TALLINN UNIVERSITY OF TECHNOLOGY

FACULTY OF CHEMICAL AND MATERIALS TECHNOLOGY

DEPARTMENT OF MATERIALS SCIENCE

Compatibility Analysis Of Jõgeva District Heating Network To 4th Generation District Heating

Master Thesis

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Materials And Processes Of Sustainable Energetics, M.Sc.

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Declaration

Hereby I declare that this master thesis, my original investigation and achievement, submitted for the master degree at Tallinn University of Technology has not been submitted for any degree or examination.

Name of the student: ……………….

Date and signature: ……………….

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ABSTRACT

This project aims to estimate possible consequences in case of installing a flue gas condenser to the district heating (DH) network. Possible outcomes of the project are also discussed, such as renewal or redesigning of the district heating network, expected energy savings, economical consequences, and concerns about public health. The thesis work was carried out with empirical data of DH network in Jõgeva. Afterwards, the data required for calculations were obtained from NetSim network simulator software. The thesis consists five sections. The first three chapters provide theoretical information for the following chapters, which the calculations were explained, and the results were discussed. Each paragraph below is abstract of the chapters, respectively.

Chapter 1: Introduction to the topic was carried out. Importance of district heating and current trends were mentioned. Aim of study and literatüre study were explained.

Chapter 2: District heating sector in Estonia described. Energy supply and demand, industry, and legislations in Estonia discussed.

Chapter 3: Fourth generation of district heating was described and explained. The health risks related to district heating networks which operate on lower temperatures were explained, current water treatments were described.

Chapter 4: The initial data, methods and limitations were described. Afterwards, the basic data which was obtained from the simulations were explained. The results of the simulaiton models were analysed.

Chapter 5: Discussion about the results and the hypothesis was carried out in the conclusion section

ACKNOWLEDGEMENTS

This project would never be done without the help of several people. I want to recognize their support during the development. First of all I am very grateful to Eduard Latõšov, my supervisor who suggested me the project. I want to thank him for all his guidance and improvements. Also, I am very thankful to Vladislav Mašatin, my co-supervisor who has helped compiling information and providing me the data from AS Tallina Küte.

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LIST OF ABBREVIATIONS AND ACRONYMS

C: Celsius

EJ: Exajoules

GW: Gigawatts

GWh: Gigawatt hours

K: Kelvin

kms: Kilometers

kPa: Kilopascals

kW: Kilowatts

kWh: Kilowatt hours

kt: Kilotonnes

m: Meter

mm: Milimeter

m^2: Square meter

Mtoe: Million tonnes oil equivalent

MW: Megawatts

Pa: Pascals

PJ: Picojoules

TWh: Terawatt hours

W: Watt

CHP: Combined heat and power

COP: Coefficient of performance

DH: District heating

EE: Estonia

EUR: Euro

EU: European Union

FGC: Flue gas condenser

GDP: Gross domestic product

GHG: Greenhouse gas

IEA: International Energy Agency

LED: Light emitting diode

LTDH: Low temperature district heating

PE: Primary energy

RES: Renewable energy sources

TJA: Tehnilise Järelevalve Amet

TPES: Total primary energy supply

USA: United States of America

UV: Ultraviolet

LIST OF FIGURES AND TABLES

1. Introduction

District heating (DH) systems are the most economical way to provide heating, steam and hot water to urban areas with high population density, according to the Danish Board of District Heating. Using heat produced during electricity generation or from factories, the technology makes a significant contribution to the efficiency of the overall energy sector. District heating systems can also use renewable energy sources such as biomass, municipal waste and biogas. District heating systems currently provide over 60% of heat and hot water in Nordic and Eastern European countries, however, only a few percentage of them were modernised in many EU member states [1].

The benefits and significant potential for reducing primary energy consumption of DH have also been recognised by the European Commission. The recently adopted Energy Efficiency Directive asks member states to provide a cost-benefit analysis of the technology's potential, as well as evaluate the savings that could be made with cogeneration and cooling networks. However, there are concerns about existing DH networks in Northern, Central and Eastern Europe countries. The networks are considered at risk of failing or collapsing due to lack of modernization, and it is feared that may lead the operator companies to bankrupt. Thus, recent efforts prioritize saving the existing networks, in order to meet the targets of Energy Efficiency Directive [2, 3].

Currently, there are ongoing renovation works in some of the European countries. For instance, the financial support was provided by KfW Entwicklungsbank of Germany, for rehabilitation of DH systems in Serbia. The funds have enabled the operator companies to renovate their pipe networks, purchase higher efficieny boilers or replace those running on coal or heavy oil, which often generate heat very inefficiently. It was stated that over 50% of the generated heat is lost during transportation by a Japan study in 2005. Results of the study show that the insulation of the pipes, which carry it underground or above ground to consumers, had deteriorated over time. According to the study, more than 32% of the district heating equipment is over 30 years old in some areas in Romania, whereas 50% of the infrastructure is between 20 and 30 years of age. Rate of heat losses is 22% in Estonia, according to 2013 IEA report [4, 5].

Renovation also tends to push consumer bills up. That may lead the consumers switching to cheaper but more pollutant primary heat sources. However, it is expected to be prevented with the help of EU's existing and new funding options, such as the Cohesion Policy, but also the Energy Efficiency Fund and the Innovative Financial Instruments [3].

1.1. Aim of Study

The goal of the project is to identify the challenges in case of using low temperature district heating with supply temperatures as low as 55 C degrees in residential heating and domestic hot water systems, and to suggest solutions in Jõgeva district heating network.

Due to the fact that adapting a new technology would require adjustments on the existing network, it was studied to define the possible outcomes of transition to low temperature district heating. The research took into consideration existing buildings. The calculations were carried out to meet the same heat demand for maintaining the same level of comfort at the end-user side. Also, sanitation methods for Legionnaires' disease prevention were studied. Thus, the project aims to detect any possible problems in district heating network by focusing on the supply side rather than the end-user. Furthermore, it was studied to calculate the possible energy and greenhouse gases savings by installing a flue gas condenser in boilerhouse, since reducing both the supply and the return temperatures would decrease the amount of the heat losses, and increase the efficiency of the flue gas condenser. The effects that can occur on the network and the pipeline were studied, and then transformed into economical results.

1.2. Literature Study

Nowadays, there is an important effort on increasing the overall efficiency in district heating networks. Several studies, projects and papers are written by the experts on this topic. Moreover, recognition of the low temperature district heating and mention of the technology in several legislations stress that improving the energy efficiency and the low temperature district heating networks are trending topics.

Many papers could be read to know more about the improvement issue. In developing this project most of them have been a good source of information. The most useful of them were the publications of the International Energy Agency (IEA), and its department of District Heating and Cooling. Some other papers of EU Comission and EU Directives were also helpful for better understanding the future expectations and targets. Other associations, such as Euroheat & Power or Danish Board of District Heating, can also give extensive information about related topics.

2. District Heating in Estonia

Estonia is considered as a self-sufficient country in terms of energy supply. Most of the electricity and heat demand is supplied by national sources. The development of the present energy systems are linked to the infrastructure which was built under the former Soviet administration. The main drawback of that situation is lacking of practical alternatives to oil shale. Oil shale reserves provides energy independence for heat and electricty production, however, energy convertion process results with high amount of carbondioxide emission. Thus, shale oil sources are neither sustainable nor ecologically friendly. This history of centralised planning and necessary reliance on a single primary energy resource indicates that remarkable steps are required for adapting the system to enable future applications of new environmentally-friendly energy technologies in both demand and supply sides.

Energy policies of Estonia has been subjected to changes in recent years, in order to conform with the latest energy directives of European Union. There are previous and ongoing researches in Estonia, about reduction of dependency on oil shale sources for electricity production. The target is increasing economical benefits and variation of the energy supply, and reducing carbondioxide emissions. In other words, it is intended to have more efficient and sustainable, and less fragile energy economics. Better energy efficiency is an essential element of new energy policies. The government is pursuing market-based policies that is expected to promote necessary innovation and diversification in Estonian energy markets.

National Development Plan of the Energy Sector aims to meet primary goals of 2020 and give an outlook to 2050 goals. The plan addresses challenges below:

- Security of energy supply
- Reduction of fossil fuels
- Dependance on single natural gas supplier
- More efficient energy consumption
- District heating
- Increasing the share of renewable energy

DH network infrastructure improvements are one of the key issues to get better energy efficiency. The potential of heat energy savings in residential areas of Estonia is high indeed. That’s why, Estonian government supports energy projects on global warming, energy efficiency and district heating networks by subsidizing financially. Also, it is unavoidable to support energy projects on mentioned topics, due to dependency on district heating networks in Estonia.

2.1. Energy Supply and Demand

Total primary energy supply (TPES) in Estonia was 5.7 million tonnes of oil-equivalent (Mtoe), according to IEA. Major source of primary energy is oil shale with share of 70%. It is followed by biofuels and waste, natural gas, oil and other renewables with shares of 13.9%, 9.5%, 8.6%, and 0.7%, respectively. Residential areas is where the energy consumed the most (32,8%) and the rest of the shares are shown on graph at Figure 2.1 [5].

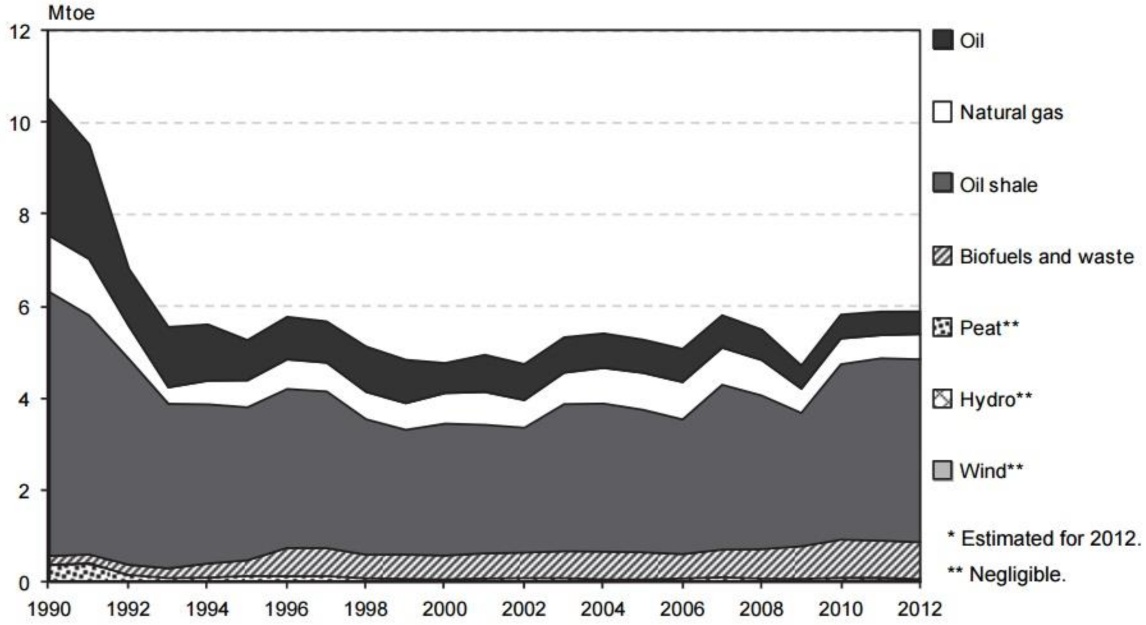


Figure 2.1: Total primary energy supply 1990-2012* *(Source: IEA)*

34.3% of the fuel consumption comes from oil products, and 20% of it is used for electricity production. Biofuels has 17.5% share of the fuel consumption, as it is used for heating dominantly (16.7%). Also, natural gas and coal are other sources of fuel consumption with shares of 7.1% and 0.4%, respectively [5].

In 2012, total energy supply (TPES) per capita was 4.3 tonnes equivalent (toe) per person, which is rather lower than the IEA average (4.5 toe/person). Estonia is ranked 11th on the list of energy supply per capita among IEA members. That ranking is behind Luxembourg, Canada, USA, Finland, Norway, Australia, Belgium, Korea, Sweden and the Netherlands.

The numerical value of TPES per capita has increased by 23% since 2002, whereas the same ratio has decreased by 9% for the average of IEA member countries [5].

Total heat energy production was 9.1 TWh in 2011. Electricity power plants and heating power plants had produced 3.5 TWh and 5.6 TWh, respectively. The amount of heat energy produced for DH systems was 6.3 TWh in 2011. Approximately, 3.9 TWh of that was consumed by residential areas. The primary energy sources are shown on Figure 2.2 [5,6].

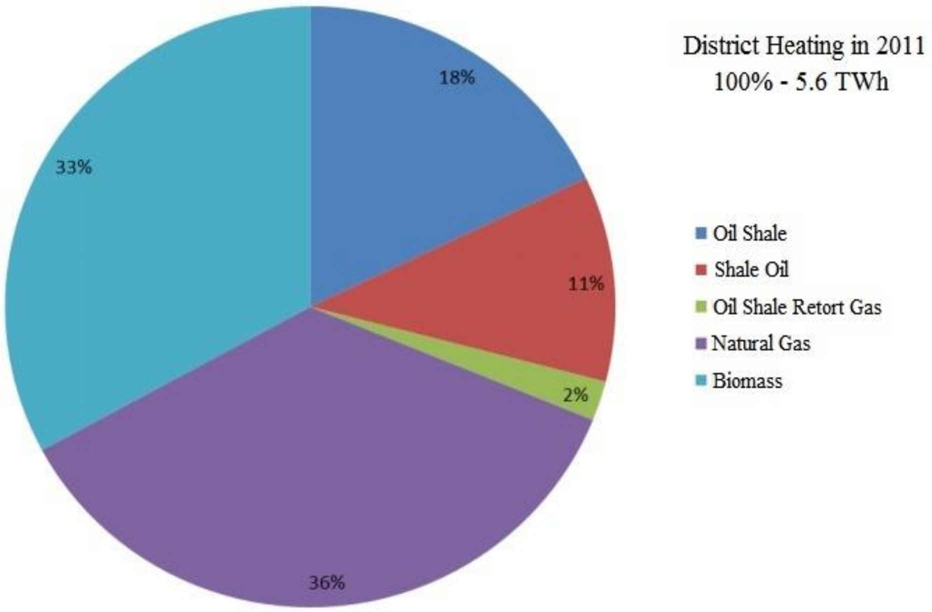


Figure 2.2: Primary energy sources of heat production for DH in Estonia in 2011. *(Source: IEA)*

Residential areas has the biggest share among other consumption types (transportation, industrial and other sectors). The main reason of that high demand is cold climate and the condition of old residential buildings. Also, low level of industrial activity in Estonia is another reason to that situation.

Average percentage of losses at DH networks is 22% [5]. Better insulation of pipes and measures of energy efficiency help to reduce that number, however, the increase in number of customers counterbalances that.

There are 630 000 housings in Estonia, approximately. The energy consumption density of current housings is 200 kWh/m^2/year. Housings and residential areas in Estonia consist of commercial and residential buildings, which are mostly old. Electricity is generally not preferred for heating purposes, but for electrical and electronical tools. DH networks are mostly preferred for heating purposes, and they serve 70% of the population of Estonia. There are ongoing efforts to reduce the energy consumption density, and the number is expected decrease to 150 kWh/m^2/year [6].

In electricity production, the share of CHP plants is at 10.4%. Recently, 50% of the gas primary energy sources (2.5 PJ) are converted to eletrical energy at CHP plants. According to the recent development plans, the share of CHP plants in energy production would rise to 20% by the year of 2018. Thus, pricing strategies about the heat energy converted at CHP plants are important; since the demand on electricity is expected to rise and the demand on heat energy is expected to decrease, due to energy efficiency applications [6].

2.2. Districts

DH plants have high potential to offer flexibility by using various primary energy sources, such as natural gas, fuel oil and renewable fuels. Therefore, DH systems play an important role in energy security and meeting future targets of energy policies. DH networks can supply heat energy for residential, commercial and industrial needs. Typically, buildings need space and water heating, while industrial companies need steam and hot water.

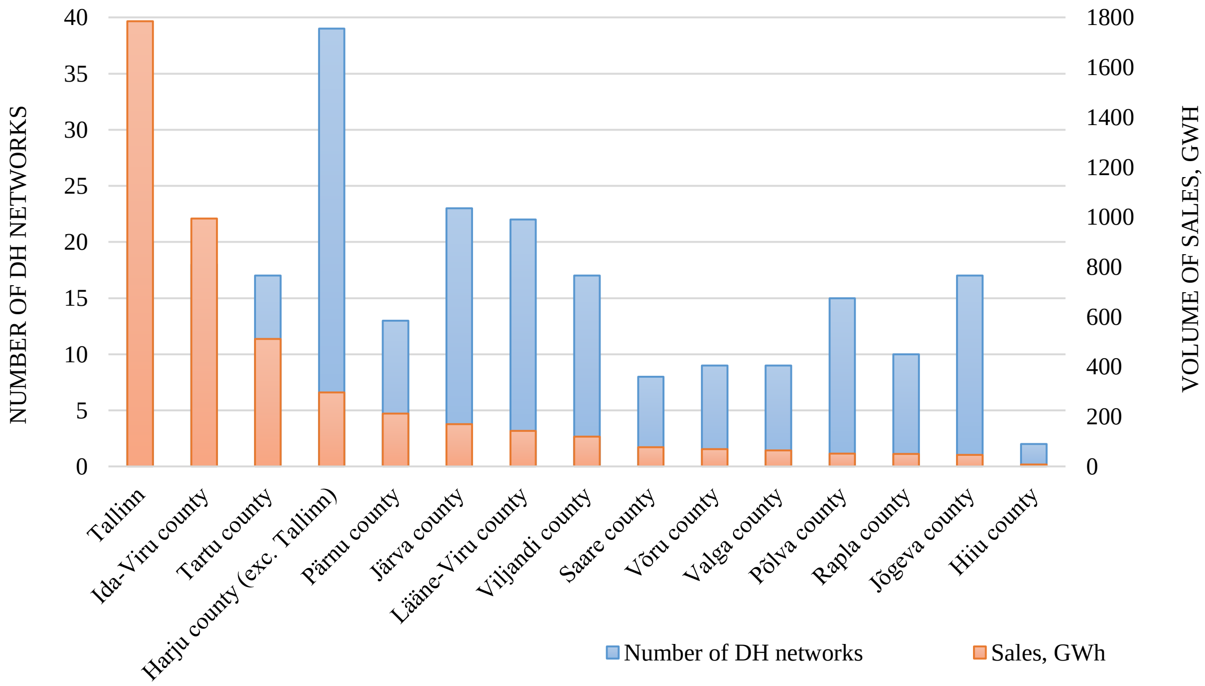


Figure 2.3: Number of DH networks and sales volumes in Estonian counties (2013)

(Source: Eesti Arengufond)

In Estonia, the heat energy supplied by DH networks accounts for 30% of overall energy consumption in residential areas. 70% of the populated areas are covered by DH networks, which consist 200 power plants in 230 districts, at total [5]. DH networks are owned by municipalities in some regions, however, most of the networks are owned by private companies. Primary energy sources are biomass, natural gas and oil shale.

The established DH network infrastructures of the country is broad but outdated. Total size of the networks are 1 400 kms in length. There are 230 districts at total, and their sizes vary between 0.25 GWh to 1 585 GWh in transmitted heat energy [6]. Figure 2.3 shows the sales volumes in Estonian counties. Most of the networks are old, thus, they have low performance. The average percentage of losses is at 22%, and it is aimed to reduce that number to 15%.

All of the consumers are obligated to engage DH network of their respective district. Only customers, who were already living there before the infrastructure work starts, have the option to not to engage [7]. However, there is not any choice to switch out of DH network if the building was already engaged. That may make operator company of a DH network the monopoly of its respective district.

Any changes in consumer prices are executed after the approval of the competition authority. Upper limits of the heat energy prices are specified for each and every district. Volume of sales, type of primary energy source and technical performance of DH system affect the economical revenues of operator company, as well as company's ability to invest in efficiency and sustainability of DH network.

The cost of primary energy sources, especially oil shale and natural gas, has increased in recent years. Thus, some companies are known to state that the cost of primary energy sources exceeds 70% of total costs, and to apply the competition authority for raising the prices. The price of heat energy is trending downward in recent years. Nonetheless, if prices go up due to costs of improvements at network or a possible energy crisis, the consumers may switch to cheaper yet pollutant fuels, especially in smaller towns and cities. Therefore, new regulations in District Heating Act are expected to promote companies and consumers to use DH systems.

2.3. Industry

Current efforts to extend the variety of primary energy sources are being executed by Estonian government. Biomass, municipal waste and waste heat energy of cogeneration power plants are being studied recently. Therefore, new biomass-powered CHP plants has started to operate in recent years.

Industry is regulated by District Heating Act 2003, which regulates production, distribution, and sales of the heat energy. It was subjected to some changes in order to conform with 2012/27/EU directive of European Union. Existence of privately or government owned companies are required to run the production, distribution or sales activites [7].

Estonian Competition Authority was assigned by District Heating Act as the only board to approve heat energy pricing lists. Therefore, CHP plant operator companies are required to declare electricity and heat energy production, and their revenues. Technical inspections of industrial heat power plants are executed regularly by national technical regulatory authority, Tehnilise Järelevalve Amet (TJA).

DH networks are generally in service in relatively bigger cities and towns. Also, solid waste powered new power plants are started to operate in recent years. Solid waste management of the country is effective, and 450 kilotons (kt) of municipal waste is collected per annum. The latest solid waste power plant started to operate in May 2013. 220 kt of the municipal waste is consumed as primary energy source annually at that power plant. Capacity of the power plant is 17 MW of electrical and 49 MW of heat energy. Biomass, municipal waste and waste heat sources are actively used, and the respective technologies are being improved in Estonia [6]. The effect of new power plants on heat energy production is shown on Figure 2.4.

The consumers in Estonia are spending 400 million EUR per year on DH services. Even though, at least 44 million EUR per year of that amount is estimated to be paid needlessly for heat losses, that is a good indicator to comprehend the importance of DH systems for reducing energy consumption and meeting future targets [5].

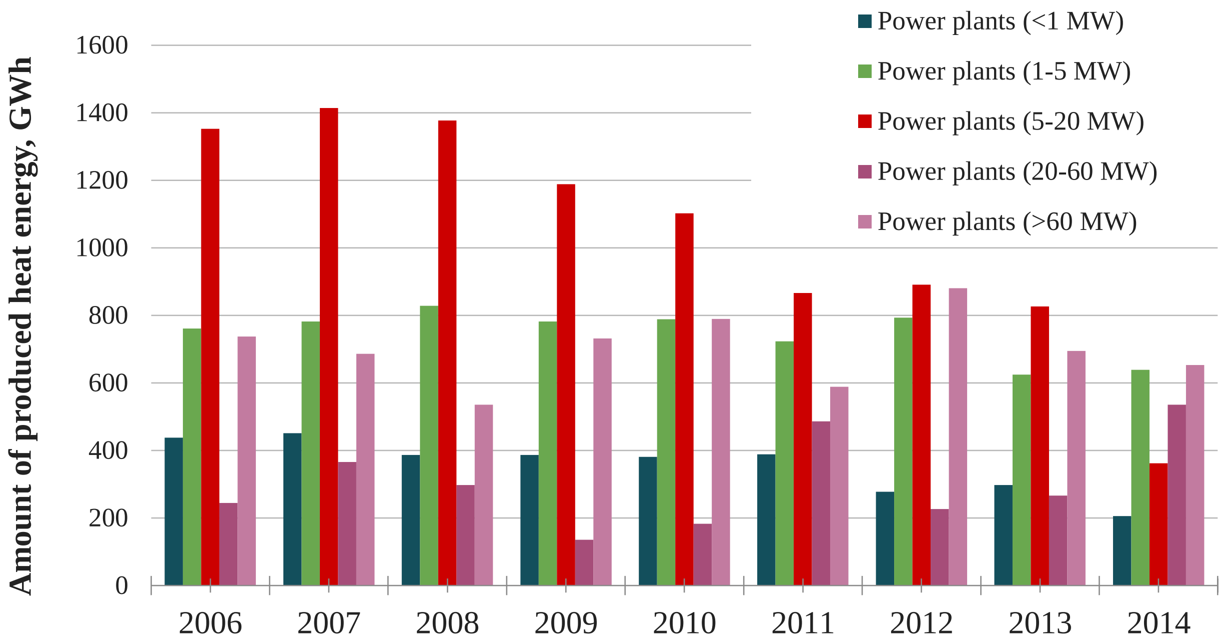


Figure 2.4: Annual heat production in different type of power plants

(Source: Eesti Arengufond)

The Environmental Investment Centre is responsible for managing the funding requests of construction of DH systems, including boilers improvements and financing heat producers for using CHP. In 2009, the centre offered 40 million EUR at total for funding 60 different DH projects in two-year period. Major electricity producer Elering AS, which is owned by state, offers fundings for electricity production projects. In year of 2015, Elering AS has paid 72 million euros at total to subsidize 151 GWh of high efficiency congeneration. Also, in the first three months of the year, high efficiency cogeneration subsidies totaled 1,5 million EUR in Estonia [8,9]

2.4. Regulations, Consumer Rights and Pricing

District Heating Act 2003 requires establishing DH network for municipalites without natural gas infrastructure or alternative primary energy sources. Hence, it is mandatory to use DH for residential heating purposes. If the consumer decides to use renewable sources instead of DH, they can disconnect to the network.

District Heating Act regulates production, distribution, and sales of the heat energy. The act was entered into force in February 2003, and it was subjected to some changes since then. Existence of privately or government owned companies are required to run the production, distribution or sales activites.

To regulate consumer prices, supervision and approval of the competition authority is also required by the act. Also, electricity market regulations state that the competition authority is the only board to apply for pricing issues, and it is compulsory for owner company of a CHP plant to declare electricity and heat energy production, and their revenues respectively. The mission of the competition authority is supervision of pricings, in order to determine the cost of heat energy by considering cross-subsidization of electrical energy.

Prices may change regionally due to the zoning system. In general, small DH networks has higher prices, due to low sales volumes and outdated equipment. In first half of 2013, the weighted average price in 89 small districts (heat sales lower than 10 000 MWh/year) was 70.99 €/MWh, while the average of 33 larger districts was relatively chaper 57.96 €/MWh [6].

Upper limit of prices are calculated by the competition authority via their own methods and procedures. Since November 2010, the approval of the competition authoriy is mandatory to change prices for every heat energy supplier. Only bigger operator companies, which supply greater than 50 GWh/year, were required the approval before mentioned date. The others were required the approval of their local government [7].

The process of calculating the upper limit price is regulated by regarding the costs and estimated sales volume. In case of the upper limit price is not suitable for network operator company to cover the costs and earn profit, the company has the right to apply the competition authority for offering another price.

Current pricing policy supports the sustainable development goals. Maximum weighted average price is 57.96 €/MWh, and the upper limit is used as sales price, according to the regulations. Even though the prices range from a district to another, 400 million €/year is paid for district heating by the Estonian consumers, approximately. According to a 2009 study, it is stated that it is more expensive to use DH instead of electricity for residential heating purposes in 36 districts out of 164 districts. The conlusion of the study states that the main reasons are relatively higher prices and heat losses because of outdated equipments [5].

The percentage of heat losses is greater than 25% in 28 districts. According to the 2009 study of Estonian Technical Regulatory Authority, the consumers paid more than 44 million €/year extra to balance heat losses [5]. However, the compensation are not reflected to consumers in some districts.

In Estonia, a network operator company can monopolize its market due to several reasons:

- Switching to different type of primary energy source is generally difficult, and sometimes impossible due to infrastructure;
- It is required to obtain licence of emissions for every primary energy source;
- Extra electricity supply may become a complicated task due to the limitations of the electricity grid;
- The vast majority of the DH networks are individual small networks.

Taking economical actions are hard decisions for operator companies, while costs are unclear and systems are unefficient. Improving thermal and economical efficiency by upgrading the conditions of DH networks is an urgent need in Estonia, as needed as in other countries.

Measuring the consumption of an individual house or apartment is often not possible at most of the DH networks. Also, it is known that total consumption is divided into the number of buildings or apartments in some districts. The consumers receive their monthly bill even if the measurements are not economical or fair.

Previous upper limit of heating prices in Tallinn are shown on Figure 2.5 [10, 11]. Graph shows that the heating prices drop in recent years, due to renovations and improvements at DH network. Also, it can be seen on the graph that the prices are tend to drop in summer season.

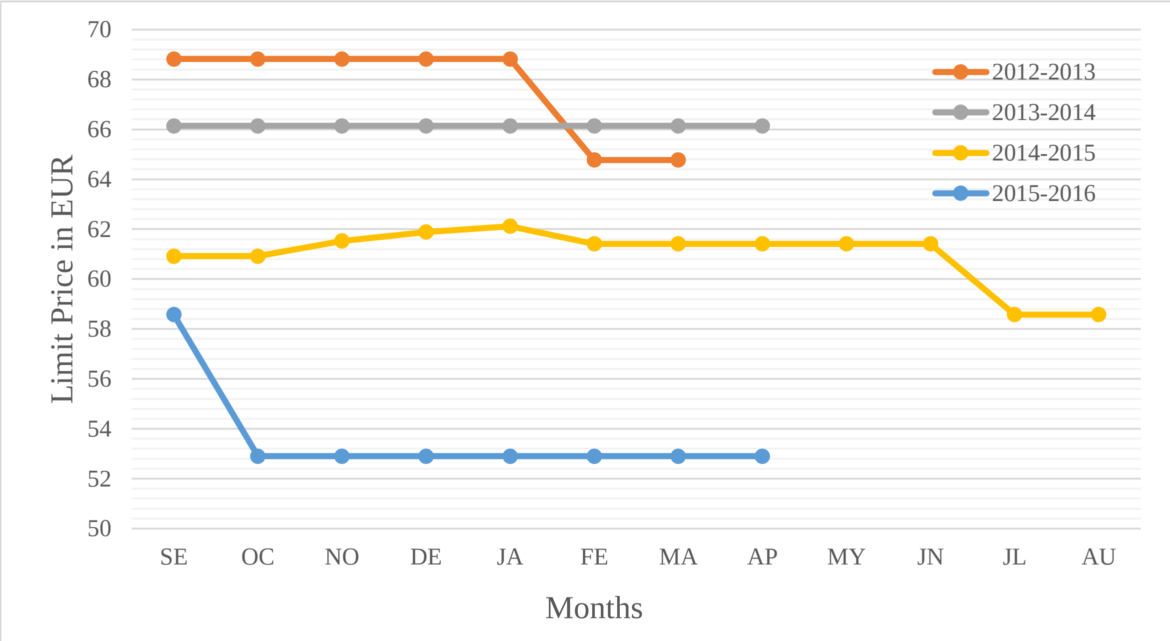


Figure 2.5 Maximum prices of heating in months in previous heating seasons

(Source: Tallinna Küte AS)

Estonia has simple income tax rates (at 21%) and undistributed profits are not taxed. With other taxes (the value-added tax and excise tax) total tax charge is at 34% of total income. Environmental taxes are split into four groups: pollution taxes, resource taxes, energy taxes and transport taxes. Resource taxes include mineral extraction charge, which is paid for the extraction, use or rendering unusable of mineral resources belonging to the state. Peat and oil shale extractions are subjected to the mineral resources extraction charge.

3. Fourth Generation of District Heating

The design criterias of future sustainable energy systems, which includes 100% renewable systems are described in this chapter. Those systems are generally based on combination of renewable energy sources (RES) such as geothermal, hydro, wind and solar power, together with other resources such as municipal waste, biogas and biomass. Such systems are expetced to be requried due to environmental impact, and possible alternative demands for food and material. For example, biomass resources in Europe are insufficient to balance the European energy demands. Affordable solutions to future sustainable energy systems must include a substantial focus on energy conservation and energy efficiency policies, in order to relieve the repression on biomass resources and investments in renewable energy [12].

According to the European Comission's 2015 report on Energy Efficiency, one of the targets of EU is to reduce Green House Gas (GHG) emissions by 2050 by 80-95% compared to 1990 [3]. GHG reduction is not only required for protecting the climate, but also beneficial in other ways. Reduction in GHG emissions means saving on fossil fuel imports, thus, increasing energy security, improving air quality and public health. Furthermore, it is expected to promote technological innovation, sustainable economic growth and job creation.

District heating (DH) infrastructures are important for increasing the energy efficiency, and thus making the precious primary energy resources meet future demands. DH includes a network of pipes connecting to the buildings in a district, town or whole city. Heat energy is served from centralised power plants or a number of heat energy producing units to residential areas. Any available source of heat energy can be used. Future sustainable cities with DH facility is highly compatible for combined heat and power (CHP) production, heat energy from municipal waste and various industrial waste heat sources, as well as geothermal and solar thermal heat. One of the future challenges will be about integrating DH with the electricity production and the transportation sector. Thus, future efforts are expected to include various processes of converting solid biomass into biogas, and different sorts of liquid biofuels for transportation fuel purposes [13].

The developments on DH has been going on according to the requirements of industry and society since the first time it was introduced. Thus, it was named after the type of transport media and the network temperature levels. The 1st generation DH system is steam-based system, yet the 2nd generation DH uses high network supply temperature above 100 C degrees. The 3rd generation DH represents the current DH system with moderate supply temperatures between 80 C and 100 C degrees. The 4th generation DH is also named as the low temperature district heating (LTDH) so far. It is a novel system, which is going to replace the existing 3rd generation DH systems. The network supply temperature is reduced down to consumer required temperature level at the 4th generation DH systems. That helps improving the quality of transmitted energy between the supply and demand sides. Moreover, LTDH system incorporated with reduced network temperature and well-designed DH network, has the potential to reduce heat losses during transmission up to 75% in comparison with the current systems [14]. Therefore, LTDH systems are capable of being economically more competitive than local heat generation systems in the areas with low heat density or with low-energy buildings.

Probably the most remarkable point of LTDH is the approach to existing issues. The traditional approach suggests to evaluate a DH system by the capability of heat energy production efficiently. However, the LTDH systems focus on the thermal comfort of the end-user at the start point. Afterwards, it addresses the issues on achieving better quality match between energy supply and consumption, finding the most economical way to satisfy the heat demand, through efficient transmission networks and supply systems based on waste heat and renewables. Therefore, this new approach starts by identifying suitable in-house substations for low-energy-demand buildings at low supply temperature, then addresses design efficiency and network reliability, and finally considers eco-friendly heat production [14].

3.1. Fundamentals

Typical city-wide DH system consists of heat generation units, DH networks, substations and end-user equipmenrs. The heat can be generated in CHP plants, municipal waste powered plants, geothermal plants, large-scale boilerhouses, or large-scale solar thermal plants, combined with peak-time and stand-by boilers. With the transition to renewable energy, fossil fuel sources in CHP plants are expected to be phased out gradually and replaced with renewable sources.

The low temperature district heating (LTDH) system is defined as a coherent technological and structured concept, which by means of smart thermal grids assists the suitable development of sustainable energy systems. LTDH systems provide the heat supply of low-energy buildings with less transmission losses and with the combination of integrated low-temperature heat sources within smart energy systems. The concept involves the development of an systematic and organisational framework to make cost efficient structures possible. An example scheme of a smart grid is shown on Figure 3.1

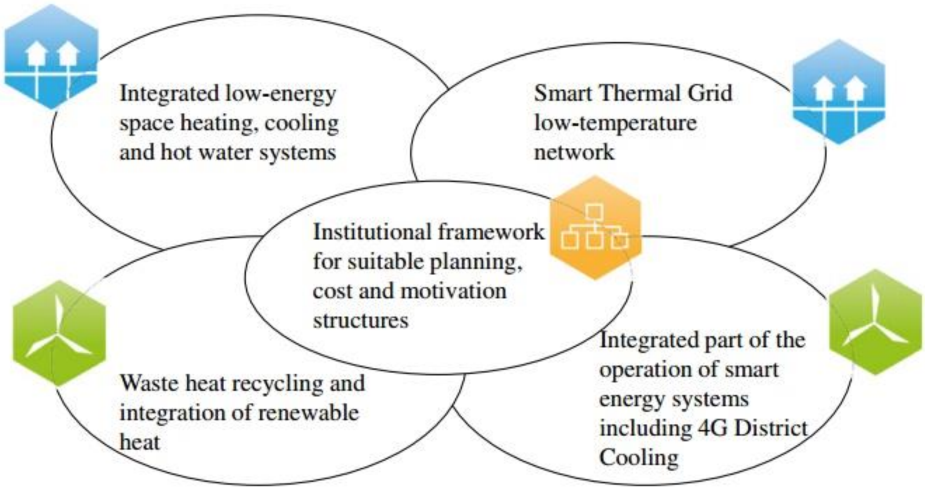


Figure 3.1: Illustration of the concept of 4th generation District Heating including smart thermal grids [20].

Much of the research on LTDH has been mainly carried out in European countries with high DH penetration rates. However, their studies are also of interest to other countries. In the EU, 2020 Framework strategy for tackling climate change focuses on three targets: reduction in emissions, increase in renewable energy supply, and improvemets in energy efficiency. The European heat energy markets for residential heating are endorsed as a key for the goal of reducing primary energy supplies in the recent EU Directive [2]. The directive states that “efficient district heating and cooling” should be a prioritized alternative in urban areas. In those regions, certain heat plans are requested to be developed for identifying heat synergy opportunities, such as waste heat utilization. Great energy-saving potential in the building sector needs to be handled for supporting efforts for energy-efficient urban areas.

The long-term target of EU is to cut greenhouse gas emissions to 80-95% by the year 2050. Supporting renewable energy by increasing its share in total energy consumption is required to achieve that low-carbon future [12, 18]. Special attention should be given to renewable energy investments due to its little share in total energy supply and its capital-intensive feature. Connoly et. al. argues that the planning of renewable heat generation technologies and their capacities should come after the building energy reduction. Thus, the energy production plants can be designed with smaller capacity, can save on capital investment and can improve their partial-load operation [19].

Extensive energy planning approach, which includes heating and electricity generation technologies, and end-user energy savings, is required to evaluate the entire energy system to achieve the best socio-economic effect. Such an approach has been studied in Denmark for planning 100% renewable energy supply system of future. Also, an extensive energy planning approach was implemented to the ‘Energy City’ project of Frederikshavn in Denmark[15]. Figure 3.2 shows the schematic of the extensive energy system planning approach of the study. Figure 3.3 shows the comparison between the DH supply cost and the building heat saving cost with a building heating demand reduction from 0% to 20% [15]. It shows that DH supply cost is higher than the average marginal cost of heat savings, among 3 scenarios made for the study.

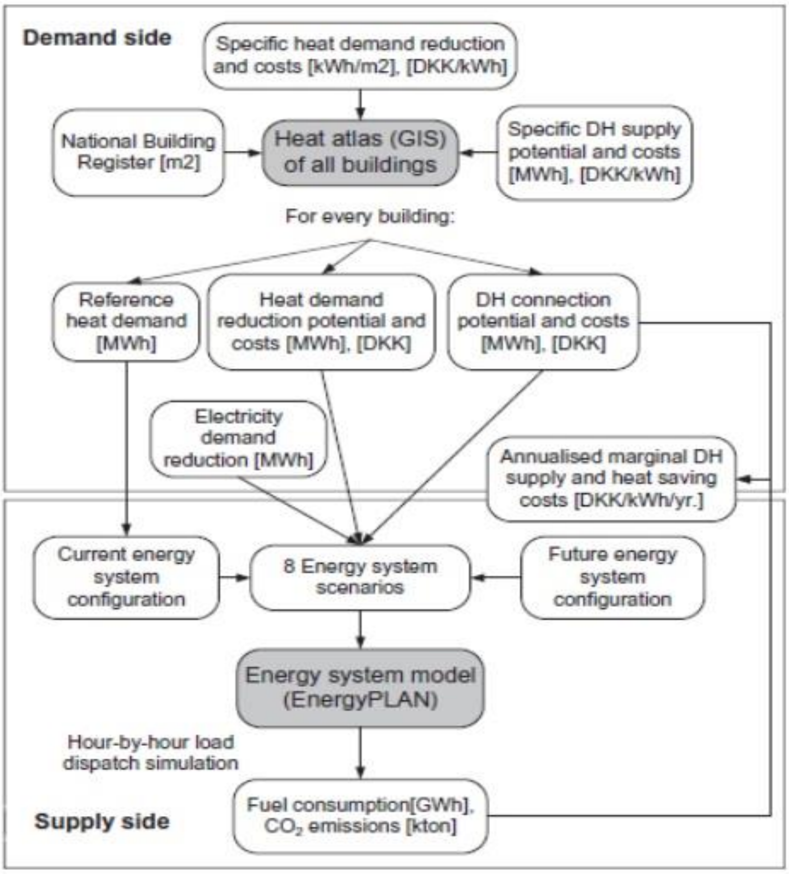


Figure 3.2 Overview of the integrated energy system analysis. [15]

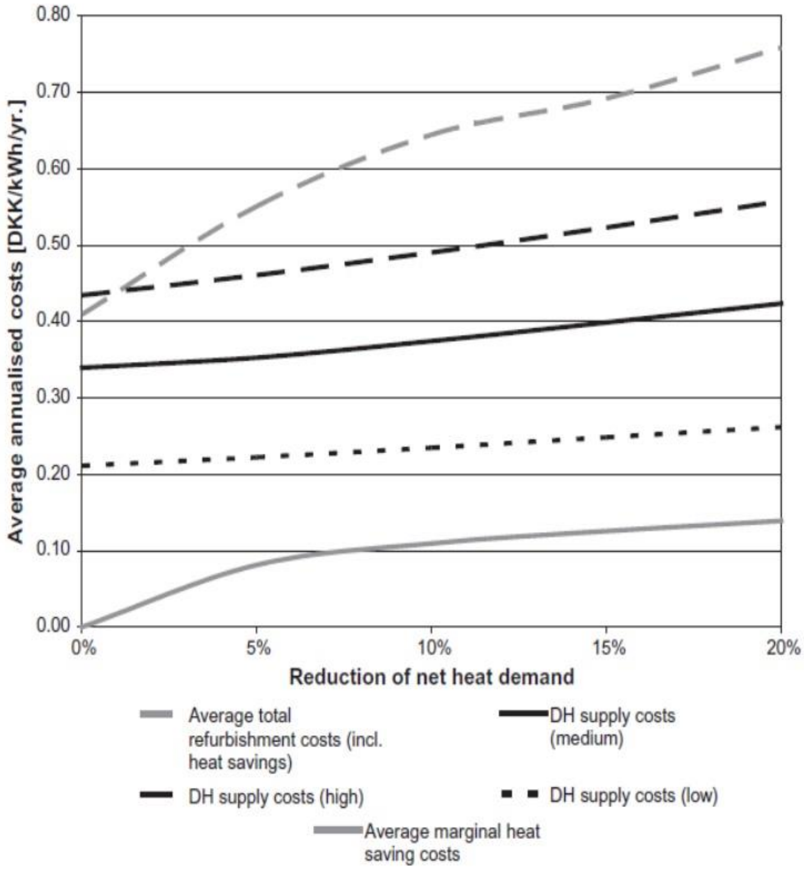


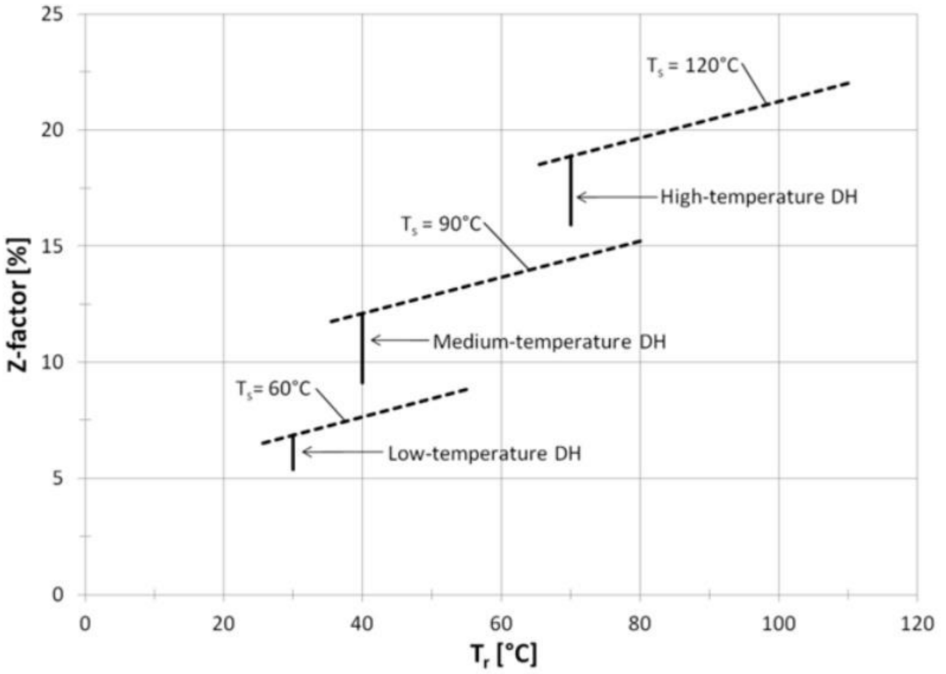
Figure 3.3 Cost curves for heat savings and district heating supply [15].

Morever, according to a 2012 study, reducing the heat demand results in smaller peak loads. That was stated to help saving capital investment and enabling more stable renewable energy plant operation. It is a cost-effective solution to achieve substantial building energy reduction, before investing in new renewable energy generation capacities for the long-term planning of the DH system [16].

If building heating demand would drop to half of the current level in Estonia, it would make the relative heat loss along the current DH network unacceptably high that government could no longer compansate by subvention. Reducing the temperature level in the network is the immediate and effective solution. Decreasing the temperature level of the network effectively reduces heat loss along pipelines. The heat loss can be further reduced with optimized network designs and better insulated pipes. This lower heat loss also means lower supply temperature drops in the flow direction than with 3rd generation DH. Most current heating systems were designed to be powered by fossil fuels, which have no problem generating higher temperatures. But, high temperatures will not be required for residential heating demands in future. The reduced network supply temperature matches better with the residential heating demand, and reduces losses from the energy quality (exergy) point of view.

With the lower supply temperature, less variation in the supply temperature can be occured along the pipeline. That reduces the risk of pipe leakages due to thermal stress, and the maintenance costs are reduced as well. Usage of plastic pipes is rendered possible by lower network temperatures in distribution areas with low pressures. In 3rd generation DH, metals such as steel and copper, are used to handle current combinations of temperatures and pressures. The reduced supply temperatures will also reduce the risk of water boiling in the network. This means lower risk of two-phase-flow in pumps and fast moving water walls, when pressurized steam escapes quickly through small pipe holes.

From the viewpoint of the heat supply side, there are also some advantages of LTDH. The profit from CHP plants greatly depends on the amount of power being generated. Low network supply and return temperatures enable more power to be extracted from steam expansion processes at the same heat load. The cost of heat generated in a steam turbine is determined by the resulting reduction in electricity production. The z-factor is the inverted value of the coefficient of performance (COP) defined for heat pumps. It can be seen how energy efficiency benefits from lower operating temperatures and that the z-factor is more dependant to the supply temperature than to the return temperature on Figure 3.4 [19]



Fgiure 3.4 Relation between z-factor and the DH operating temperatures in a condensing steam turbine of CHP [14].

Furthermore, lower return temperature makes direct flue gas condensation from flue gases possible. This is especially relevant for biomass and waste-based CHP plants, due to their high moisture content. In this way, the flue gas condensation recycles some of the difference between the upper and lower heating values in the fuels. Some biomass plants in Sweden have flue gas temperatures of 30 C degrees. Greater heat recovery from gas engines by condensing water content of flue gases, and the recovery of some of the intercooler heat, can increase the heat recovery yield by up to 25%. Lower network temperatures make heat pumps more competitive, for both pressure and temperature can be lower in the heat pump condenser. This situation requires less electricity for the compressor, and gives a higher coefficient of performance. Lower network supply temperature enables further exploitation of low-exergy excess heat, either from industrial processes or by heat recovery from cooling processes. Also, it is possible to combine with geothermal heat sources and make them competitive in relation to residential heat generation technologies. Fluid temperatures below 60 C degrees make geothermal plants more advantageous, since satisfying the base load demand is possible. The vast majority of geothermal resources in Europe have temperatures between 40 and 80 C degrees. Another potential is solar energy. Lower network temperatures increase the conversion efficiency from solar energy to solar heat in solar thermal collectors. Thermal storage units in a DH system range from large seasonal storage tanks to small-scale tanks in the installation areas. Lower network temperatures will reduce heat losses from thermal storage units, if they operate within range of the supply and return temperatures. If higher temperatures are available in heat supply, lower return temperatures can increase the capacity in water-based heat storages in boreholes and water tanks [18, 19].

LTDH systems are known for their capacity to improve energy quality and cost efficiency. However, there are some drawbacks about the technology, since it is not the ultimate solution to the residential heating issue. Current heat demands and current radiator sizes require rather high radiator temperatures in most of the end-user radiator systems. Radiator sizes have traditionally been designed for rather higher operation temperatures, for it has been easy to supply these temperatures. But, high return temperature at the end-user side is a limititation for LTDH systems. They significantly reduce the available temperature difference for the DH network. That means hydraulic limitation, and high additional energy for the network pumps, which is often higher than the values of 3rd Generation systems. It also leads to higher heat losses as a consequence because of higher average network temperatures.

Another issue is health related risks, especially about Legionella bacteria. National regulations require high hot water temperatures in DH networks as a safety rule, in order to counteract and avoid Legionella growth [7]. Thus, these regulations with respect to the health have become barriers for lower network temperatures in DH systems. Various faults in substations can result in higher return temperatures than expected in the design phase.

Substation faults create overconsumption of the circulated water and can occur in heat exchangers, control chains, and system design. They could be due to mistakes made in the design phase or operation, or due to malfunctioning components or system errors. These faults must be immediately identified by real-time monitoring, and avoided in future LTDH to maintain low temperature levels in the networks. Short-circuit flows, which are direct flows between the supply and return pipes without passing any heat exchanger in a substation, may also occur at DH network intentionally, or untentionally by lacking of sufficient technical analysis.

The focus on low network temperature aims not only to bring about a new (more economical) design concept for the next generation of DH systems, but also to provide energy planners and DH netwrok operators with a solution for further increasing their market share in the current situation. In the well developed DH countries, further market penetration means exploration of areas that are currently supplied through individual heat generation units like natural gas furnaces and oil boilers, but are in the surroundings of urban districts supplied by DH. Consumers in such areas may prefer individual heat generation units, since the DH heat loss would exceed the energy savings from central heat supply, if current DH technologies were implemented. Furthermore, the DH market penetration is hindered by the fact there is no obligation to connect to an available DH network in low-energy density regions. Under these circumstances, LTDH can be one of the most suitable technologies to help removing these hurdles. In less developed DH countries, LTDH can improve current energy efficiency of the system and bring additional economic benefits. For areas, which still use the 2nd or even the 1st generation DH system, upgrade to the LTDH system means a leap forward of local current DH technologies. On the other hand, due to the small share of DH market in the less developed DH areas, the implementation of LTDH tends to be easier than countries where DH already adapted.

The intention of designing a new generation DH is to develop a flexible, smart and secure energy supply, transmission and distribution system with effective combination of energy-efficient buildings and low temperature energy sources. The reduction of DH distribution temperature requires the development of domestic hot water and residential heating systems that can meet the low-temperature requirements and use the limited available temperature difference between the supply and the return temperature. An extensive design approach must be applied during the design process with overall technical, economic and environmental evaluation of the buildings, the DH network and energy supply systems based on renewable energy, waste-to-heat and excess heat.

3.2. Trends of Energy Supply and Demand for Residential Areas

It is estimated that total (heat and electrical) energy demand for residential areas will rise 50% until year of 2050, if the energy efficiency of buildings would not be improved [12]. The rise in demand is affected by population and gross domestic product (GDP) per capita, as well as the number of residential buildings, total residential area, and usage of electrical tools and gadgets. However, the mentioned 50% increase in demand can be limited to 10% only, without any changes in demand or the level of comfort [5].

Previous researches states that total energy savings of the residential areas can reach up to 40 exajoule (EJ) until 2050, by implementing the current most advanced technologies. To compare, that amount of energy is roughly equal to the recent energy consumption of India and Russia together [17, 18]. In order to achieve that amount of energy savings, usage of optimum outlayer insulation, better insulated windows, reflective surfaces, heat pumps, solar energy for heating purposes, combined heat and power (CHP) plants, better district heating (DH) networks, higher energy-efficient electrical tools and light emitting diode (LED) illumination components are essential. New buildings with high performance components and systems would reduce the demand for heat energy significantly. Figure 3.5 and Figure 3.6 below shows expected heat demand in future by sectors and services.

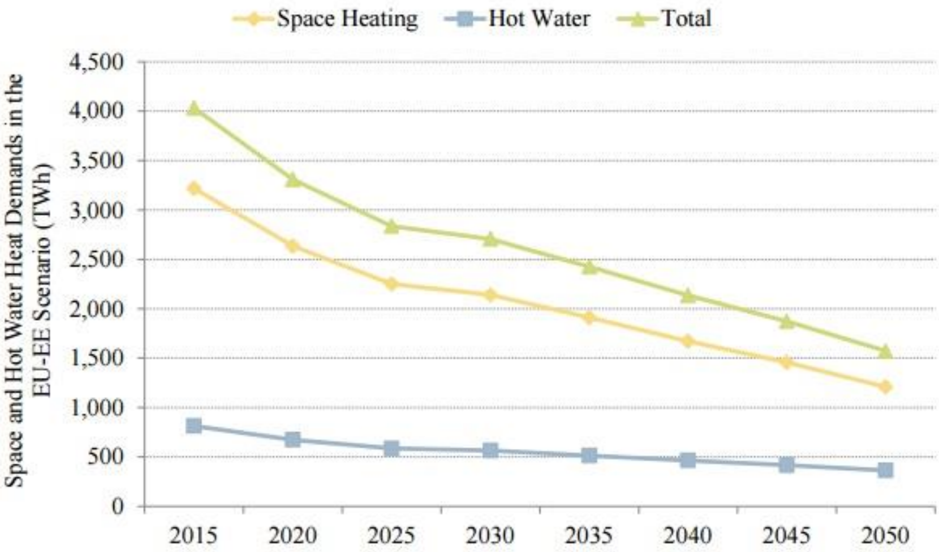


Figure 3.5: Space heating and hot water demand for the residential and services sectors in the EU-EE scenario between 2015 and 2050 [18]

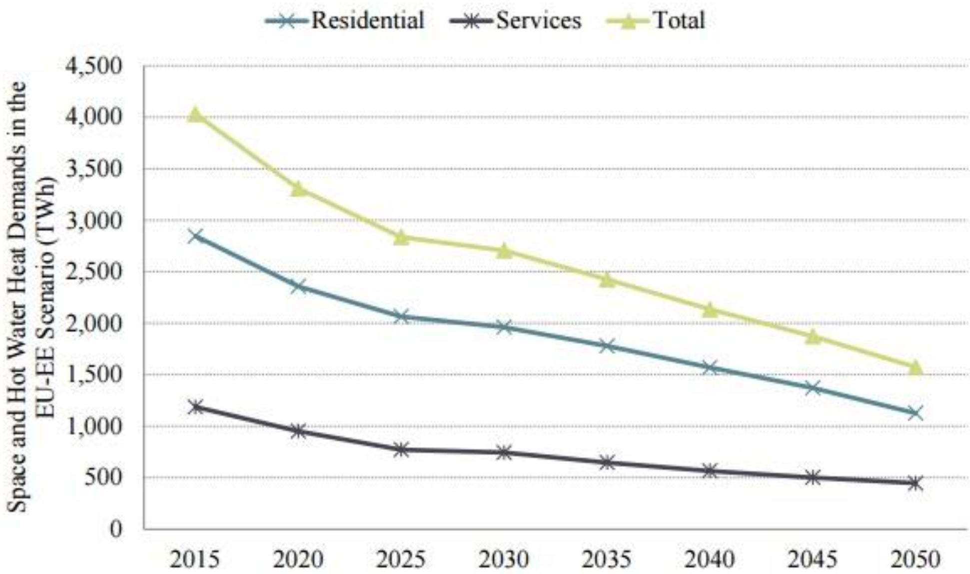


Figure 3.6: Heat demand for the residential and services sectors separately in the EU-EE scenario between 2015 and 2050 [19]

Carbon-footprint from residential sources need be reduced 77%, in order to achieve the target of limiting global warming under 2C degrees until year of 2050 [3]. Decrease in energy demand, increase in energy production from renewable sources and reduction of the carbon-footprint of electricity production are the key elements to achieve that target.

Sharper energy-efficiency standards, better heat pumps, solar energy for heating purposes, CHP plants and better DH networks can help to increase the savings 2000 TWh more. That amount of energy is the half of the energy consumption in USA in 2010 (Source:

IEA). That amount of savings can help to prevent capasity increase of 330 GW in coal powered power plants or 460 GW in natural gas powered power plants, which is equal to 70-150 billion US$ economically [17, 18]. Moreover, that can decrease the requirement of investment for broader transmission networks.

Also, DH networks are expected to draw more investments and increase its share in heat energy demand. In Europe, district heating from renewable sources are expected to grow in the short term, as CHP plants and DH networks are expected to grow in the medium term [3, 18, 19]. In European Union, final consumption of district heating slightly increased in the 2007-2012 period due to the increasing consumption of residential and services, while the industrial consumption stagnated [17]. Expected heating productions in EU member countries under a business-as-usual scenario and in case of exapansion of district heating and CHP to 30% in 2030 and 50% in 2050 are shown on Figure 3.7.

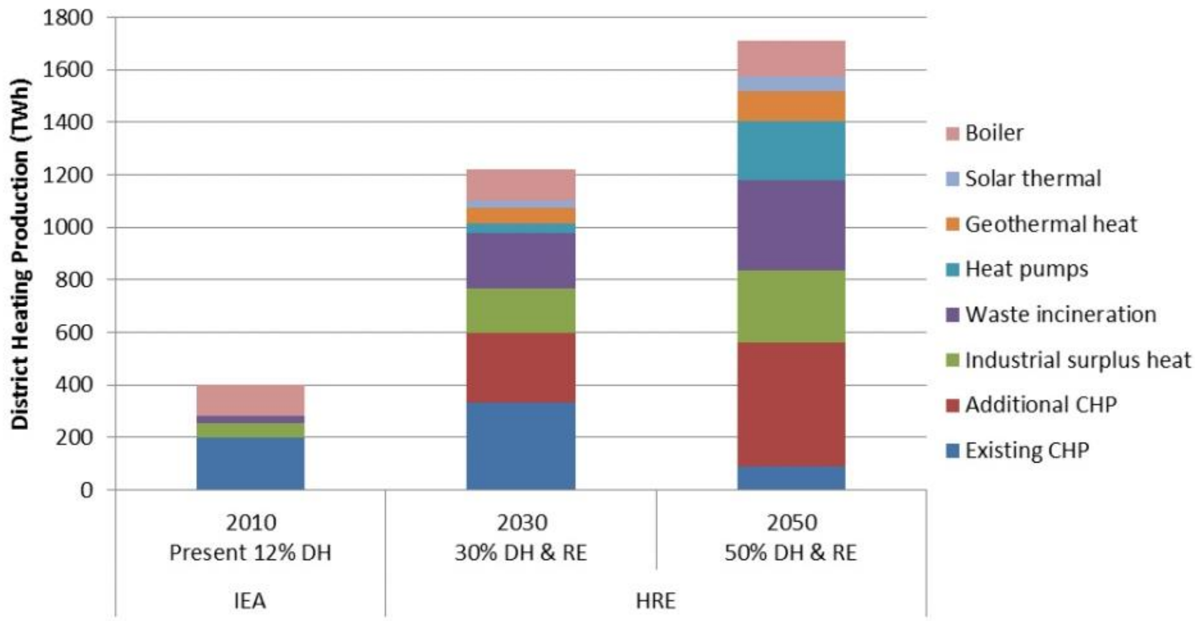


Figure 3.7: DH predictions for the EU27 energy system in 2030 and 2050 along with the production in 2010 [18]

Current energy policies states that fossil fuel sources are planned to be reduced and to be replaced with renewable sources. At the energy supply side, continuous growth trend of the renewable based and waste based heat production in EU can be observed. Renewable energy sourced heat production and renewable energy sourced DH grew by 43% and 85% respectively between 2007 and 2012, while in the case of DH from waste and waste CHP the increase was 17% and 42% [17].

2015 report of Towards2030 group, it is considered as a good indicator, since fossil based CHP production reduced sharply whereas CHP based total heat production increased.

The reduction in building energy demand means that electricity demand are tend to increase its share of the total energy demand. This means that CHP plants should be designed with high operational flexibility. CHP plant energy conversion efficiency and power generation capacity can be increased with the use of LTDH, since demand on direct heat generation is going to reduce.

It is stated that the cost of DH and individual gas heating stay close to eachother in 2015 report [17]. That situation indicates that LTDH systems are going to play an important role in short term. Because, a significant difference can be observed even by the reduction in heat losses during transmission. In areas with relatively low heat demand, LTDH networks can ensure greater cost-effectiveness by lowering the heat losses. Also, required pumping power is generally less significant since the media pipe sizes are optimized by reducing the diameters. Another advantage is decreased the risk of water leakage and increased durability of the equipment and pipes by keeping the static pressure of the DH network low [20, 21].

Periodic maintenance and replacement of equipments are always required at existing infrastructures with 2nd or 3rd generation DH. However, the major issue is that the dimensions of older generations of DH might be over-sized for the future situation. New and renovated buildings with low energy demand are ideal for implementing LTDH. However, due to their long lifetimes, the buildings with high energy demand that exist today will remain in a majority for a relatively long period. Thus, the potential in applying LTDH networks to existing buildings is also being studied [22].

3.3. Health Risks

The LTDH concept aims at reducing the supply temperature, while still fulfilling comfort requirements for domestic hot water and residential heating. First, residential heating systems can be designed and operated at temperatures that are only slightly above the indoor operative temperature. With regard to domestic hot water heating, the minimum domestic hot water temperature depends on the requirements for health and customer comfort. Traditional domestic hot water systems have to ensure that the return temperature from the recirculation is much higher than 50 C degrees in order to prevent the risk of diseases. Any part of the network such as the large volume domestic hot water storage tanks, vertical risers in multi-floor buildings, T-pipe connections, large-diameter pipes or recirculation pipelines, should be operating properly in order to avoid any contaminations later on. As a consequence, the current DH minimum supply temperature is above 60 C degrees.

Hazardous microorganisms such as *legionella pneumophila, pseudomonas aeruginosa, stenotrophomonas maltophilia,* and *acinetobacter baumannii,* can be found in treated or non-treated network supply water [23]. Water treatment and periodic maintenance of pipelines in the network are key issues to prevent those microorganisms, since they are capable to spread quickly and lead to a dangerous disease among inhabitants. Also, health centers such as hospitals, nurseries are especially vulnerable. Thus, sanitation problems in DH networks, which operate for those kind of buildings, may cause outbreaks of diseases that can affect whole city or town.

The most renown and dangerous type of nosocomial infections is Legionnaires' disease. Since the symptoms (fever, headache, diarrhea, hyponatremia) can easily be confused with another illness, the fatality rate of the disease is serious [24]. *Legionella* is a group of gram-negative bacteria that grow in water and humid environment. Factors that can influence growth of the bacteria are water temperature, the dimensions and age of the network, its hydraulic structure, pipeline materials, stagnation of the water inside the pipelines, scaling and particle in the hot water itself, and the presence of microbial flora (biofilm) in the pipelines [23]. The water temperature has the most critical impact on *Legionella* growth among these factors. Because, the optimal proliferation temperature ranges between 30-45 C degrees. However, that means the bacteria can easily spread to the whole DH network, if the water quality is not monitored and controlled.

Health risks related to bacteria, amoebae and other microorganism growth in water systems has been an important limitation for domestic hot water preparation in DH networks and substations. Contaminations can occur in four different ways:

- Public water supply: Contamined cold water enters from the domestic hot water system of building.
- Central system: Domestic hot water system generator is contamined at the enter or outlet point.
- Partly central system: Domestic hot water system generator and distribution pipes are contamined.
- Peripheral: Domestic hot water system, distribution pipes and tapping points are contamined.

The advantages of LTDH systems are related to not only the potential heat savings in the domestic hot water supply in the building, but also to the opportunity of widening the application of low-temperature and eco-friendly heat supply systems. Therefore, studies about LTDH will enable improving technologies of domestic hot water treatments against microorganisms, which are hazardous to human health, as they reduce domestic hot water temperatures to satisfy the end-users' real needs (40-47 C degrees).

Protective methods can be divided into groups as written below:

- Thermal treatments,
- Chemical treatments,
- Physical treatments (e.g. ultra-filtration, UV radiation)

The water treatmet methods are summarized on Table 3.1 below. They can also be grouped in two main types of purpose: the first group is based on killing the bacteria in the water, while the second group limits the concentrations of bacteria by blocking them contaminating domestic hot water system. However, one important is that most of the treatment methods are allowed only for a small period (in case of a contamination situation) in any country, not as a continuous method. This is an issue which should be considered, due to insufficient or wrong disinfection problems. For instance, the latest Legionnaires' disease outbreak, which had regrown two months after killing 12 people, has killed 1 person in New York City, USA in October 2015 [25].

Table 3.1: Overview of technologies for domestic hot water treatment against *Legionella* bacteria [14]

Type of treatment	**Description**	**Active substances**
Thermal treatment	-Flushing time with weekly flushing: 20 min (60°C); 10 min (65°C); 5 min (70°C) -Reheating time: 10 min (60°C); 1 min (65°C); 10 s (70°C)	None
Sodium hypochloride dosing	Short-term application for several hours with high concentration. High concentration may cause significant corrosion of copper pipes	NaOCl: minimum 20 mg/L
	Continuous low concentration in the entire system	NaOCl: up to 5 mg/L (max. 8 mg/L)
	Short-term application for several hours with high concentration. Minor effects on the pipe material.	ClO_2 up to 1.5 mg/L

Chlorodioxide dosing	Continuous low concentration in the entire system	ClO_2 up to 0.2 mg/L
Chloroamine dosing	Continuous low concentration in the entire system. In the process, ammonia forms strong complexes with copper, thus possibly prevents the formation of a protective covering layer	$ClNH_2$ up to 2 mg/L
Hydrogen peroxide dosing	Solely for short, periodic treatment, applied for a maximum of 24 h. It kills bacteria in the entire system	H_2O_2 with concentration of 200-500 mg/L
Anodic oxidation	It kills bacteria in the entire system. Substances present in the water are converted into oxygen radicals, atomic oxygen, hydroxyl radicals, elementary chlorine and HOCl	Organic products < 5 mg/L
Copper/silver ionization	Formation of copper and silver ions by way of ionization	-Cu ions 100–400 mg/L -Ag ions 10-40 mg/L
Membrane filtration	Microfiltration and ultra filtration to keep out incoming bacteria	None
UV disinfection	Local UV radiation which kills passing bacteria	None
Electrical pulses	Electrical pulses affect the bacteria cell walls	Presumably none

The safe methods to supply domestic hot water are divided into two groups by means of the system size. Water treatment is carried out either individually in house or system-scale processes. In new single-family buildings, such as cottages or terraced houses, the layout of the domestic hot water distribution pipes can be designed with individual connection of feeding pipes between the source and each tap. Therefore, the water content in each domestic hot water supply can be kept below 3 liters. That method is suitable with German Standard, which obligates to keep the total volume of a domestic hot water system below 3 liters in order to prevent *Legionella* bacteria growth risk below 50 C degrees temperature [14]. In new multi-family buildings, a similar concept can be applied by providing every apartment its own substation, instead of central equipment for domestic hot water production. The same can be implemented in existing buildings, however, financial cost may counterbalance the benefits of renovating the existing domestic hot water preparation and distribution equipment.

The system-scale water treatment against microorganisms is a more effecttive technology. The level of relevant contamination of the domestic hot water system is continuously measured and monitored via online system, and the samples are taken both from pipes and tap water. The system-scale water treatment technology is generally an integrated method, which combines thermal, and physical or chemical methods. 2011 study from Sweden shows that the health risks related to *Legionella* bacteria and amoebae can be eliminated with the combination of oxidation and low temperature thermal treatment method even at temperatures below 50 C degrees [14]. However, the system and all of the components should be cleared of bacteria before the installation of low temperature domestic hot water system, since the contamination at the dead-ends such as shower heads or tanks may spread the other sections of the system and the sanitation technology can not reach success. Copper–silver ionization were stated as the most reliable technology by a 2011 study [24]. Utilization of cost-effective filters and its flexibility in terms of application makes the technology one step ahead of the other methods.

Consequently, the studies about the health risks of LTDH and low temperature domestic hot water supply show that the implementation of 4th generation DH is feasible. Even though, community service buildings such as health centers are vulnerable due to their human population density, the concerns about health issues can be resolved by real-time monitoring, proactive environmental culturing and suitable disinfection of domestic hot water system.

4. Modelling and Analysis of Jõgeva District Heating Network

In this chapter the calculations of the project are explained. The aim of the chapter is to quantify the effects of supply and return temperatures decrease, and of flue gas condenser installation in Jõgeva district heating network. The studied supply temperature is 55 C degrees. The value of supply temperature has been chosen within the supply temperature range of 4th generation district heating, as it has been described in the section 3.

First part of this chapter will describe the studied DH network, whilst the second part will describe the methods used, and the limitations. Following parts will describe the alternative models and explain their results, then, evaluate their results, respectively.

4.1. Jõgeva District Heating Network

Jõgeva is a small town with a population of 5 577 people (2012). It is the administrative centre of Jõgeva County (*Jõgeva maakond*) in Estonia.

Jõgeva boilerhouse is built in 1970's with three heavy fuel oil powered steam boilers. Along with the urban development and the growth of heat consumption in the boiler house was extended in 1980, and it was installed two additional steam boilers. Jõgeva Soojus was established as a municipal enterprise in the early 1990's for operation and management of the boilerhouse and DH networks. Boilerhouse and DH network was owned by AS Eraküte during the privatization in 2001. Two natural gas powered Viessmann steam boilers 7.8 MW and 5.3 MW capacities are used from the year of 2003. The natural gas supplier is AS Eesti Gaas. In February 2014, reconstruction was finished and biomass powered boiler, which uses local wood chips, started to operate. New technology is effective and reliable, which ensures the security of energy supply. During the reconstruction work, it was installed 6 MW biomass powered boiler with a pre-furnace and auxiliary equipment, and a biofuel warehouse was built. Currently, biomass powered boiler covers the base load of the DH network, and natural gas fueled boilers used for peak demands. Average annual heat production is 25 GWh/year. Heating season runs between mid-September and beginning of May. The phase-out ambient temperature is 11 C degrees, where the heating operation stops. The end of heating season is the beginning of maintenance season on DH network.

The hot water produced in the boilers described above, is delivered to the end-users through the DH network in Jõgeva. Supply pipes transport the hot water from the boilerhouse to the substations in buildings. Then, the heat energy is transferred in a heat exchanger to the tap water and the water of the radiators. The return water with lower temperature is returned to the boilerhouse where it is heated again. During the phase-out season, the end-users use residential electric heaters for domestic hot water preparation. Jõgeva DH network has length of 8 754 m, which is 4 264 m of pre-insulated pipes. Heat losses on the network range between 14-15%. DH service is used by 87 active consumers in Jõgeva; among which there are 52 residential apartments, one of the private houses, and 34 administrative and service buildings. Figure 4.1 shows the plan of the DH network.

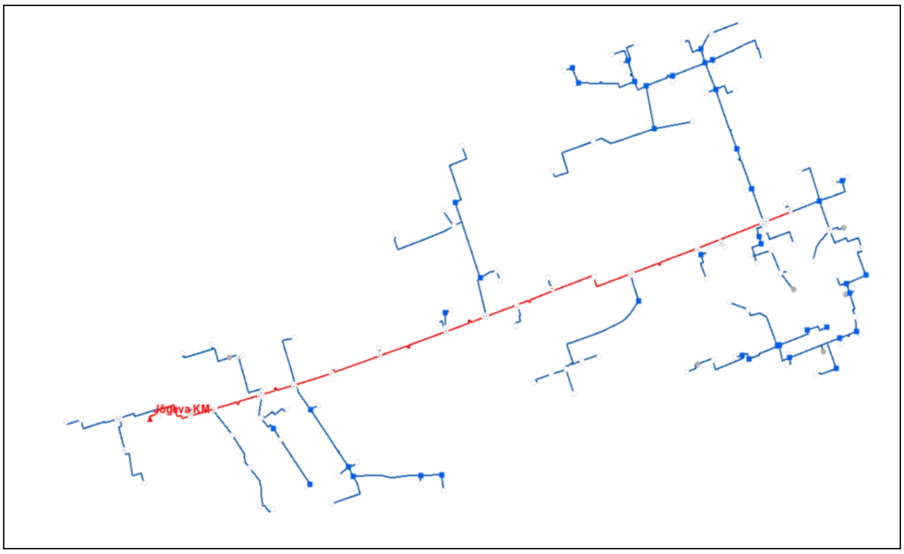


Figure 4.1: Schematic plan of the network and boilerhouse in Jõgeva.

(Source: AS Eraküte)

4.2. Methods and Limitations

This project has been developed with an experimental methodology. All the implications of changing parameters in a boilerhouse have different consequences, which makes it hard to study. Therefore, it has been chosen to work with empirical data instead of studying the results thermodynamically. However, that does not mean the outcomes would be less accurate. In fact, working with empirical data ensures that all the internal relations between parameters are considered.

That's why, compiling data from the DH network in Jõgeva was a major task. The data of 2015 was used. The data includes daily values of the supply and the return temperatures, mass flows, values of the heat production, and also pressures and pressure gradients of the pumps. Vitec NetSim simulator software was used to calculate the initial and basic data, which is described at sub-section 4.4. NetSim is a network/grid simulation software for District Heating/Cooling/Steam which provides accurate values for several parameters in the grid such as pressures, velocity, temperature, flow. The software is popular among various DH network operator companies, and it helps to calculate a static or dynamic simulation where the effect on production can be obtained effortlessly.

The second task was calculating time series. In order to have all the data summarized in a useful format, it was arranged according to the weather temperatures. The outdoor temperature data, which includes datasets of 2011, 2013 and 2015 years, were collected from Estonian Meteorology Institute.

Once all the data was in a proper format, the models were named as *Alternative*, with numerical order. Respective spreadsheets have been developed via Microsoft Excel software. These sheets are shown in the appendices, and its results are explained in subsection 4.4.

The limitations of the project are explained in order to evaluate results better. This project is based on time series of 2015. It means that the results would not be valid for longer terms, since the heat production may vary. For example, if much more customers are connected to the DH network, or the consequences of the climate change intensifies, the results would change.

The economical analysis is based on the current energy prices. It must be considered that the heat energy prices are subjected to the approval of Estonian Competition Authority, but the unit prices of primary energy sources fluctuate with market tendencies. Therefore, the economical results should be updated in future.

The accuracy of the results could be improved if the following subjects were studied seperately. The percentage of heat losses represents an average value, however, there are still ongoing improvements at pipelines. So, the heat transfer coefficiency may change. Thus, dynamic fluid simulation could be applied. Moreover, the pumping work could be analysed with the pump characteristic curves. Also, the behaviour of flue gas condenser needs to be studied thermodynamically since the different types of boilers are utilized in the boilerhouse.

The aim of this project is to obtain preliminary results and to give an insight into the impact of these improvements. In order to have moer accurate results, all the equipments and elements related with the DH network needs to be investigated. Studies on different DH networks would provide broader range of data, and that would improve the reliability of the preliminary results.

4.3. Initial Data

The term of initial data represents the technical information that was received from AS Eraküte, which is the operator company of the Jõgeva boilerhouse and DH network. In this subsection, it is described how the initial data was processed in order to plot necessary graphs.

Heat Energy Production

Heat energy in a DH network is produced by boilers. Technically, boiler is a type of vessel with installed heat exchangers to heat or boil fluids (water, oil, etc.). The boilers of the Jõgeva boilerhouse contains a biomass powered boiler and two natural gas powered boilers. The supply water is being heated in boilers and then, delivers the heat energy through DH network. In heat exchangers at boilerhouse, water flow is continuously heated. A benefit with steam is homogeneous heat surface temperatures, since temperatures on heat surfaces depends on steam pressure. The mean heat transfer can be expressed as below.

$$q = cp\ dT\ m / t \qquad \text{(Eq 1)}$$

where

q = mean heat transfer rate (kW (kJ/s)) *m / t = mass flow rate of the product (kg/s)*

cp = specific heat of the product (kJ/kg.°C) *dT = change in fluid temperature (°C)*

The received data contains information about mass flow and supply water temperature from boilerhouse to the buildings. NetSim simulation software uses real-data and the equation above in order to simulate the network at specified conditions or situations. Estimatation of heat energy production is shown on Figure 4.2.

Currently, the supply temperature of Jõgeva DH network ranges between 105 C and 65 C degrees. As the outdoor temperatures decrease, the supply temperature increases linearly in order to meet heat demand. Thus, it is possible to plot a graph to determine the supply temperature, as well as the heat production.

Annual heat production in Jõgeva DH network is approximately 25 GWh/year. That number represents the heat energy delivered to the end-users. Therefore, boiler efficiency and heat losses need to be considered to calculate the amount of fuel consumed for heat production.

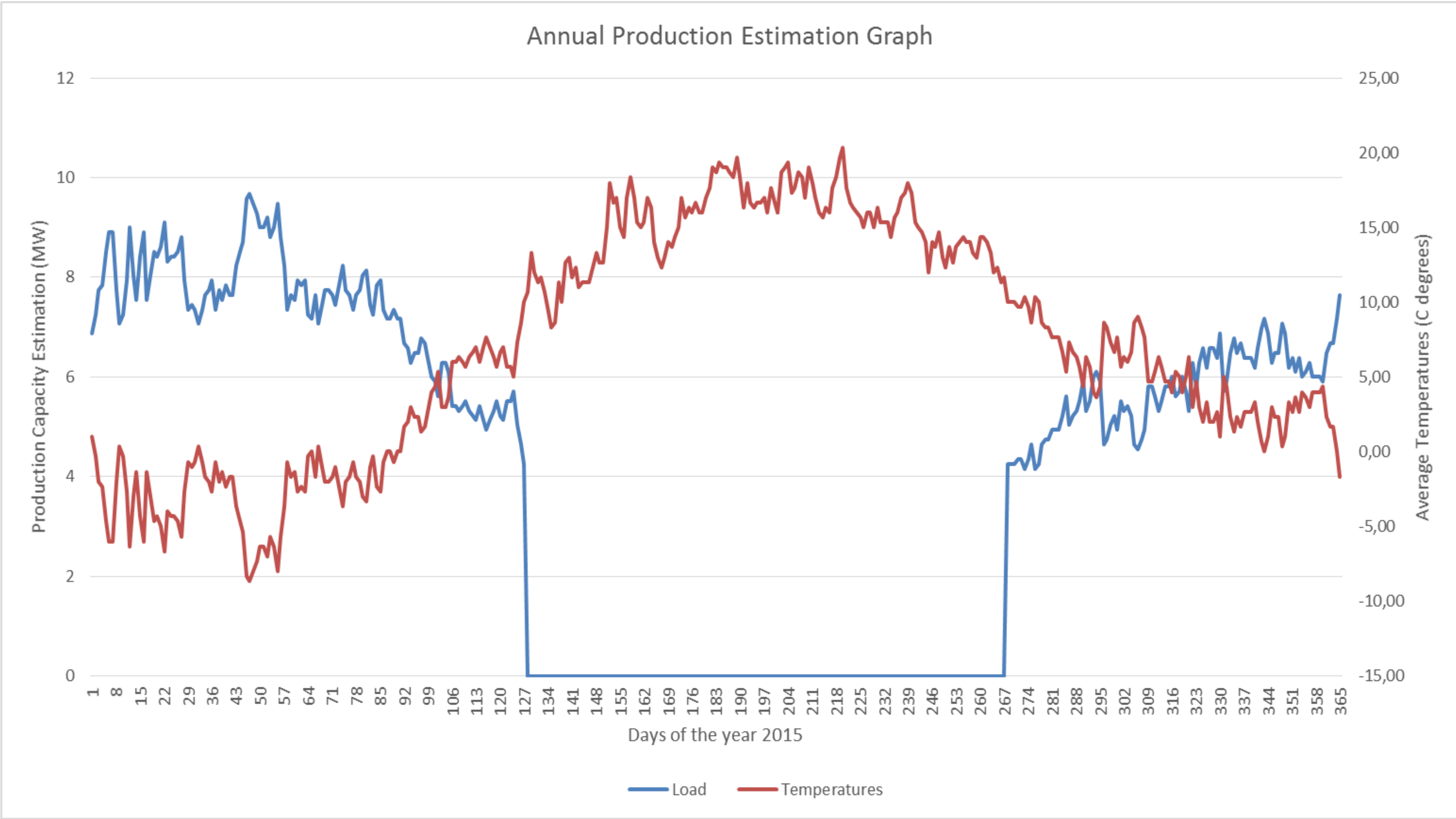


Figure 4.2: Estimated heat energy production. [26,27, 28]

Flue gas condenser installation in a heat power plant is a good investment since it can improve the energy efficiency of a boiler by extracting some amount of heat energy, and it helps to meet the requirements of EU Directive on energy efficiency. The calculations with flue gas condenser are described at subsection 4.4, and its results are shown at subsection 4.5.

Heat losses

Reducing heat losses in a DH network is a crucial task, since the amount of heat energy is emitted to ambient where it is not possible to extract back. Thus, the heat transfer coefficient of network pipelines is required to be kept at low level by utilization of pre-insulated pipes. Heat losses depend on various factors, such as level of insulation, temperature difference with the ambient, diameter and length of pipes. Hence, it is a challenging task to obtain data. That's why, the formulas below are used for the results reliable enough to work on. Almost half of the pipeline in Jõgeva are consisted of pre-insulated pipes, however, an average value (2 W/m^2K) was considered for calculations. Surface of the network were calculated by the equation below, as the average diameter *(d = 129 mm)* and the total length of pipelines *(l = 8754 m)* are known.

$$A_{pipes} = 2.\pi.(d/2).l \quad \text{(Eq. 2)}$$

The surface area of pipes for one way is calculated by the equation 2, thus, the result is doubled. With that result, it is possible to get the heat losses at a specific temperature by the equation below.

$$Q_{loss} = A.k.\Delta T = (2.A_{pipes}).k.(T_{DH}\text{-}T_{Ambient}) \quad \text{(Eq. 3)}$$

It can be stated that the heat losses are related to the outdoor temperature, from the equation above. Supply and return temperatures depend on the expected heat loads, thus, the colder is the outdoor temperature, the hotter should be the supply water. During cold winter days the heat demand is higher, and the temperature needs to be kept at higher values for previous generation of DH networks, in order to deliver greater amount of energy. Therefore, decrease in the supply temperature can help reduction of the heat losses in the DH network. That is expected to decrease the return temperature, as well. That's why, the equipments in buildings, such as heat exchangers and radiators, needs to be renovated to provide the same level of comfort. In this study, it is considered that LTDH-compatible equipments are already installed at the end-user side of the DH network.

The decrease in the supply and return temperatures help to save production of heat energy in boilerhouse. For the boilerhouse in Jõgeva, the amount of decrease is equivalent to the reduction of the heat losses. According to technical information from AS Eraküte, the heat losses in Jõgeva DH network are approximately 14%. That number is equivalent to 4.7 GWh of annual production in terms of heat energy.

A dramatic reduction in the heat losses can have a large impact in energy efficiency by increasing the amount of energy save. In Jõgeva boilerhouse, there are two natural gas powered boilers, which are used for peak-demands. If heat losses are reduced, more energy is being supplied to the end-users, and the heat produced by the imported natural gas will be reduced, resulting in economical savings.

Pumping Work

In large district heating systems, the energy used for pumping all the water from the boilerhouse to the end-users is important. By reducing the supply and return temperature of the DH network, the amount of water transported is expected to increase for delivering the same amount of heat energy and meeting the heat demand.

In this study, it has been used the heat production of 2015. With this data, it can be observed that satisfying the same heat energy demand with lower supply and return temperatures would require greater amount of water flow, and increases the pumping work. However, the pumping work can be kept within the technical limits of the existing pipeline, if the temperature gradient between supply and return temperatures increased.

4.4. Basic Data

The ininital data was processed by the simulation software and the results are explained in this subsection.

Models were created to study the initial data and the basic data. The outdoor temperatures were chosen as -21 C, -14 C, -7 C, 0 C and +7 C degrees, in order to cover the extremities of the outdoor temperature range of the location, and to avoid excessive numbers of specimens. Simulation with the initial data is named as *Alternative 0*, since it represents the reference condition for comparison.

Supply temperature of 55 C degrees is chosen for the simulation of other specimens. The reason to propose that temperature is to study the compability of LTDH in Jõgeva DH network, since that temperature falls within the operation temperature range of LTDH. Also, being significantly lower than the existing supply temperature enables easier observation of the heat losses on DH network. Moreover, mentioned temperature causes concerns about the health risks, which was explained in subsection 3.3, as it is suitable for *Legionella* bacteria and other types of microorganisms to augment themselves. The measures to take against the health risks, in case of Jõgeva DH network switches to LTDH, were mentioned in the section 5.

Supply temperature of 55 C degrees and return temperature of 35 C degrees were chosen as *Alternative 1* the model. Since those values are used commonly among existing LTDH implementations, the mentioned values were chosen.

The model *Alternative 2* has supply temperature of 55 C degrees and return temperature of 27 C degrees, in order to broaden the range of temperature gradient. The reason for proposal of that return temperature is to observe the effect of increasing the temperature difference clearly.

Supply temperature of 55 C degrees and return temperature of 35 C degrees were chosen as the model *Alternative 3*. Those values are the same with the model Alternative 2, however, the main difference of the model is flue gas condenser. Flue gas condenser (FGC) is a kind of economizer, which is basically a heat exchanger that transmits the heat energy from return water to heat feed-in water. FGC increases the energy efficiency as it extracts heat energy, which is wasted otherwise, from return water. Installation of a FGC is essential for LTDH networks, as it saves energy and money, and performs better results with lower return temperatures.

Heat Energy Production

Annual heat produciton of Jõgeva boilerhouse is approximately 25GWh/year. The calculations were carried out to demonstrate the relation between outdoor temperatures and heat energy production.

According to the computation which was carried out for *Alternative 0*, the annual heat production was calculated 35.76 GWh/year. After consideration of boiler efficiency and heat losses on the network, that value corresponds to 26.41 GWh/year. That number means the calculation method is in line with real conditions, and the rate of error is 5,3%. Figure 4.3 shows load-duration graph of *Alternative 0*.

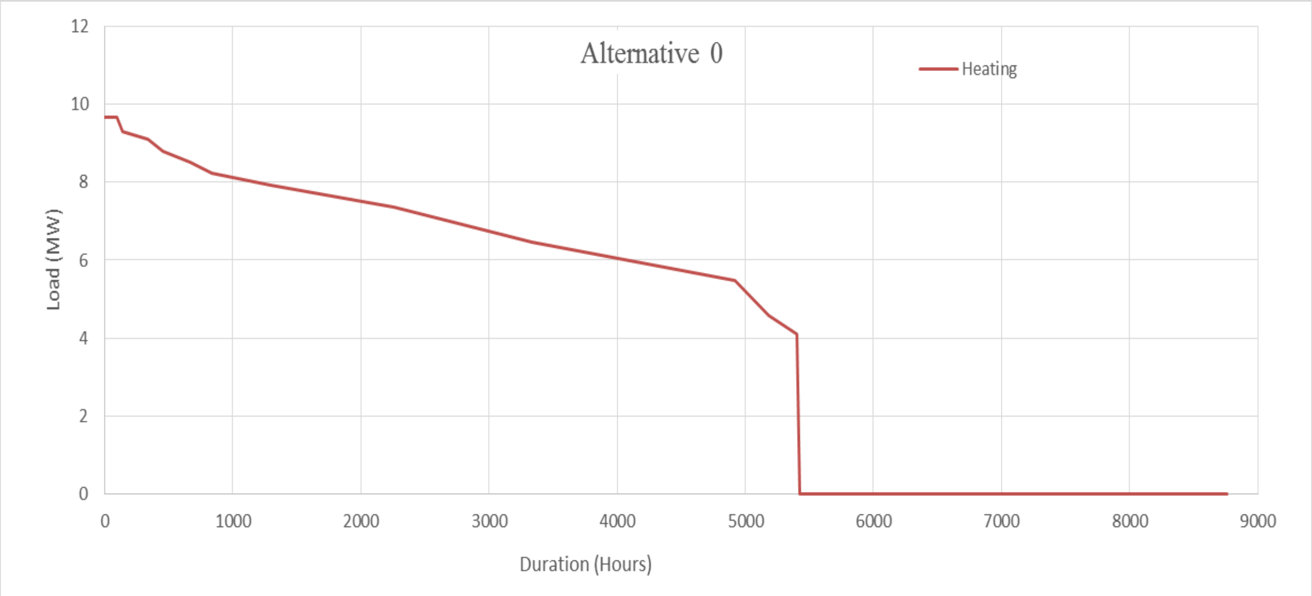


Figure 4.3. Load-duration graph of *Alternative 0*.

Annual heat production of *Alternative 1* is 33.70 GWh/year. Decrease in heat energy production shows that the energy saving is caused by reduction in heat losses. Heat production of *Alternative 2* is 33.67 GWh/year, which is very close number to the result of *Alternative 1*. The reason for further decrease is the better energy delivery to the end-user, due to broder temperature gradient between supply and return temperatures.

Annual heat production of *Alternative 3* is 25.89 GWh/year. That model demonstrates a significant decrease due to energy recovery by FGC installation. The energy savings are very successful, since the rate of savings goes up to 28% for the same heat demand at the end-user side of the network. Figure 4.x shows load-duration graph of *Alternative 0*.

Heat losses

Heat losses on Jõgeva DH network represents 14-15% of the annual heat production, as it was mentioned at the subsection 4.1. Even though the half of the total network length is insulated to reduce heat losses, the heat energy is still being delivered in lesser amounts than it was produced. The average heat transfer coefficient of $2\ W/m^2.K$ was calculated from the initial data.

That means, approximately 4.7 GWh of heat energy is lost every year during transmission at the conditions which were described at *Alternative 0*. However, the amount of lost energy might be higher, since the calculated rate of heat loss is 13.12%, which corresponds to 6% of possible error rate.

As it was anticipated, the heat losses were reduced remarkably, as the supply and return temperatures drop. Annual heat losses of *Alternative 1* is 3.01 GWh/year, which means the rate of heat losses can be reduced to 8.93%.

Annual rate of heat losses decline further to 8.32% at the conditions of *Alternative 2*. The reason for smaller amount of lost heat is linked to the better delivery of heat energy, thanks to the broder temperature gradient. The amount of heat energy calculated to be lost is 2.80 GWh/year.

Furthermore, it is interesting to observe the results of *Alternative 3*, since the rate of heat losses are calculated that to increase. Even though the supply and return temperatures are the same with *Alternative 2*, the rate of heat losses seems to increase due to the reduction of heat energy production. Consequently, the amount of heat losses is 2.80 GWh/year which is the same with the result of *Alternative 2,* but the rate of heat losses is 8.40%.

The real amount of lost energy during transmission shall not be known until it was studied with the help of fluid mechnanics, thus, the obtained results should be considered preliminary. Table 4.1 demonstrates the heat losses of each simulation model.

Table 4.1: Calculated rates of annual heat energy losses on Jõgeva DH network

Rate of Annual Heat Losses on Jõgeva DH Network	Alternative 0	Alternative 1	Alternative 2	Alternative 3
TOTAL	13,12%	8,93%	8,32%	8,40%

Pumping Work

Delivery of supply water to every customer, which connects the network through respective node, requires continious pumping work. Pumping work is carried out by Wilo pumps with 660 m^3h total capacity in Jõgeva DH network (Source: AS Eraküte).

The pressure difference betweeen supply and return water gives an idea about the condition of overall quality on network. As it is shown on table 4.5 below, pressure difference at the conditions of *Alternative 0,* goes up to 350 kPa during the cold winter days.

However, the amount of water that required to be delivered in order to meet the same heat demand is relatively higher, and it may lead to failure of the pipelines and the network. Thus, it is simulation data is important to detect those possible failures.

It is demonstrated by the simulation that the required pumping conditions of *Alternative 1* affects the network unfavorably, as the pressure difference can excess the limits of pipeline. The pipe, which serves to end-user at the node N1009, is the most problematic since the pressure gradient increases up to 500 Pa/m. The problematic pipe which detected by simulationis shown on Figure 4.4.

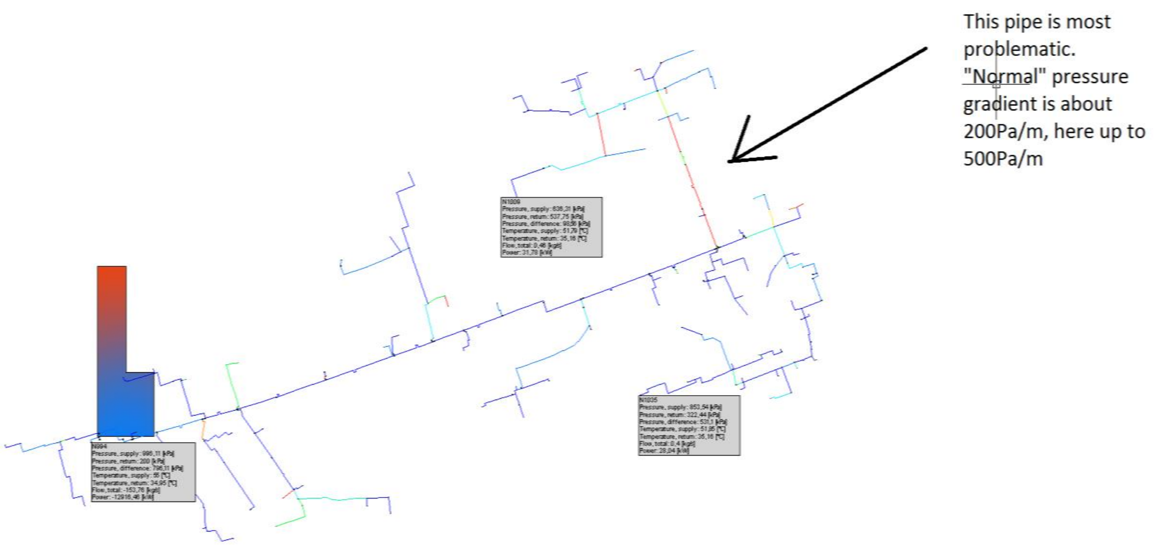


Figure 4.4. Possible excessive pressure failure on the Jõgeva DH network at the conditions of Alternative 1.

Simulation data of the other models, *Alternative 2* and *Alternative 3*, demonstrated that they would be suitable to work with the existing pipeline. The greater difference between supply and return temperatures is supposed to be the reason of more convenient pressure differences. The Figure 4.5 shows the pressure differences at boilerhouse for different conditions of models.

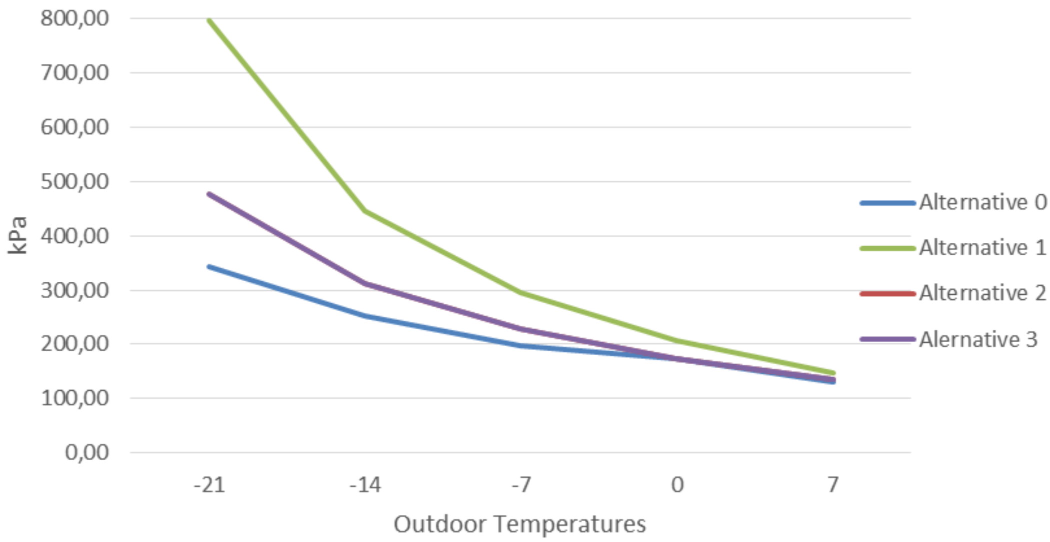


Figure 4.5. Pressure differences of the simulations at the boilerhouse

4.5. Analysis

The key figure for analysis of project is the compatibility of Jõgeva DH network to LTDH, and potential energy savings. Compatibility of the DH network depends on multiple factors.

Heat Energy Production

Heat energy production is anticipated to be affected postiviely. As the heat losses reduce and flue gas condenser enables energy recovery, annual heat energy production is expected to decrease. The reduction of heat energy production decreases fuel consumption and increases overall energy efficiency. Figure 4.6 and 4.7 below shows the calculated amounts of heat energy production and the amount of heat energy delivered to the end-users.

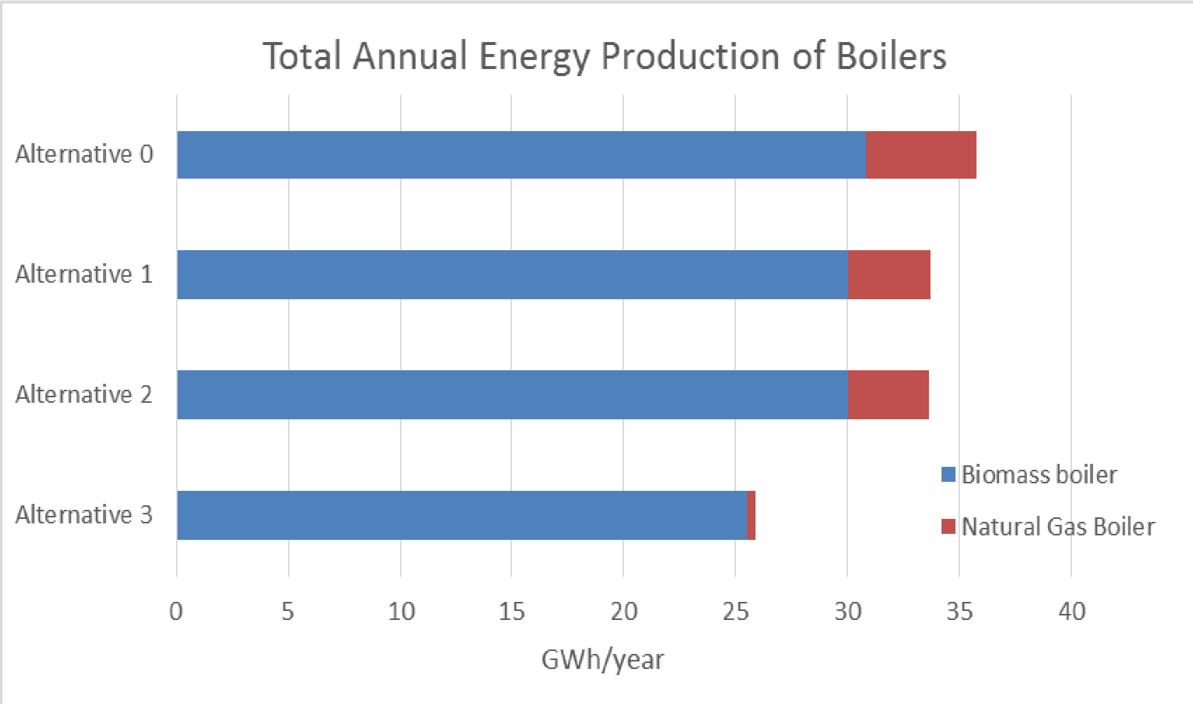


Figure 4.6: Total annual energy production of boilers

(Source: AS Eraküte)

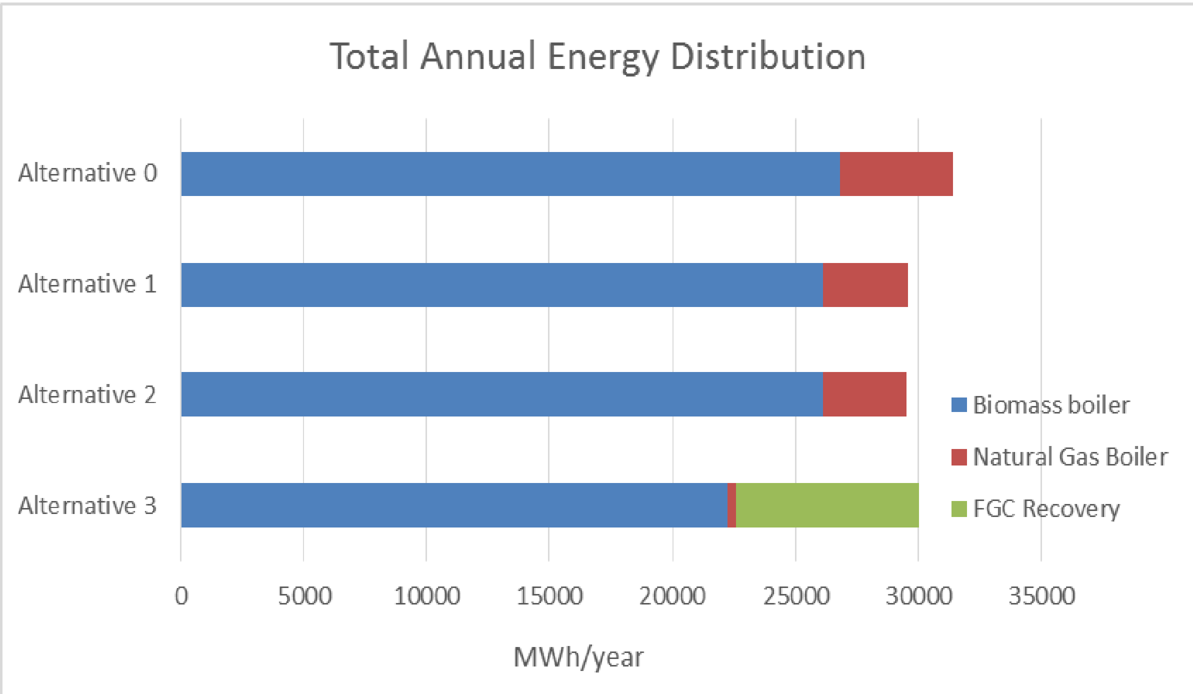


Figure 4.7: Total annual energy distribution from Jõgeva boilerhouse

(Source: AS Eraküte)

As it is shown on figure above, the amount of annual distributed heat energy exceeds 25GWh/year. Thus, it is possible to state that the proposed *Alternative* models are able to meet current heat demand.

Heat Losses

In terms of heat losses, all of the proposed models are capable to reduce the heat losses significantly. Due to the reduction of supply and return temperatures, the amount of heat energy wasted during transmission can possibly be declined to minimal levels.

Figure 4.8 shows the reduction of heat loss on Jõgeva DH network. It can be seen that *Alternative 3* model has slightly higher rate of heat losses than *Alternative 2* has. That situation is caused by FGC utilization. Due to heat energy savings of FGC, biomass and natural gas boilers produce smaller amount of energy. Since the calculations were carried out by comparison to heat energy produced, *Alternative 3* is shown as if the heat losses are higher, although the heat losses are at the same level with *Alternative 2*.

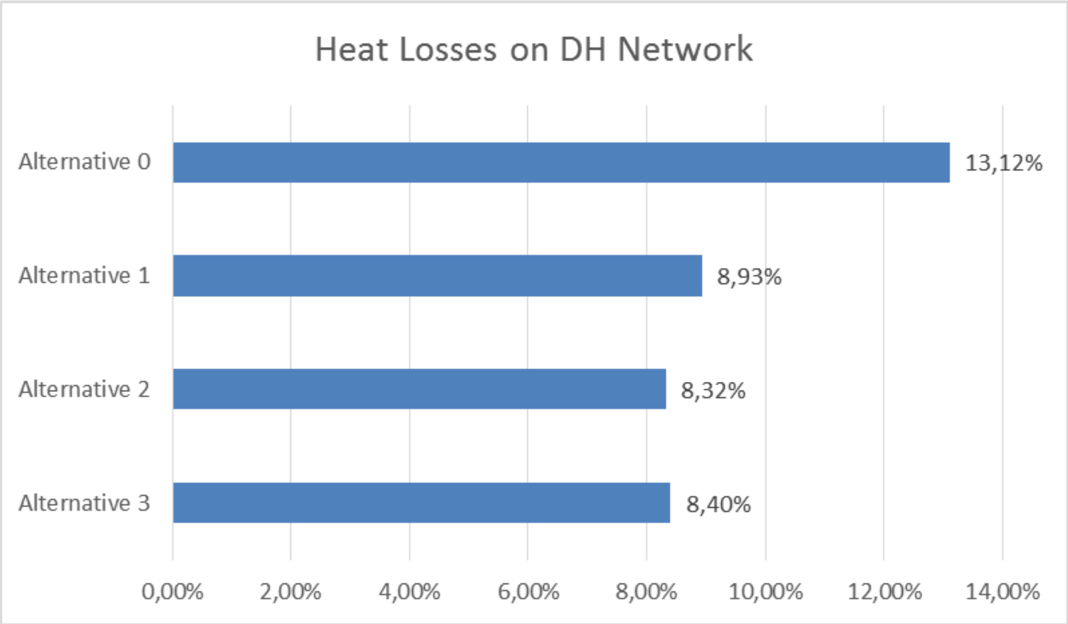


Figure 4.8: Rates of annual heat losses on Jõgeva DH network

Pumping Work

Pumping work is anticipated to increase, but, to stay within the technical limits of the pipeline. According to the simulation data from NetSim software, *Alternative 1* is not suitable to work with the existing pipeline, as bottlenecks occur at the specified conditions due to excessive pressures.

Alternative 2 and *Alternative 3* are compatible to work with the existing pipeline without requiring further maintenance on the pipeline. The simulation data demonstrates that any bottlenecks would occur at specified conditions. Figure 4.9 shows the plan of Jõgeva DH network under the conditions of Alternative 2 at 0 C outdoor temperature.

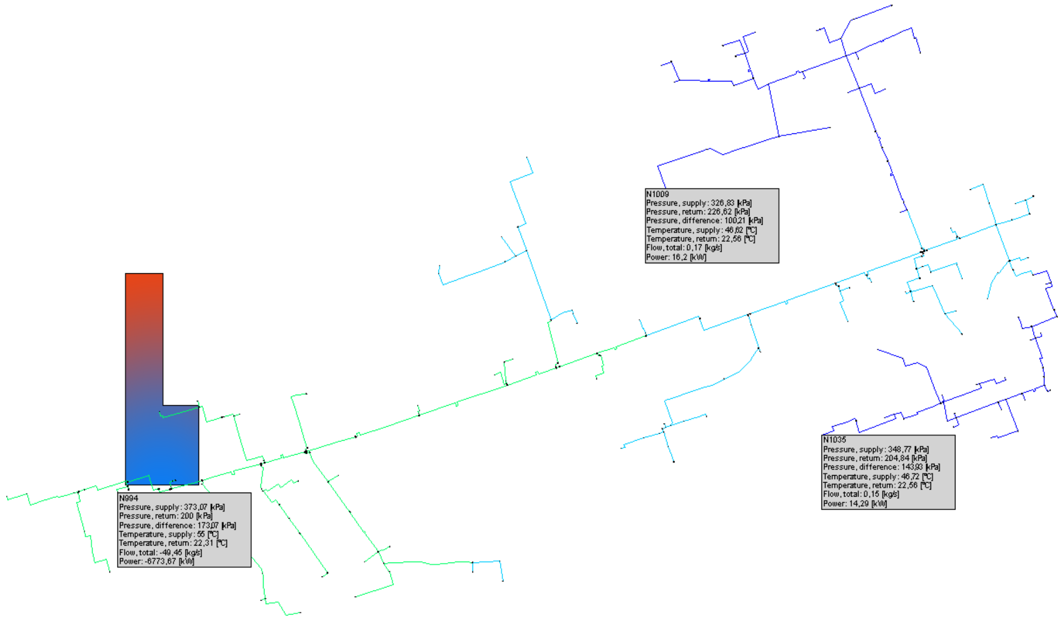


Figure 4.9: Plan of Jõgeva DH network with the simulation Alternative 2 at 0°C outdoor temperature

Fuel Consumptions

Total fuel consumptions of the boilerhouse is anticipated to decrease due to reduced heat losses. Since the heat losses are strictly related to supply and return temperatures, it can be stated that any amount of reduction in supply or return temperatures would affect energy efficiency in a positive way. Moreover, it can be observed that numerical value of subtraction of annual heat production and amount of heat losses are roughly the same for every model.

Fuel consumptions for models *Alternative 1* and *Alternative 2* are very close to eachother, as both models offer reduced heat losses and decrease the heat production at very similar levels. However, the fuel consumption of *Alternative 3* is remarkably lower due to higher energy efficiency. FGC helps to recover the heat energy from the return water, thus, the heat energy from biomass boiler is capable to meet the demand. In turn, natural gas powered boiler is used less, and that helps to save natural gas, which is imported and more expensive. Total fuel consumptions are shown on Figure 4.10 and 4.11 below.

Fuel savings bring economical benefit in return. Operator company of Jõgeva DH network is expected to reduce its fuel costs 40%, after implementing LTDH technology and installing a FGC at boilerhouse. Total annual fuel costs are shows on Figure 4.12 below.

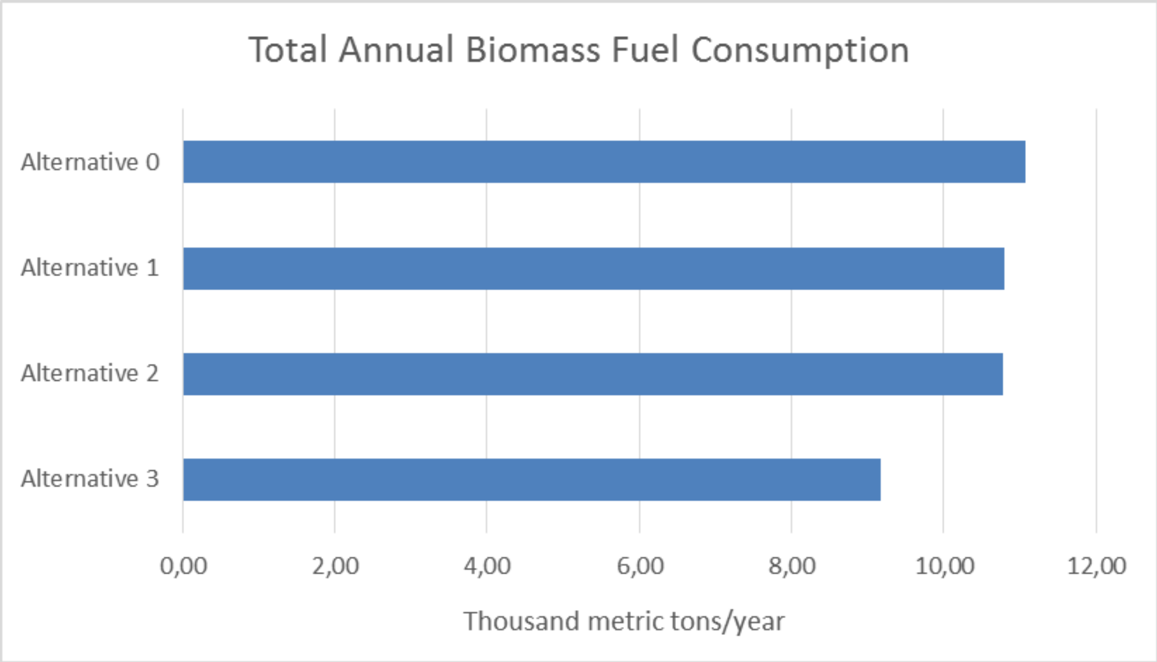


Figure 4.10: Total annual biomass fuel consumption

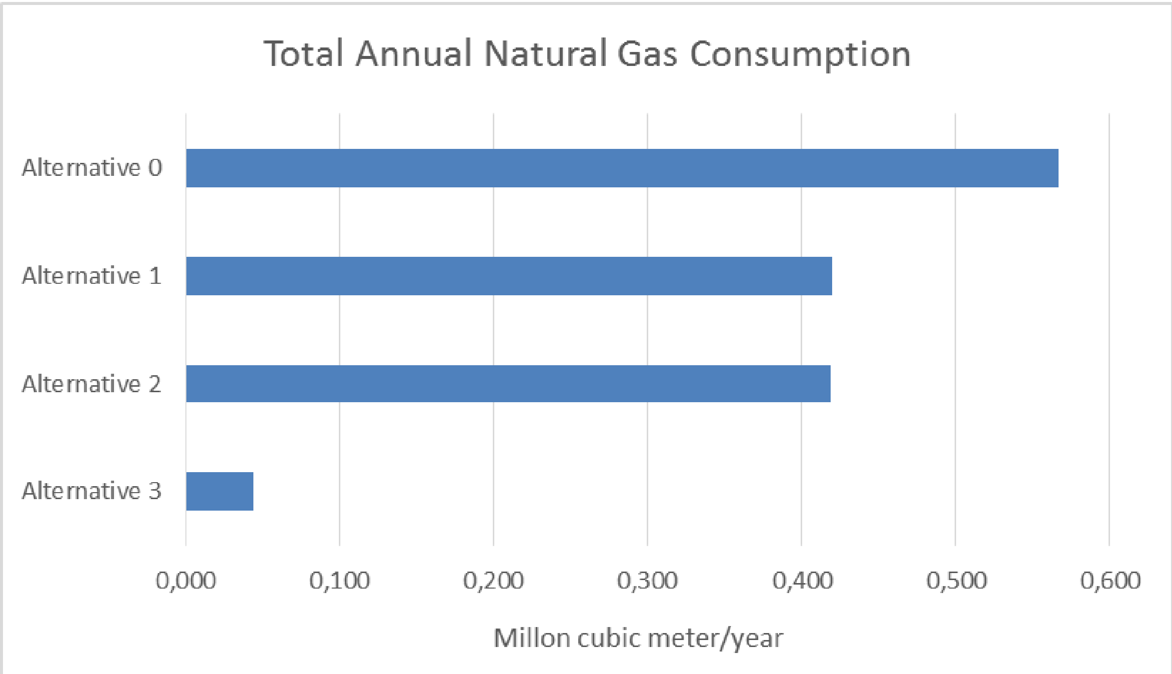


Figure 4.11: Total annual natural gas consumption

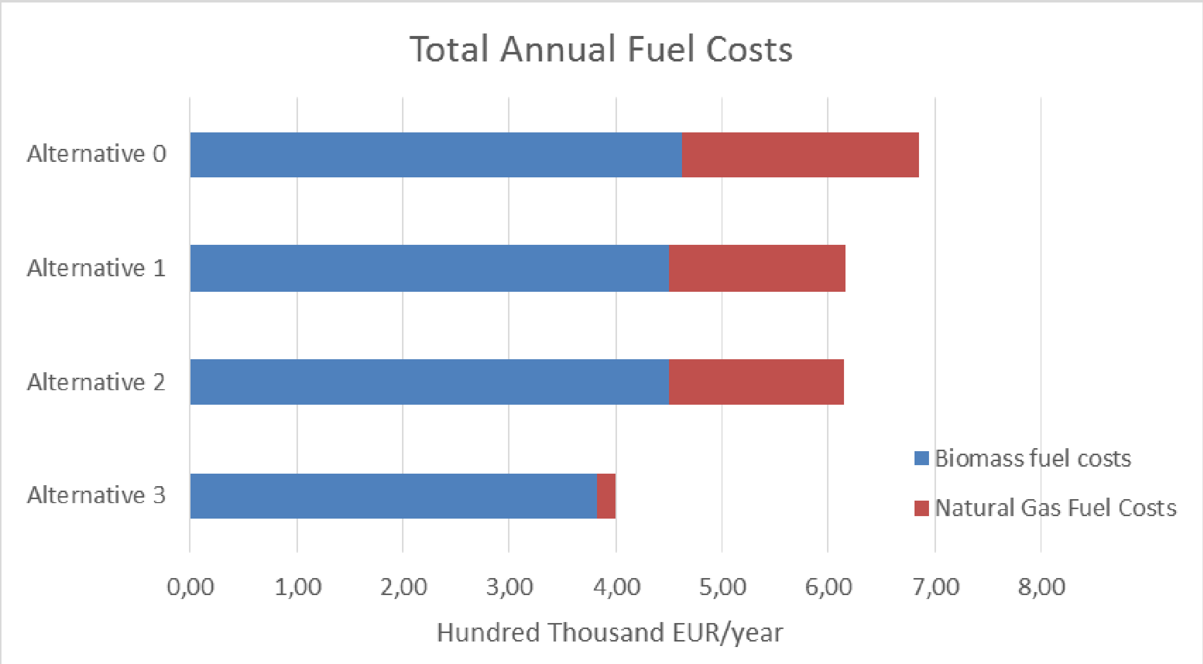


Figure 4.12: Total annual fuel costs (Source: AS Eraküte)

Primary Energy and Greenhouse Gas Emissions

Primary energy is a unit of energy, which is used by governments to keep statistics. Total Primary Energy Supply is a term used to calculate the sum of production and imports, subtracting exports and storage changes. Both of the terms are used in energy statistics. Calculations of total primary energy (PE) consumptions are shown on Figure 4.13 below.

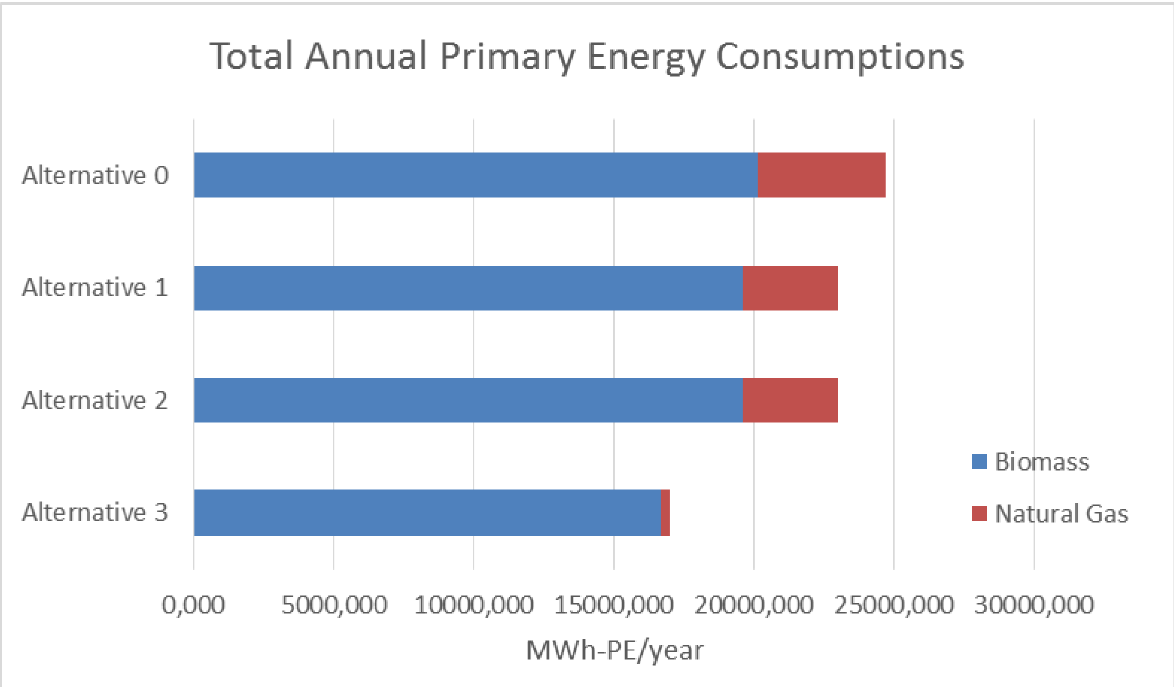


Figure 4.13: Total annual primary energy consumptions

Greenhouse gas emissions are important for countries, as they are considered as the key reason to the global climate change. Therefore, emissions are strictly controlled, and reduction of greenhouse gases (CO_2, etc.) are supported by subsidizing. The figures below show difference between two calculation methods. Figure 4.14 shows the calculated amounts of CO_2 emissions, and Figure 4.15 shows the amount of emissions which are subjected to taxation. The reason of difference is energy policy of Estonian government. Biomass fuels are calculated as 0 kg.CO_2/MWh, in order to subsidy biomass fuel utilization and support local energy sources.

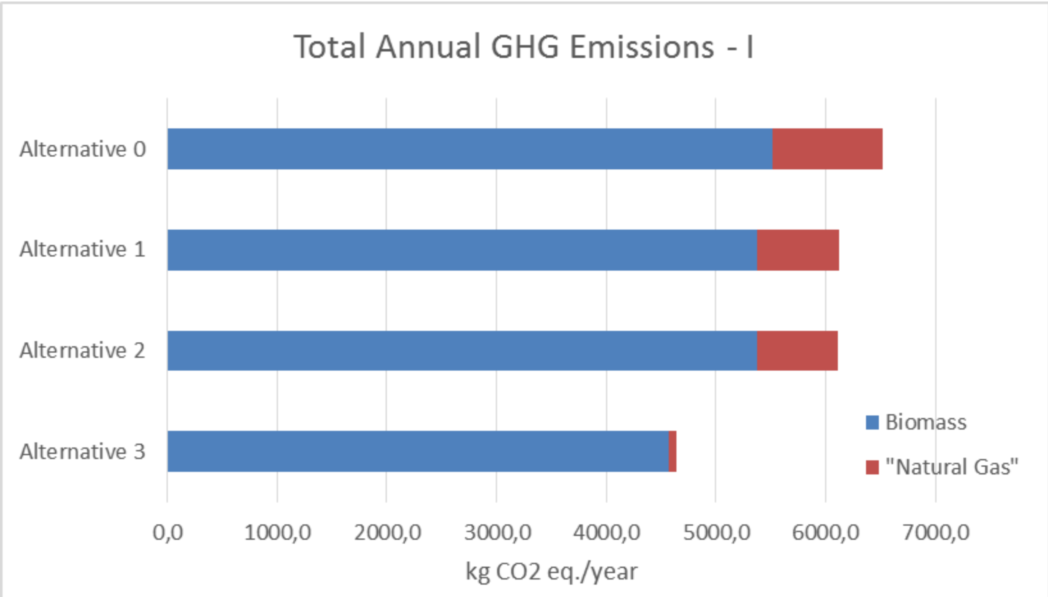


Figure 4.14: Total annual greenhouse gas emissions

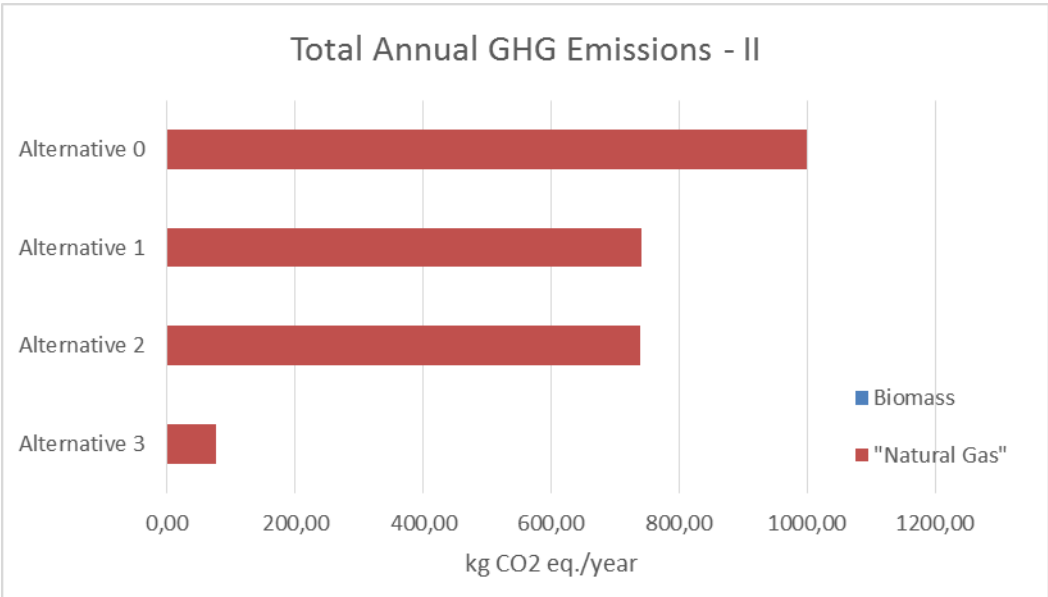


Figure 4.15: Total annual greenhouse gas emissions subjected to taxation.

5. Conclusions

Interest in using locally available and cheap biomass energy sources is increasing. In this study, NetSim network simulator software was used to study the compatibility of Jõgeva district heating network to 4th generation of district heating. Reduction of supply and return water temperatures, and installation of a flue gas condenser were studied.

Achieved results show the possible benefits of the LTDH technology in Jõgeva district heating network, from both energetic and economic points of view. Reduction of supply and return temperatures enables to decrease the heat losses. Implementation of a flue gas condenser will result in energy efficiency increase in heat production and will save costs of fuel. Also, that will make district heating more available economically and more environmentally-firendly.

The reduction of supply temperature to 55 C degrees and return temperature to 27 C degrees, results in estimated economical savings of 70 259 EUR/year. Furthermore, economical savings of 285 148 EUR/year can be achieved by installing a flue gas condenser to the Jõgeva boilerhouse.

It is known that the way to achieve high energy efficiency is long and expensive. However, the amount of economical savings can be invested to renovation projects in order to extend the lifetime of DH network and to avoid utilization of cheap but pollutant fuels by consumers for residential heating purposes.

It may need time and money to obtain high reductions in supply and return temperatures. But, it must be accounted that district heating is closely related with large investments and long pay-back times. Further studies needs to focus on long term evaluations since extending lifetime of district heating network is crucial.

The economical results are also dependant on the energy prices. Consequently, the economical benefits will be determining the feasibility of the investments, thus, long term studies should incllude forecasts for energy prices.

From the environmental point of view, the reduction of supply and return temperatures results in a decrease of greenhouse gas emissions to the atmosphere. The increase of energy efficiency in the boilerhouse makes it use less fuel per unit of heat energy produced. In the same way, the decrease of heat losses along the network reduces fuel usage in all the district heating network. Furthermore, the most important reduction is obtained for the natural gas, since it is imported from Russia and expensive than local energy sources. The proposed model *Alternative 3* would reduce the usage of biomass and natural gas, and it means that also CO_2 emissions would be reduced. It is important, as the increase of CO_2 emissions is the key factor of the global climate change.

In addition, the implementation of flue gas condenser enables to recover remarkable amounts of heat energy, and to filter pollutant substances or particles that otherwise would be emitted to the atmosphere.

Further Studies

An average numerical value of heat transfer coefficient was considered at this study. The heat loss reduction can be studied with dynamic fluid simulations in order to calculate the heat losses accurately.

The results demonstrate that the pipeline and the network is ready to switching to LTDH. However, the electricty consumption of the increased pumping work can be studied with specific power curves of pumps.

Energy recovery of flue gas condenser from return water can be studied thermodynamically. Since there are two different boilers with different type of fuels, the energy recovery behaviour of the flue gas condenser can be studied to obtain accurate results.

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APPENDIX 4

TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY
Faculty of Chemical and Materials Technology
Department Materials Science

Professor ....

You are kindly asked to review (name of the student) master thesis

....
Head of the Defence Committee

REVIEW

1. Topicality of the thesis

    a) Regarding social aspects

    b) Regarding aspects of economy

    c) Regarding creativity

    d) Regarding engineering aspects

    e) Regarding technical aspects

2. Outline of the thesis

3. Based on the graduation thesis, how would you describe the author's understanding and use of field-specific literature?

4. Evaluation of the research part of the thesis
   Evaluation on scale from 1 to 5
   Comments

5. Evaluation of the author's contribution to the subject matter in the thesis.

Evaluation on scale from 1 to 5
Comments

6. Evaluation regarding engineer-technical aspects (calculations, planning etc)
   Evaluation on scale from 1 to 5
   Comments

7. Evaluation regarding aspects of economy, and/or potential economic viability
   Evaluation on scale from 1 to 5
   Comments

8. Evaluation regarding graphic aspects and illustrations
   Evaluation on scale from 1 to 5
   Comments

9. Evaluation regarding the use of field-specific vocabulary and the structure of the thesis
   Evaluation on scale from 1 to 5
   Comments

10. Positive aspects

11. Negative aspects

12. Questions and comments to the author

13. General evaluation (scale form1 to 5)

Submitted scientific papers a) Graduation Thesis .... pages
b) Graphics...........
c) Tables.............
d) List of used literature........... Including reference
e) Technical drawings .... pages
f) Other.........

Reviewer.. Phone.............................
Name and Signature

....
Profession

....
Education (name of university, qualification, year of graduation)

Date..

*Note.
Grading system: 5 - excellent - 91-100%, 4 - very good - 81-90%, 3 - good - 71-80%,2 - satisfactory - 61-70%, 1 - sufficient - 51-60%