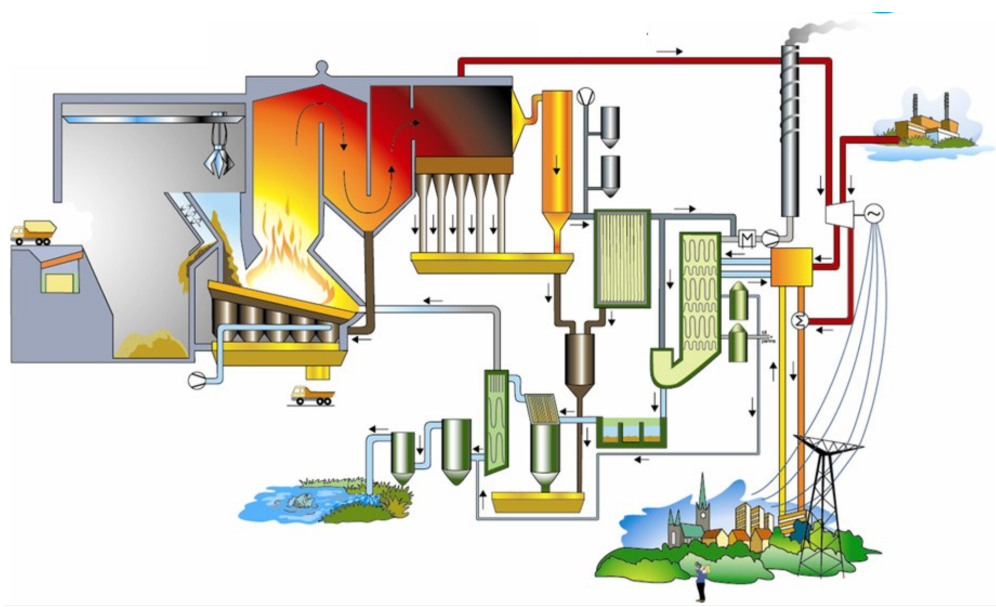

Figure 27: Tekniska Verken's Gärstadverket plant design. [30]

4.2.1. District Heating and Cooling

The incineration plants in Linköping must follow the European regulations for emissions in the whole process, since the waste is collected until the waste materials from the process are treated. The limitations that must be fulfilled are established as a consequence of the BAT (Best Available Technology) document about the incineration of waste to obtain future benefits. This document was proposed by the members stated of the European Union, the industries involved, and Non-Governmental Organizations (NGOs). These requirements for valorization and elimination of wastes in incineration plants gathered in this article are to be fulfilled by all the member states before 2023. They are applied to industries where more than three tons are burned each hour, and the fuel used is non-dangerous waste, as it happens with municipal waste incineration in Linköping. Although there are some years left, Tekniska Verken has already achieved these requirements, as I have been told by personal communication on April 28th with Henrik Lindståhl, Senior R D (Research and Development) adviser in Tekniska Verken.

When municipal waste is used as fuel, various pollutants are created, especially during the incineration process. The compounds emitted when waste is being burned are NO_x, NH_3, N_20, CO, SO_2, HCl, HF, Hg, particles, metals... Moreover, other concerns must be taken into account, such as the noise produced or bad smells that can be created.

From a general point of view, some measures must be considered, to act responsibly regarding the environment and to reach good combustion. First, the kind of waste that is to be incinerated must be determined. Depending on the installation characteristics, the kind of wastes that are going to be used as fuel must be analyzed, regarding its physical characteristics. These characteristics are the moisture, the size, the heating value, or if it might have dangerous chemical properties. Besides, the delivered fuel must be controlled to check if it has the desired attributes. For this purpose, it is of remarkable importance the separation process carried out in Linköping when the green bags are separated from the other waste. However, continuous control must be done.

Moreover, in the incineration plants where municipal waste or other non-dangerous residues are burned, the process where waste is delivered to the plant must be controlled too. On this step, the radioactivity of the waste has to be controlled, it also has to be weighted, visual monitoring is also a need, and periodic tests must be carried out so the main physical characteristics are checked. Since waste rests for a while in a deposit until it is burned, determined measures must be taken too. The envelope structure must be waterproof, so no liquid leaves the deposit. Besides, a drainage system must be installed so it is possible to deal with these liquids. On the other hand, the maximum capacity of the deposit should not be excessed. This capacity depends on the kind of waste stored.

Maybe the most important activity in these industries is the incineration process. In order to achieve better combustion, some measures are taken. If the combustion appropriately takes place, more energy can be extracted from the fuel, emissions are avoided and the combustion is more complete. On that purpose, a mixing homogenizing process is carried out. As it is shown in the visit to the Gärstadverke plant, the mixing process is carried out by an industrial crane. This crane is also used to throw the waste into the combustion chamber. In fact, during the non-working hours, the crane works automatically only throwing the waste to be burned.

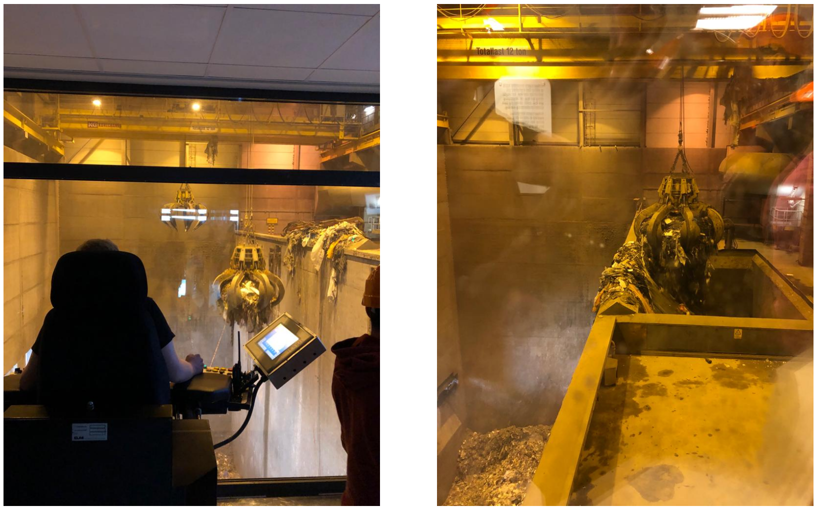

Figure 28: Tekniska Verken's mixing and throwing process into the combustion chamber using an industrial crane. Pictures taken during the visit to Gärstadverke plant.

Also, the combustion process can be enhanced by computer-controlled systems that can monitor the oxygen input to the combustion chamber, watch the emission released in the process, regulate the waste input flow, or the temperature.

Other measures can be carried out in order to achieve better energy efficiency in the incineration installation. For instance, reducing and redistributing the flow of the combustion gases or minimizing the heat losses by systems that recover the heat leaking out by the walls, by improving the insulation of the walls or by recirculation of the combustion gases. Other options are to recover heat by heat exchangers from the leaving gases of the boiler or from the water vapor gas that releases the latent heat from the condensation process. Besides, another technology popularly used is cogeneration (also called Combined Heat and Power). It is the one found in Linköping, where heat is recovered to be distributed or to produce cool in a centralized way.

Besides, the smell and the noise produced by the plant must be under control too. To prevent the generation of smell, the deposit must be kept under a determined pressure, and the gases that leave that chamber may be used as combustion gas when there is no risk of explosion. To avoid excessive noise levels, the machinery should be located as far as possible from where it can be disturbing, and in a way that the walls or other elements act as a protective element. Also, the plant must remain with closed windows and walls and the machinery should be used by an experienced workforce.

Regarding the emissions to the atmosphere or the water used in the process, several measures are applied, depending on the component aimed to be controlled. Some of the Best Available Technology Associated Emission Limits (BAT-AELs) for different compounds and the frequency of the controls that must be carried out are gathered in the following table. The concentration is expressed in mg/Nm^3.

	BAT-AELs		Check frecuency
Dust particles	2-5		Daily average
	New installation	Existing installation	Check frecuency
HCl	<2-6	<2-8	Daily averge
HF	<1	<1	Daily average or average during sampling period
SO_2	5-30	5-40	Daily average
NO_x	50-120	50-150	Daily average
CO	10-50	10-50	Daily average
NH_3	2-10	2-10	Daily average
Hg	5-20	5-20	Daily average or average during the sampling period

Table 7: BAT-AELs for emissions to the atmosphere.

For cleaning the water used in the process, so it can be put back in the environment, several measures are taken. One option is to use gas cleaning methods that do not generate wastewater, but this can not be applied in every situation. Also, the water used in these plants can be recycled several times in the same plant, although the possibility of recycling is limited by the purity requirement of the process where it is used. In some kind of boilers (grill boilers), cooling without water is a possibility that sometimes can be used. Anyway, the water that is finally wasted is treated by different methods, where first water flows are balanced, acids are neutralized and water is filtrated to separate big pollutants. Then, various physicochemical processes are carried out, and finally, some other solids are extracted so the water can be put back into nature. In the following table, some of the BAT-AELs in mg/l when the treated water is directly delivered into a water mass are gathered. Treated water in Gärstadverket plant is delivered directly to a water mass.

Parameter	Process	BAT-AELs
Total amount of suspended solids	Combustion gas cleaning Ashes treatment	10-30
Total organic carbon	Combustion gas cleaning Ashes treatment	15-40
As	Combustion gas cleaning	0.01-0.05
Cd	Combustion gas cleaning	0.005-0.03
Cr	Combustion gas cleaning	0.01-0.1
Cu	Combustion gas cleaning	0.03-0.15
Hg	Combustion gas cleaning	0.001-0.01
Sulfate SO_4^{2-}	Ashes treatment	400-1000

Table 8: BAT-AELs for emissions into the water that will finally be directly delivered into a water mass.

On the other hand, there is a distinctive factor between District Heating and Cooling and the other alternatives. This factor is that heat and cool are not produced where they are consumed, so a complex piping system is required.

Figure 29: Piping system for District Heating in Linköping

The fact that the heat and cool production is carried out in a determined place, and then it is dispersed might involve issues because of energy losses when distributed. Thus, the losses that may occur in the piping system is a factor that should be considered, as if they were too high, this system would not be a good option.

For estimating these energy losses in relation to the length of the distribution flow, a thermic study of the piping system is conducted, for the different characteristics of the distribution system. By using the formulas proposed by Frederiksen and Werner [4], the heat power lost in the distribution process can be determined.

The heat power lost in the distribution process depends linearly on the distance covered by the pipe (which is half the pipe length, since there are supply and return pipe). The rest of the parameters involved are the pipe and environment characteristics.

The heat power losses are determined by the following equation for a supply and return pipe, buried in the ground and also taking into account the heat losses for each pipe as a consequence of the presence of the other:

$$P_{hl} = P_{supply} + P_{return} = L\pi d \cdot \frac{\Theta_s + \Theta_r}{R_i + R_g + R_c} \, (W) \tag{5}$$

L is the distance covered by the pipe. In other words, it is half the pipe's length, as there is a supply and a return flow.

Θ_s is the supply temperature minus the ambient temperature ($t_{supply} - t_{ambient}$), in Celsius.

Θ_s is the return temperature minus the ambient temperature ($t_{return} - t_{ambient}$), in Celsius.

$\mathbf{R}_i$ is the thermal resistance for the insulation, in m^2K/W.

$\mathbf{R}_g$ is the thermal resistance for the ground, in m^2K/W.

$\mathbf{R}_c$ is the thermal resistance as a result of the coinciding temperatures of both pipes, in m^2K/W.

The equations for the thermal resistances are:

$$R_i = \frac{d}{2\lambda_i} \cdot log(\frac{D}{d}) \, (m^2K/W) \tag{6}$$

$$R_g = \frac{d}{2\lambda} \cdot log(\frac{4h}{D}) \, (m^2K/W) \tag{7}$$

$$R_c = \frac{d}{2\lambda} \cdot log(\sqrt{(\frac{2h}{s})^2 + 1}) \, (m^2K/W) \tag{8}$$

d is the inner diameter of the pipes, in meters.

D is the outer diameter of the pipes, in meters.

h is the distance from the center of the pipes to the ground level, in meters.

s is the horizontal distance between the center of the pipes, in meters.

λ_i is the heat conductivity for the insulation material of the pipes, in W/mK

λ is the heat conductivity for the ground, in W/mK

The data considered is the one used in the simulation by Frederiksen and Werner [4, page 80] for analyzing the heat losses distribution in a vertical cut in the ground. Besides, other considerations taken in the book such as the heat conductivity for the ground and for the material chosen for the pipe, and the dimensions of the pipe are used. The aim now is to determine the heat losses depending on how long the pipes are. The data considered is gathered in the following table.

Standard pipe used	DN 150
D	0.1683
d	0.15408
Material used for the pipe	Polyurethane foam
λ_i	0.03
Installation considerations	
s	0.66
h	0.52
Other considerations	
λ	1.5
t_s	85
t_r	45
t_a	6

Table 9: Parameters considered to estimate the power losses for District Heating and Cooling in relation to the distance covered by the pipes. [55]

The following lines are the code used in MATLAB to plot the power losses in relation to the distance covered for the pipe, and the exact value of power losses in W for 2000, 5000, 8000 and 10000 meters.

```
>> %Parameters
>> ts=85;tr=45;ta=6;
Ts=ts-ta;Tr=tr-ta;
d=0.15408;D=0.1683;h=0.66;s=0.52;
li=0.03;l=1.5;
>> %Thermal resistances
>> Ri=d/(2*li)*log(D/d);
Rg=d/(2*l)*log(4*h/D);
Rc=d/(2*l)*log(sqrt((2*h/s)^2+1));
>> %Plot
>> L=linspace(0,10000);
```

```
>> Phl=L*pi*d*(Ts+Tr)/(Ri+Rg+Rc);
>> plot(L,Phl)
>> %Some evaluation points
>> L=[2000,5000,8000,10000];
>> Phl=L*pi*d*(Ts+Tr)/(Ri+Rg+Rc)

Phl =

   1.0e+06 *

    0.2722    0.6806    1.0889    1.3612
```

The obtained plot is:

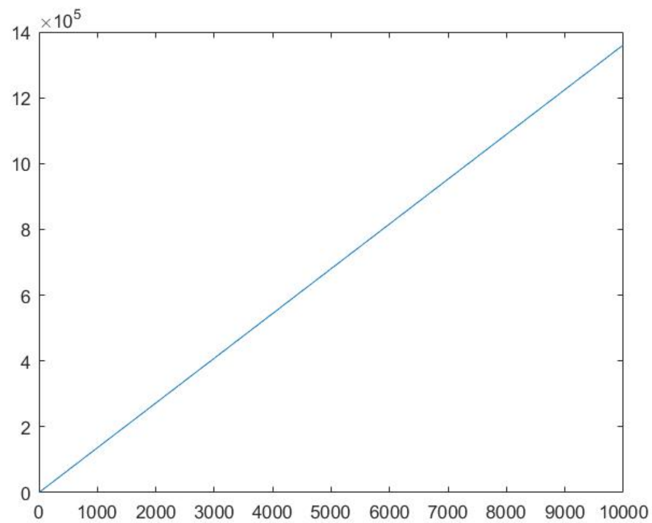

Figure 30: Heat power losses in W for the distance covered by the piping system.

As it can be determined from the previous formulas, the heat power losses only depend on the length of the pipe system, for a determined kind of pipe and temperature conditions. Making the assumption that all the pipes in Linköping are of the same kind, and all the pipes work with the same temperature condition as indicated before (Table 9), the heat losses can be estimated. For making this, the L value in equation 5 must be equal to 500 km, as it is the total length of the piping system in the city [30]. The value obtained is around 68 MW, which is a similar value to the power of the steam production in a chimney in Gärstadverket or Kraftvärmeverke plants (Tables 2 and 3).

4.2.2. Combined Heat and Power

Combined Heat and Power is a method of energy production tightly linked to District Heating and Cooling because of the purpose of using energy wisely. In fact, the DHC is a very reasonable way to use heat leftovers from industrial processes. The energy recovery thanks to CHP is illustrated in the following figure, in case that a steam turbine is used.

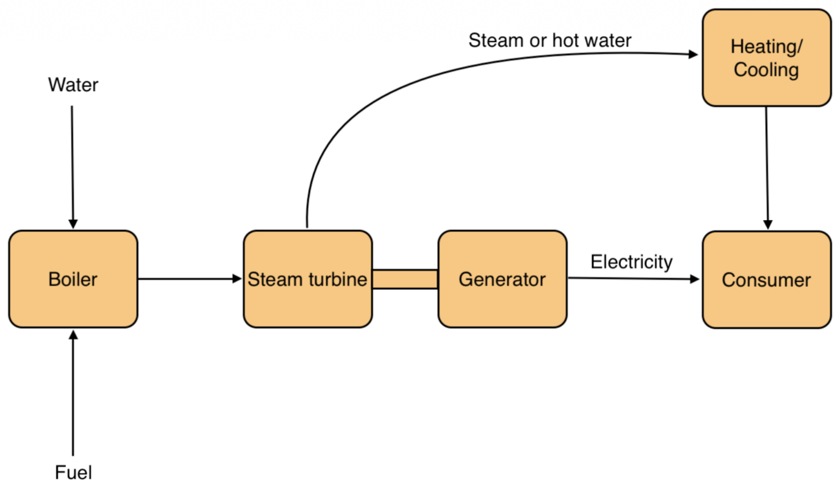

Figure 31: Process flow in a Combined Heat and Power plant using a steam boiler.

In traditional electricity generation plants, exhaust gases are not used and the energy that they carry is wasted.

Incineration plants in Linköping work as a CHP plant. According to the Tekniska Verken presentation, the energy saving achieved is as follows.

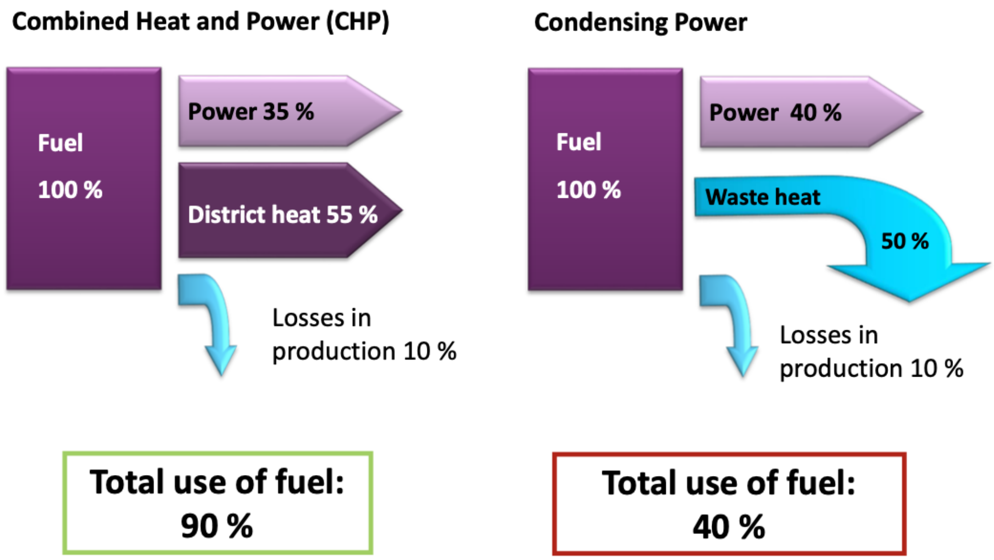

Figure 32: Energy flows comparison when CHP is used and when it is not, according to Tekniska Verken. [30]

It is remarkable the fact that the efficiency of the electric power generation decreases when CHP technique is applied. The reason for this is that CHP plants need a "back pressure turbine" to use the heat from the steam after is passed the turbine. In a plant for condensing power a condensing turbine is used, which involves cooling down the steam is part of the process in the turbine. Using this technique generates more electricity, but the heat will be lost. This information has been provided to me by personal communication on May 15th by Teresia Goransson, an Energy engineer at the department for Optimization and Policy instruments in Tekniska Verken.

According to the U.S. department, the increase of efficiency can turn from 50% to 75% considering a grid power with an on-site boiler and a CHP plant [56]. The efficiency improvement is clearly stated in the following figure, arriving into the same conclusions.

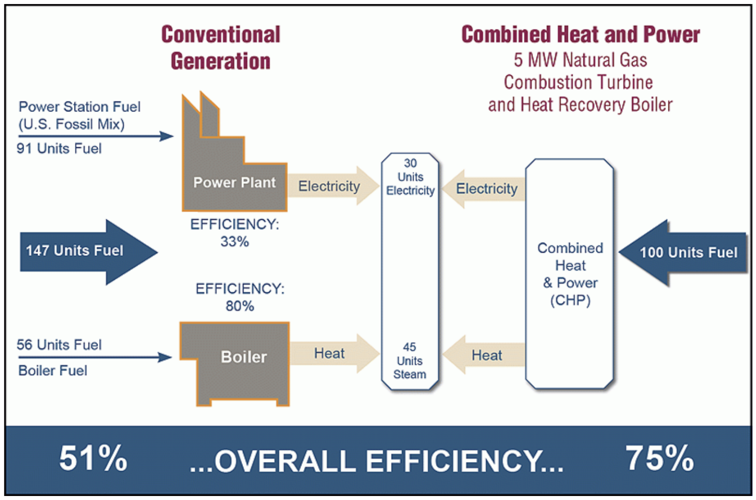

Figure 33: CHP consequences in the efficiency of the process. Extrated from United States Environmental Protection Agency (EPA) [57]

4.2.3. Large scale Cooling systems

Large scale cooling production in Linköping is carried out by three different methods. First, cool is obtained by free cooling, a method that does not require any energy input. The only environmental concern for this method is not to affect too much the environment where it is installed. Then, absorption and compressor chillers need an energy input, which can be fulfilled with the energy supply from the plant. Thus, regarding the energy requirements, the limitations and measures to take are the same as presented for District Heating (section 4.2.1).

Besides, attention must be paid to another factor that might be dangerous for the environment. The traditionally used refrigerants for cooling production equipment caused considerable damage to the ozone layer and increased the greenhouse effect. These refrigerants are Hydrofluorocarbons (HFC). In Linköping, following the Kigali amendment, these compounds are being phased out, and NH_3 and CO_2 are the refrigerants used.

Production method	COP	Enegy input
Free cooling	100	No energy input required
Compression chiller	7-10	Work (electricity consumption in the compressor)
Absorption chiller	15-18	Heat from the CHP plant

Table 10: Cooling production methods in Linköping, its Coefficient of Performance and the kind of energy input required. [33]

5. Discussion

Two main factors have been considered so far in this project to compare the different alternatives for the heat and cool market. These factors are the emissions to the environment (pollutants to air or water) and energy efficiency.

5.1. Emissions

Regarding the emissions as a result of heat production, the main method to take into account in Spain is the natural gas boilers. Actually, several fuels are used in Spain for heating purposes, but in this project, attention has been paid to natural gas, since it is the least harmful for the environment. First, although carbon dioxide emissions are inherent to the combustion process of any kind of fuel, some of them require more emissions than others. Natural gas emits 40-50% less carbon dioxide than coal and 25-30% less than fuel oil. [58]

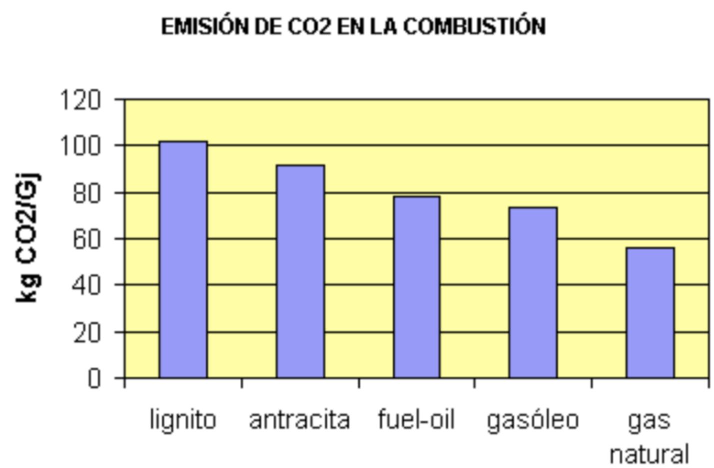

Figure 34: Comparative of CO_2 emissions for the same amount of heat released for different fuels. Chart extracted from Ministerio para la Transición Ecológica y el Reto Demográfico. [58]

Considering other pollutants that can be released, natural gas is also a better option. For instance, NO_x emissions occur when the combustion is carried out at high-temperature levels. In that case, a mixture of NO (95-98%) and NO_2 (2-5%) might be produced. Since the reaction occurs in the gas state, natural gas and air are well mixed, so it is more likely that there is not incomplete combustion, and these emissions are avoided. Compared to coal, natural gas produces half NO_x emissions and 2.5 less than fuel-oil. [58]

NO_x compounds and SO_2 are responsible for the acid rain. SO_2 emissions in the natural gas combustion depend on the composition of the fuel. As a result of its purity (10 ppm of S), the emissions of this compound are very low. Coal produces between 70 and 1500 times the S that natural gas does, meanwhile fuel-oil S production is 2500 times bigger. [58]

Lastly, methane (CH_4) emissions should be considered as well. Methane is an important factor in the greenhouse effect, having a greater impact than CO_2, although it disappears from the atmosphere in a shorter time than CO_2. Since CH_4 is the main compound of natural gas, it might be a pollutant to take into account. It has been estimated that 1% of the natural gas extracted is lost during the extraction, transport, and distribution process. Nowadays, 50% of the methane emissions by humans are produced by livestock farming and agriculture, so the emissions because of natural gas utilization remain in the background. [58]

On the other hand, the consequences of natural gas extraction might be marked for an overall evaluation. The extraction may involve environmental issues when it is linked to an oil reservoir and the reinjection process is not available. About the purification process, it is a simple transformation where heavy components are separated, and no other waste is produced.[58]

All in all, the previous statements reveal that natural gas is the best option for own production boilers where a combustion process is carried out, from and environmental point of view. Also, the calculations in the data analysis show that the main emissions are reasonable amounts of CO_2 and other pollutants, for the considerable heat released. Besides, if they are condensation boilers, as it is mandatory by law, good efficiencies can be achieved.

However, regarding the emissions because of heat production, the best alternative would be electric heating. Since there is no combustion process, no pollutants are emitted. Nevertheless, it would be unfair not to take into account the pollutants created during the electric production. Depending on the country (and the precise moment of the day), this production involves a different amount of pollutants. Anyway, the fact that more electric energy is generated has as a consequence more emissions to the environment, without regard to which country it is. In fact, this method is not a reasonable choice, if it is analyzed from an efficiency perspective.

An interesting factor to discuss is whether the production in a single place has positive consequences for the emissions produced in the whole process.

The fact that the production is carried out in a particular place makes possible to have higher control of the emissions created. As it is mandatory by law, all the enterprises in the sector must follow the European Union requirements, so acceptable emissions are produced. Indeed, these requirements are exigent enough so it is possible to directly pour the water from the process to the environment since the necessary characteristics are achieved. Although the emissions created by each own producing methods are obviously much lower because of the production size, there is a lack of control of each device, compared to the centralized methods. Anyway, it is a fact that Sweden has achieved to minimize the emissions of CO_2 for the residential sector [6], so there is no scattered production of pollutants, and better control can be carried out.

Moreover, large incineration plants have computer-controlled systems that make it possible to monitor the combustion process, so it is carried out properly and no other pollutants are emitted. Besides, the emissions to the air and to the water are constantly controlled, so any failure can be immediately detected and corrected.

Due to the fact that heat production is located in a determined place, measures are easier to implement. In Sweden, during the 1960s and 1970s, it was demonstrated that in the cities where District Heating is installed, the SO_2 levels are considerably lower, because it was emitted in punctual chimneys at a considerable height. Also, the NO_2 emissions were reduced by 65% as a result of the fee created by the Swedish government to the large combustion industries. This kind of measure is hardly implemented in own production methods. Lastly, during the latest 1980s, society's concern about climate change was getting bigger, so the European Union discussed a tax for the emissions of CO_2 to the atmosphere, that was not finally implemented. Nevertheless, the Swedish government followed this idea and in 1991 a tax for the CO_2 was created. This tax has grown up to 1100 SEK/ton of CO_2 produced. This measure pushed the big incineration plants to reduce its emissions and punished the own producing methods, which usually use fossil fuel whose emissions are considerable. As a result of these requirements and measures, the production of greenhouse gases in large combustion plants for District Heating systems has decreased considerably in the last decades. In the following figure, the emissions of CO_2 for each MJ of heat produced for the last years are represented, for the combustion of fossil fuels. [59]

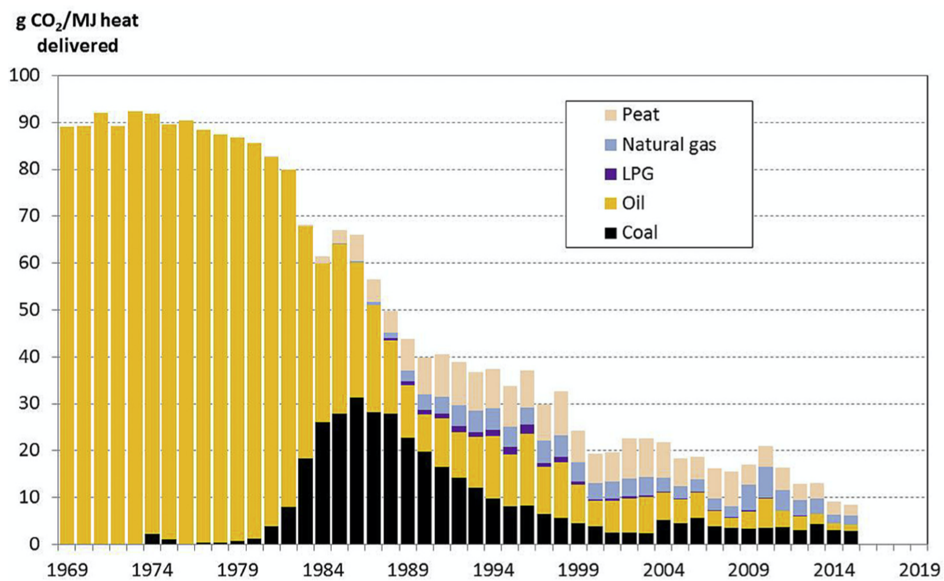

Figure 35: CO_2 emissions in the large incineration plants in Sweden for the last years. Extracted from District Heating and Cooling in Sweden, by Werner (2017). [59]

5.2. Efficiency

The efficiency of each method is determined by how well the energy capacity in the energy source is harnessed. For the own production methods, this analysis only concerns the heat or cool production process, meanwhile, for District Heating and Cooling, the fact the heat and the cool must be transported is key to analyze the overall efficiency of the process. Besides, the possibilities that the concentrated energy-supplying methods can involve energy harnessing should be considered as well.

For natural gas boilers, the efficiency levels achieved thanks to the condensation process are considerably good. In fact, it is possible to obtain more heat than the one that is in the fuel burned. In this regard, this method appears as a good alternative.

On the other hand, electric boilers are not an efficient method, since a remarkable amount of energy is needed. Nowadays, the aim of reducing electric consumption is pushing LED technology and other kinds of electrical consuming devices that require less energy for doing the same tasks. Thus, it is not congruent to make efforts to have a low consumption refrigerator and to change the whole installation of a house to LED lights, for instance, if the heating system is consuming that much when other options are available. Actually, due to its high consumption, electric boilers are installed wherever the temperatures are not low, so the consumption is reduced and concentrated in some determined moments in the year. The consequences of using an electric boiler for the medium heat demanding consumer are estimated in the data analysis, where it is noticeable the increase in the invoices, as a result of the enormous consumption.

As stated before, the efficiency in large incineration plants concerns both the combustion process and the heat and cool distribution until the consumer. For the incineration process, computer-controlled systems enable the workforce in the plant to achieve the desired efficiency, something that can not be done in the own producing method. As it was noted in the data analysis, this is also monitored to assure that complete combustion takes place, and pollutant emissions are avoided.

Regarding the losses in the distribution process, they depend on the characteristics of the pipe used and the ground where it is buried, and on the ambient circumstances. The formula in data analysis (5) provides the power lost when the installation characteristics are known, and the inlet and outlet temperatures are determined. From the calculations done in the data analysis, it can be extracted that the losses in the piping system are not negligible. According to these estimations, the power lost (about 68MW) when the whole installation in Linköping is used (500 km) is a similar value to the power developed by one of the chimneys in the incineration plants. According to Werner [59], two-thirds of the exergy fed into the distribution system is lost in the whole distribution process before it gets to the final consumer.

Although improving the insulation of the pipes would be an option to reduce the heat losses, efforts are being done to lower the temperatures in the system, so the losses would fall remarkably. As it can be appreciated in the equation 5, the power lost in the distribution depends linearly on the sum of the supply and return temperature. Thus, it would be desirable to reduce these temperatures. However, these temperature levels are used because in case of failure of the substations and costumer heating systems, having higher temperatures enables to keep the heating supply. If systematic identification is carried out, these failures can be fixed faster and the temperatures used could be lower, and as a result, losses would fall.

About the overall energy efficiency, District Heating and Cooling stands as a method that enables to harness energy more efficiently, thanks to the cogeneration process. This technology can not be used in own production systems. Hence, although the District Heating system involves great losses, they are compensated with the considerable energy saving in the generation process, thanks to Combined Heat and Power. According to Tekniska Verken [30], in a Condensing plant, 50% of the fuel energy is wasted, leaving the process in the hot flue gases (figure 32). According to Werner [59], in a DHC system, two-third parts of the heat released to the piping system is lost, so it would involve 37% energy losses, for a CHP plant ($\frac{2}{3} \cdot 55\%$). In both cases, 10% of extra losses have been considered (figure 32). As a result, energy is more efficiently used when DHC is integrated with CHP.

On the other hand, the production of cool in large-scale chillers use energy in a considerably better way, since the efficiency of these machines is remarkably higher than the small refrigerators machines. The COP of the chillers used in Linköping (Table 10) is considerably higher than the typical values for the individual devices, which are around 4 in the most efficient machines [60]. Besides, free cooling is an alternative too. Although the results obtained are not as good as with other methods, it is a cheap and non-consuming method. Nevertheless, the losses in the distribution of the District Cooling should be considered as well. In this case, the supply and return temperatures tend to be closer to the ambient temperatures, so the losses are not as high as in District Heating.

Another factor to take into account is that the refrigerant used in the large scale systems will always be more controlled than in the case that the production is carried out in a scattered way. In this regard, Tekniska Verken has accomplished the objective of getting rid of HCL compounds, as it is mandatory since the Kigali agreement was implemented.

6. Conclusion

The debate raised when comparing the models used in Sweden and Spain is whether using large-scale production for heating and cooling purposes involves less environmental impact and a better energy harnessing.

Regarding own production methods, electric boilers is not a future option. This technology is against the philosophy of reducing energy use. Although its production might be respectful with the environment if renewable sources are used, nowadays' society must work for demanding less amounts of energy. Thus, natural gas stands as a better option for small-scale heat production, with a reasonable environmental impact. However, if a long-term way of thinking is used, this option will not be a choice within 50 years, when the natural gas reservoirs are supposed to be finished [61][62][63]. If society is really looking responsibly to the future, fossil fuels can not be an option anymore.

When the possibility of using other fuels is considered, large-scale production methods are the best choice. The energy sources that are to be used in the future, as they are renewable, tend to be difficult to handle. The waste-to-energy production can only be carried out if large combustion chambers are used and a complex system is installed in order to collect the residues and to treat the wastes of the process. The same happens when biomass from forests is used, for instance. The possibility of using alternative energy sources is maybe the biggest advantage that District Heating and Cooling can bring to society. Also, if integrated with Combined Heat and Power, electricity production can be done more efficiently, harnessing energy to the most. In the following figure, the development of the fuels used for District Heating and Cooling is shown. It is remarkable the tendency of having a heterogeneous mix of energy sources, reducing the consumption of fossil fuels, which will be finished, sooner or later.

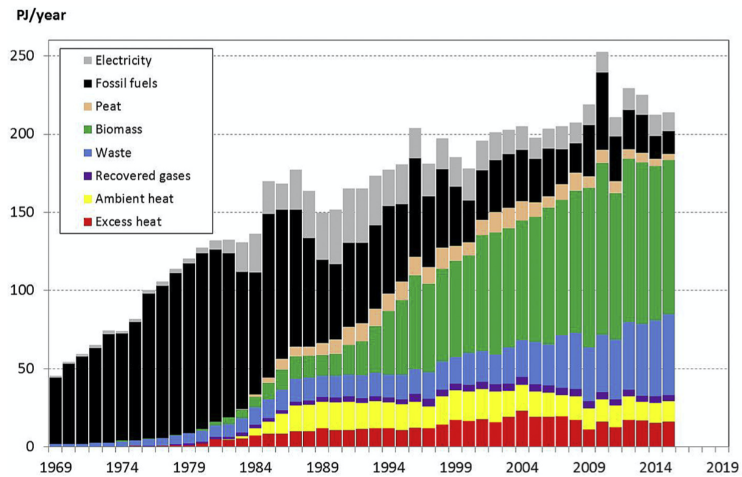

Figure 36: Energy sources used for District Heating and Cooling in Sweden, from the 1969 until 2015. Extracted from District Heating and Cooling in Sweden, by Werner (2017). [59]

The expansion of District Heating and Cooling in Sweden is the consequence of several factors that have appeared over the years. In the middle of the 20th century, DHC was used as an alternative to the electricity purchase. Later, in the 1970s the oil crisis also pushed this technology in the country. In the 1980s, the climate change debate in Europe pushed the Swedish government to establish emissions tax and restrictions (the CO_2 tax, for instance). Since these limitations can be achieved by large-scale producers, DH in Sweden has this increasing share. For DC, the expansion has achieved an 8% growth each year since 2000.

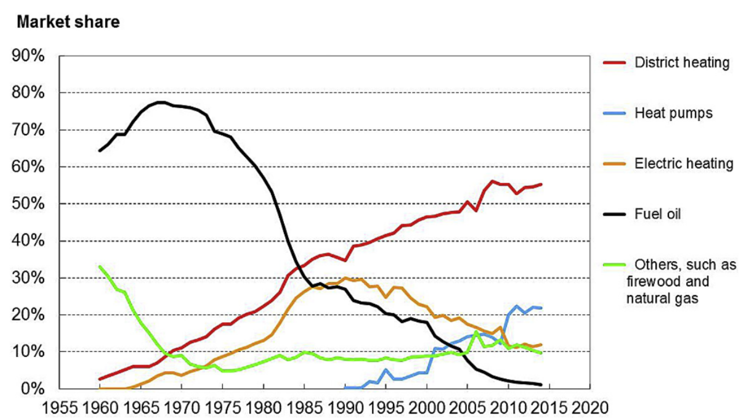

Figure 37: Heating methods market share in Sweden tendency over the years. Extracted from District Heating and Cooling in Sweden, by Werner (2017). [59]

The generation of any kind of product in big amounts tends to make cheaper the facility commercialized (economy of scale). Thus, although the losses in the distribution system are not at all negligible, they are offset in an overall analysis. Also, for the cooling methods, better performance are achieved when the machine is bigger, and other methods such as free cooling are possible to be used.

The main advantages of District Heating and Cooling regarding the consumer are that the supply is carried out in a comfortable and reliable way. Since energy extraction is not done in the consumption point, there is no need to use a specific space for the installation of heating devices. Thank this, the danger of explosion or emission of harmful compounds near the consumer is avoided. Besides, the consumer only pays for what they consume, so they will never pay for an over-sized installation. Lastly, this method brings the possibility of using non-fossil fuels, without the need for extra investment for the consumer. This should be a driving factor for the consumer engaged with the environment.

Regarding the consumer, DHC systems involves some drawbacks and criticisms mainly related to the fact that a monopoly is created when the installation is settled. As a consequence, the consumer loses power to negotiate the price and delivery conditions they are paying for. The lack of competition in the sector might also involve negative consequences. Besides, it must be noted the high investment required for the consumer to switch to DHC. Lastly, if a failure occurs in the system, as it is all connected, it may affect other consumers.

In a future perspective, DHC technology will have to adapt to the nowadays changing society. For instance, the new building houses will have lower heating and cooling demand, since their insulation and energy use will be better. Lower demands should be compensated with a bigger amount of consumers. Besides, other industries will also use biomass in their processes, so the competition for owing these kinds of resources will be higher. However, heat recovery from other industries using biofuels will hopefully become a more common alternative. Other energy sources will optimistically become a good alternative in the future, as the developing solar energy, for instance. Moreover, CHP plants will enter in the electrical market as a renewable energy source that does not depend on other factors so it can supply energy. Thus, it can become an agent to balance the electrical market. Also, an improvement in the heat and cool storage is highly desired, so for the peaks of demand there is no need to burn fossil fuels, and industries can finally get rid of them.

Finally, if a future spreading of this technology is desired, the goal is to be also an appropriate supplier for the low-density heat demand consumers. In other words, the technology should become efficient also when the consumers are not concentrated. To achieve this, the losses in the distribution system must be lower. As it was pointed out before, this will be possible when the supply and return temperatures are reduced.

There are other concerns involved by DHC technology. First, one of the main consequences of the high share of the waste-to-energy technology is that in Sweden there is no landfilling. This characteristic has positive social acceptation, although in general, citizens do not want to have a combustion plant near their house. This is called the "not in my backyard" effect.

Besides, there is another factor that has not been considered in this project that is key nowadays. The economical part of a project of these characteristics is the main factor since the investment required is considerably high. For the District Cooling system in Linköping, Tekniska Verken has invested a total of 30M €. The profitability of the inversion is increasing each year [33]. Moreover, in order to push DHC, some governments offer economics aids, as it happens in Asturias (northern Spain), for instance [64].

Finally, DHC is a technology that will hopefully spread all over the world. The possibilities of using heat from other sources is a great way to reduce the impact of humans energy generation in the world. Besides, it will optimistically change the perspective of engineers and society in general of harnessing energy from other processes and resources. This technology might not be a final solution to the environmental problem we are all facing nowadays, but there is no doubt it is a step forward on the right direction.

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List of Figures

List of Tables

Appendix

In this appendix the invoices used for the reference data and other informarion for the data analysis are gathered.

- Gas invoice for two periods: from December 5th to December 31st 2019, and January 1st to February 7th 2020.
- Electrical invoice January 4th to February 4th 2020.
- Technical revision of a non-condension gas natural combustion boiler.

AUT_HC_SIGLO_CJTA_ES_20200210_070454_633.36789

Tu factura de gas natural y servicios
Factura nº

Fecha emisión: 09.02.2020

Electricidad	Gas	Servicios	Tasas e impuestos
Contratar	84,92 €	20,99 €	26,35 €

Periodo facturación gas: 05.12.2019-07.02.2020
Período facturación serv.: 09.12.2019-08.02.2020

¿Cuánto tengo que pagar?
132,26 €
¿Cuándo?
02.03.2020

Tus puntos

puntos Tu saldo actual es de **14.497** puntos

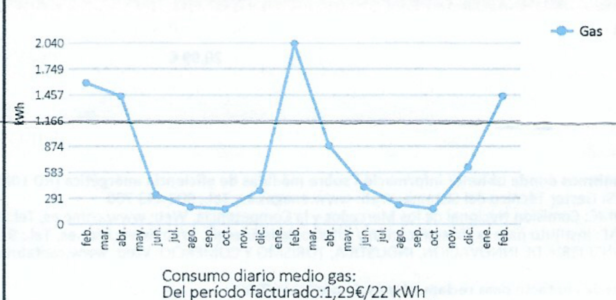
1.447
Puntos obtenidos

Date de alta en Facturación Electrónica
Te regalamos 2.000 puntos para canjear por energía gratis o regalos.

¿Qué te facturamos?

Tu "**FÓRMULA GAS HOGARES**" incluye el suministro de gas natural y servicios
Disfruta de tus descuentos:
20 % de descuento en disponibilidad de gas

Tus consumos



Consumo diario medio gas:
Del período facturado:1,29€/22 kWh
De los últimos 24 meses:0,87€/14 kWh

¿Quieres más?

Información importante
Hemos mejorado las condiciones de tu funciona.
Disfruta de un servicio de mantenimiento más completo en tu vivienda.
+ Reparaciones de fontanería gratuitas.
+ Iluminación eficiente LED con funciona.
Todo por solo 7,49€/mes*(IVA incluido). Si te acogiste a alguna promoción en los últimos meses, mantienes las condiciones hasta cumplir el primer año de servicio.
Infórmate llamando al **900 907 337** o en **www.edpenergia.es.**
*Esta nueva cuota se aplicará automáticamente a partir del 1 de febrero de 2020 sin perjuicio del consumidor a resolver su contrato vigente antes de esa fecha sin penalización alguna.

Tus contactos

En **edponline** podrás ver tus facturas y consumos, además de realizar tus gestiones. Visita nuestra página web, www.edpenergia.es, para conocer nuestras ofertas.

Línea EDP	900 907 000
Funciona Directo	900 907 007
Emergencias gas	900 400 523
Aportación lecturas gas	900 902 934
Reclamaciones	900 907 002

Para cualquier comunicación escrita, dirígete a atcliente@edpenergia.es o a EDP, Plaza del Fresno, 2 Bajo 33007 Oviedo

Factura gas y servicios nº por valor de 132,26 euros (Total Base Imponible: 109,30 euros - Total IVA: 22,96 euros) emitida por EDP COMERCIALIZADORA, S.A.U.
Esta factura no acredita por sí sola que el pago se haya satisfecho.

GAS — Período facturación: 05.12.2019-07.02.2020

Consumo

Período	x	Cantidad	x	Precio	Total sin IVA
05.12.2019 - 31.12.2019		601 kWh		0,05399016 €/kWh	32,45 €
01.01.2020 - 07.02.2020		846 kWh		0,05196457 €/kWh	43,96 €
					76,41 €

Disponibilidad

Peaje de acceso (tarifa): 3.1 BOE: 26.12.2014

Término Fijo	x	Nº días	=	Subtotal	-	Descuento	=	Total sin IVA
0,140384 €		27		3,79 €		20%		
0,139672 €		38		5,31 €		20%		
								7,28 €

Alquiler de equipos (65 días) 1,23 €

Total gas natural 84,92 €

Lecturas

Equipo de medida: 901107591 CUPS: ES0219090003707359PJ

Actual 07.02.2020 0006182

Anterior 04.12.2019 0006055

Consumo (real) 127m³ 1.447 kWh

Los kWh resultan de multiplicar los m³ por el factor de conversión (11,3937 kWh/ m³), el cual, a su vez, es el resultado de multiplicar el factor de corrección de volumen (0,9828 Nm³ /m³) por el Poder Calorífico Superior (11,5931 kWh / Nm³).

TASAS E IMPUESTOS

Impuesto sobre Hidrocarburos	Consumo	Conversión (1kWh = 0,0036 Gj)	Tasa	Total
	1.447 kWh	5,2092 Gj	0,65€/Gj	3,39 €

IVA	Base Imponible (Consumo+Disponibilidad+Alquiler +Impuesto sobre Hidrocarburos)	% Impuesto	
	88,31 €	21 %	18,55 €

Total tasas e impuestos 21,94 €

IMPORTE TOTAL GAS NATURAL + TASAS E IMPUESTOS 106,86 €

SERVICIOS — Período facturación: 09.12.2019-08.02.2020

Servicio Funciona	Período	Precio	=	Total sin IVA
Servicio Funciona	09.12.2019-08.02.2020	20,99 €		20,99 €

Total servicios 20,99 €

Funciona es el servicio técnico que cuida los aparatos y las instalaciones eléctricas y de gas, previene las averías y las soluciona cuanto antes. En todas las reparaciones, el desplazamiento y las 3 primeras horas de mano de obra son gratuitos.

TASAS E IMPUESTOS

IVA	Base Imponible (Funciona)	% Impuesto	Total
	20,99 €	21 %	4,41 €

Total tasas e impuestos 4,41 €

IMPORTE TOTAL SERVICIOS + TASAS E IMPUESTOS 25,40 €

Organismos donde obtener información sobre medidas de eficiencia energética (RD 1085/2015):
GTS: Gestor Técnico del Sistema, Web: www.enagas.es, Tel.: 902 443 700
CNMC: Comisión Nacional de los Mercados y la Competencia, Web: www.cnmc.es, Tel.: 914 329 600, Email: info@cnmc.es
IDAE: Instituto para la Diversificación y Ahorro de la Energía, Web: www.idae.es, Tel.: 913 146 673
CONSEJERÍA DE INNOVACIÓN, INDUSTRIA, TURISMO Y COMERCIO: Web: www.cantabria.es/industria, Tel.: 942 20 00 33

Datos de contacto para reclamaciones de personas físicas

En caso de tratarse de una persona física, para reclamaciones sobre el contrato o facturación, puede dirigirse a la Consejería de Innovación, Industria, Turismo y Comercio de la Comunidad Autónoma de Cantabria en el teléfono 942 200 033, o a la entidad de resolución alternativa de litigios J.A. de Consumo de la C.A. de Cantabria en el teléfono 942 208 497, sistema al que están acogidas las comercializadoras del grupo EDP para ofrecer a sus clientes la posibilidad de resolver gratuitamente cualquier discrepancia de forma amistosa e independiente. Para más información consulte en: www.edpenergia.es

EDP COMERCIALIZADORA, S.A.U. - C/ General Concha, 20. 48010 Bilbao (Bizkaia)- Inscripción 1ª, R.M. de Bizkaia. Tomo 3728. Folio 204. Hoja BI-23.997 CIF A-95000295

DATOS DE LA FACTURA DE ELECTRICIDAD

IMPORTE FACTURA: 59,57
Nº factura:
Periodo de consumo: 04 de Enero de 2020 al 04 de Febrero de 2020
Fecha de cargo: 15 de Febrero de 2020
Número de contrato:

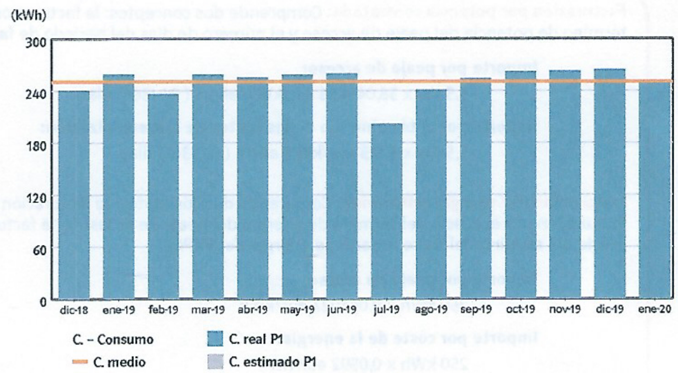
FACTURA RESUMEN

Por potencia contratada	19,17
Por energía consumida	25,81
Suplemento Territorial	1,08
Impuesto electricidad	2,35
Alquiler equipos de medida y control	0,82
Impuesto aplicado IVA (21, %)	10,34
TOTAL IMPORTE FACTURA	**59,57**

INFORMACIÓN DEL CONSUMO ELÉCTRICO

	Periodo1 0h-24h
Lectura Actual (Real) 04 Febrero 2020	13.199
Lectura Anterior (Real) 04 Enero 2020	-12.949
Consumo del periodo (*)	250 kWh

(*)Datos medida horaria distribuidora en: **http://viesgodistribucion.com/**



Su consumo medio diario en el periodo facturado ha sido de 1,49 €
Su consumo medio diario en los últimos 14 meses ha sido de 1,56 €
Su consumo acumulado del último año ha sido de 2.984,73 kWh

DATOS DEL CONTRATO

TIPO DE CONTRATO: **PVPC sin discriminación horaria.**
TIPO DE CONTADOR: **Con contador inteligente efectivamente integrado en el sistema de telegestión.**

Peaje de acceso: 2.0A
Referencia del contrato de suministro (RÉGSITI, S.L.U.):
Referencia del contrato de acceso (Viesgo DISTRIBUCION):
Fecha final contrato: 01 de Julio de 2020 (renovación anual automática)
Fecha emisión factura: 08 de Febrero de 2020

Potencia contratada: 5,5 kW

Código unificado de punto de suministro CUPS:
Atención al cliente (RÉGSITI, S.L.U.): 900 10 10 05 (gratuito)
Averías/Urgencias (Viesgo DISTRIBUCION): 900 10 10 51
Reclamaciones (RÉGSITI, S.L.U.): 900 10 10 05 reclamacion@regsiti.com
Dir. postal reclamaciones (RÉGSITI, S.L.U.): C/ Isabel Torres nº19 (PCTCAN)-39011 Santander

Para reclamaciones sobre el contrato de suministro o facturaciones podrá dirigirse a la Dirección General de Innovación e Industria (órgano competente en materia de energía) de la Comunidad Autónoma de Cantabria, en el teléfono 942 20 00 33 o a través de su página web www.dgicc.cantabria.es.
Adicionalmente, en el caso de tratarse de una persona física, podrá dirigirse a la Dirección General de Comercio y Consumo (órgano competente en materia de consumo) de la Comunidad Autónoma de Cantabria, en el teléfono 942 20 84 97 o a través de su página web www.cantabria.es.

DATOS DE PAGO

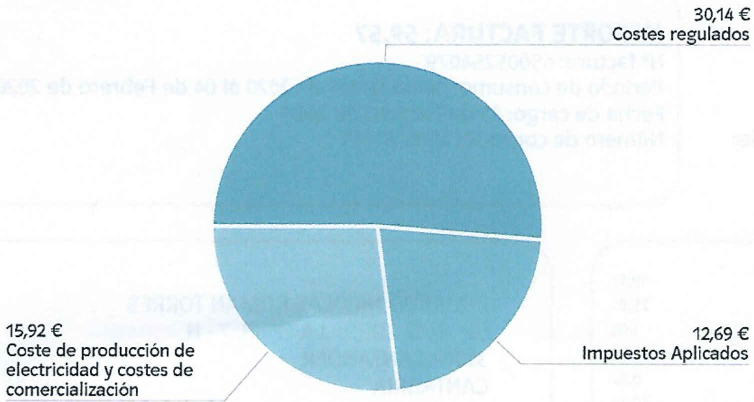
INFORMACIÓN PARA EL CLIENTE

Te informamos de que en esta factura ya estamos utilizando el consumo horario de tu contador inteligente. Como consecuencia de esto, el consumo informado por diferencia de lecturas puede diferir por redondeos de decimales del realmente facturado.
Estamos cerca de ti para hacerte la vida más fácil en tu oficina de Paseo Pereda 30 de Santander

Régsiti Comercializadora Regulada, S.L.U. Inscrita en el Registro Mercantil de Cantabria, Tomo 1007, Folio 141, Hoja S-20817 – NIF B39702436. Domicilio Social: Calle Isabel Torres, 19 – 39011 Santander

DESTINO DEL IMPORTE DE LA FACTURA

El destino del importe de su factura, **59,57 euros**, es el siguiente:



Costes regulados

11,88€ Incentivos a las energías renovables, cogeneración y residuos

12,16€ Coste de redes de transporte y distribución

6,10€ Otros costes regulados (incluida la anualidad del déficit)

A los importes indicados en el diagrama debe añadirse, en su caso, el importe del alquiler de los equipos de medida y control, además de otros conceptos recibidos de la distribuidora (no energía).

DETALLE DE LA FACTURA

Facturación por potencia contratada: Comprende dos conceptos: la facturación por peaje de acceso (resultado de multiplicar los kW contratados por el precio del término de potencia del peaje de acceso y el número de días del periodo de facturación) y la facturación por el término fijo de los costes de comercialización.

Importe por peaje de acceso:	
5,5 Kw x 38,043426 eur/kW y año x (31 /366) días	17,72€
Importe por el término fijo de los costes de comercialización:	
5,5 Kw x 3,113 eur/kW y año x (31 /366) días	1,45€

Facturación por energía consumida: Comprende dos conceptos: la facturación por peaje de acceso (resultado de multiplicar los kWh consumidos en el periodo de facturación por el precio del término de energía del peaje de acceso) y la facturación por coste de la energía (resultado de multiplicar los kWh consumidos por el precio del término del coste horario de energía del PVPC).

Importe por peaje de acceso:	
250 kWh x 0,044027 eur/kWh	11,01€
Importe por coste de la energía:	
250 kWh x 0,0592 eur/kWh	14,80€
Suplemento territorial por tributos autonómicos de la Comunidad Autónoma donde se ubica su punto de suministro del año 2013.	1,08€
Subtotal	46,06€

Impuesto de electricidad: Impuesto especial al tipo del 5,11269632% sobre la facturación de la electricidad suministrada según lo dispuesto en la Ley 28/2014.

Impuesto de electricidad: (46,06 x 5,11269632%)	2,35€

Alquiler de equipos de medida y control: Precio establecido que se paga por el alquiler de equipos de medida y control.

Alquiler de equipos de medida y control: (31 días x 0,026 eur/día)		0,82€
Subtotal otros conceptos		3,17€
IMPORTE TOTAL		**49,23€**

Impuesto de aplicación: Impuesto IVA al tipo del 21, %

Impuesto IVA (21, %)	21, % s/ 49,23	10,34€

TOTAL IMPORTE FACTURA **59,57 €**

Referencias regulatorias:
Precios de los términos del peaje de acceso publicados en Orden ETU/1282/2017.
PVPC calculado según RD 216/2014.
Costes de comercialización publicados en RD 469/2016 y Orden ETU/1948/2016.
Precio de los equipos de medida y control establecido en IET/1491/2013 e ITC/3860/2007.

(*) Suplemento territorial por tributos autonómicos de la Comunidad Autónoma donde se ubica su punto de suministro del año 2013.
Periodo regularización: 31/12/2012 a 31/12/2013 — Potencia en periodo (kW): P1 5,500
Energía activa (kWh): P1 3054,00 — Número de cuotas de regularización por cada mes de consumo: 7

INSTALACIONES RECEPTORAS INDIVIDUALES DE GAS Y APARATOS (*)

CERTIFICADO DE INSPECCIÓN / INFORME DE REVISIÓN

Orden Nº
Cl. Actividad: **Equipo responsable:**
Fecha / Hora Creación: **Fecha / Hora Ejec. prevista:**

DATOS DEL CLIENTE

DATOS DE LA INSTALACIÓN

CUPS: **Suministrador:**	**Distribuidor:** **C.I.F.:**	**Tipo de gas** [X] GN ☐ GLP canalizado

APARATOS INSTALADOS

Aparato	Tipo	Marca	Modelo	Año	Potencia (kW)
Caldera Gas	ESTANCA	FAGOR	FEE 20	1999	23,00

DATOS DEL INSTALADOR QUE CERTIFICA

Nombre y Apellidos:	**D.N.I.:**	**Categoría:**
Empresa instaladora:	**C.I.F.:**	**Categoría:**

CERTIFICA: Haber sido comprobada en sus partes visibles y accesibles la instalación receptora individual de gas y el funcionamiento de los aparatos de gas conectados a la misma, habiéndose obtenido como resultado:

[X] **NO existen anomalías** ☐ **Existen anomalías**

Anomalías principales (Ver dorso)
Anomalías secundarias (Ver dorso)

SITUACIÓN EN QUE QUEDA LA INSTALACIÓN

[X] En servicio
☐ Precintada instalación por Anomalía Principal
☐ Precintada parcialmente instalación por Anomalía Principal
☐ Precintado aparato por Anomalía Principal
☐ Instalación con Anomalías secundarias. PLAZO MÁXIMO CORRECCIÓN DEFECTOS 6 meses, a excepción de faltas de estanquidad secundarias que se deben corregir en un plazo inferior a 15 días naturales
☐ Aparato con Anomalías secundarias. PLAZO MÁXIMO CORRECCIÓN DEFECTOS 6 meses

ANÁLISIS DE COMBUSTIÓN

	ºC Temp. Amb.	ºC Temp. Gases	ppm CO corregido	% O2	Lambda	% CO2	Mbar Tiro	% Rendimiento	ppm CO ambiente	Nº serie Analizador
Análisis 1:	26,10	89,60	76	14,90	3,44	3,46	0,070	92,40	0	
Análisis 2:										

PIEZAS sustituidas

PIEZAS	
IVA	
TOTAL	

Relación de PIEZAS sustituidas:

Este documento no es válido como justificante de pago

OBSERVACIONES (Indicar aparatos precintados)

☐ El Cliente/Usuario NO DEJA CORTAR instalación/aparato con Anomalía Principal

EL CLIENTE, USUARIO o REPRESENTANTE		**Empresa instaladora:**	
			Hora inicio 16:35:00 **Hora fin** 16:53:00

(*) Este documento será válido como Certificado de Inspección Periódica conforme a lo establecido en el RD 984/2015, de 30 de octubre, por el que se regula el mercado organizado de gas y el acceso de terceros a las instalaciones del sistema de gas natural, exclusivamente cuando el mismo se expida dentro del año natural en el que corresponda realizar la inspección periódica obligatoria conforme a los plazos establecidos en la normativa vigente (RD 919/2006, de 28 de julio e ITC-ICG 07 'Instalaciones receptoras de combustibles gaseosos'). En el resto de casos será considerado como Informe de revisión de las Instalaciones receptoras y aparatos de combustibles gaseosos.

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