TALLINNA TEHNIKAÜLIKOOL
TALLINN UNIVERSITY OF TECHNOLOGY

School of Engineering.

Assessment of Waste Heat Potential in Estonian Industries

Jäätmeküttuse potentsiaali hindamine Eesti tööstustes

Name : Syed Ahsan Akhtar
177345KAYM

Supervisor : Anna Volkova

Senior Researcher
Faculty of Engineering
anna.volkova@taltech.ee

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AUTHOR'S DECLARATION

Hereby I declare, that I have written this thesis independently.

No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

25/05/2019

Author: Syed Ahsan Akhtar.

/signature /

Thesis is in accordance with terms and requirements

25/05/2019

Supervisor: Anna Volkova.

/signature/

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Chairman of theses defence commission:

....

/name and signature/

School of Engineering

THESIS TASK

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2. To estimate District heating that can be covered using waste heat
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/signature/

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/signature/

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List of abbreviations and terms

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

m2: 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

USA: United States of America

UV: Ultraviolet

V: air volume [m^3/s]

ρ: density of air [1.202 kg/m^3]

Δh: enthalpy difference [kJ/kg]

Abstract

Waste heat energy and Waste heat recovery systems are often ignored by companies and industries. The reason for this ignorance could be due to many different factors which might be economical, financial or simply lack of knowledge about the system. District heating is part and parcel of Estonian lives and using the waste heat recovery systems can help the dependence on the primary fuels such as natural gas. Natural gas is not a local fuel and it is imported from Russia in Estonia. To reduce the usage of the natural gas, waste heat recovery system can be a viable option. Though, the natural gas is and will remain a big source of energy in Estonia for some years to come but the usage of it can be reduced. The thesis gives an overview about the utilization of waste heat in some of the industries and how the waste heat can be recovered. The Thesis also emphasis on the usage and how much waste heat can be recovered from the three most energy consuming industries in Estonia which are Paper and Pulp industry, Wood and wood products industry and Food, beverage and tobacco industry. Based on the results provided in the thesis, it is recommended that the waste heat recovery systems should be in installed in those industries and the estimation for the how much energy can be recovered from those industries are also provided.

This thesis is written in English and is 68 pages long, contains 4 chapters, 13 figures and 4 tables.

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Preface

I would first like to thank my thesis advisor Dr Anna Volkova of the Department of Engineering, Tallinn University of Technology. The door to Prof. Anna Volkova office was always open whenever I ran into a trouble spot or had a question about my research or writing. She consistently allowed this paper to be my own work, but steered me in the right the direction whenever her thought I needed it. As my teacher and mentor, she has taught me more than I could ever give her credit for here. She has shown me, by her example, what a good scientist (and person) should be.

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Contents

1.1 Introduction to Waste Heat and statement of problem

The waste heat is the leftover or un-utilized heat which is released in the environment. When collecting the data for the energy consumption for certain industries, Waste heat potential is often neglected. The waste heat can be trapped and re-used but in most of the cases the waste heat gets ignored. This could be due to many reasons such as financial difficulties, not enough knowledge about the usage and productivity, and some other factors. The potential for waste heat recovery is immense and it will help to reduce the emissions in the environment. The EU has set goal for its member countries to bring down the emissions and Waste heat recovery is one good solution for the reduction in the emissions. Recovery of the waste heat does not only prevent the emissions but also it helps reducing the cost of the processes and fuels. If waste heat recovery technology is placed, then the heat can be reutilized and will not additional fuel for the same process hence it brings down the cost of the operation and less usage and dependence on the fossil fuels. In today’s world, the environment is of prime concern across the world, but EU has always been on the forefront for solving the problem. EU have invested heavily in infra-structure that will reduce the industrial impact on environment. The popular belief is that the waste heat can only be used for the power generation in the industry, but the waste heat recovery has far more applications than just power generation. The main purpose of the study is to estimate the waste heat potential in three most energy consuming industries in Estonia. The research will be based on theoretical estimations and data taken from the official websites.

1.2 Literature review

World is fast moving towards the industrialization and new industries are being built. The temperature in these industries have risen. The higher temperature gives potential chance to recover the waste heat coming from different industries and use it for technical and mechanical work. Numerous studies have been conducted for the waste heat recovery estimation and potential. One such study was carried out by Aneke in 2012. The Research revolved around the waste heat coming from the fryer of crisps. The waste heat from the foul gas, waste heat from the hot oil of the fryer, waste heat from the effluent was considered. Since crisps manufacturing takes a lot of electricity, it is crucial to use the waste heat from the system and use it for the electricity to bring the cost of the operation down. The waste heat from the effluent gas stream from the heat exchanger was used to drive an ORC system for power generation. The study concluded that the use of the ORC system for recovering the waste heat from the crisp fryer and reusing it in the system is economically viable option (Aneke et al.).

Thermal energy storage (TES) is another method which is used to store the hear. The use of this can also bring down the fuel costs and increase the efficiency of the system. TES is a powerful tool by which energy supply and demand can be managed. The TES can be located on-side or off-site. It can be used with the IWH plants. If the TES is installed on-site then it can be utilized in preheating of the incoming water or combustion air. (Miró et al.) (Raine et al.) investigated the potential uses of IWH from three steel making industries in UK using thermal energy steam accumulator as TES system. The TES system was used for the internal DH. The sources at the temperature range of 600-1500°C were identified. The estimated CO_2 saving as the result of implementing these TES systems were 22482 tCO_2. (Miró et al.)

In a study carried out by Steven in May 2017, the study proposed to use the ORC system for the low heat electric furnace. It involved the integration of the electric furnace with the ORC system. The electric furnace is a process with large time variation in available thermal capacity and temperature. The study concluded that buffering of the heat is necessity for which steam loop is identified. (Steven et al.)

In 2009, Enova conducted a survey in Norway and Svensk Fjarrvarme. The potential in the study of Svensk Fjarrme was presented and listed in terawatt hours including a comparison to the former values. The study done by Enova concluded that 37% of the waste heat has the temperature range of over 140°C and rest of the 63% are the temperature ranges between the 40°C to 60°C. (Arens)

This prompted the study done by Hammond in the UK which classifies the temperature ranges of above 140°C. This study was conducted in UK in the year 2012. (Forman et al.) Later on, Germany conducted using the enova results for the untapped waste heat and referring final energy consumption to corresponding branches in Germany. (Panayiotou et al.)

In 2011, Tahsin and Hepbasli conducted a study into a heat demand estimation for a single building. The calculations are heavily dependent on the heat losses and heat gains which needs great deal of accuracy, so the study made assumptions very carefully to make it accurate enough. The study applied exergy analysis to the educational building and examined energy and exergy flows and calculated from the first stage. The study concluded that the installation of well insulated building materials can reduce the exergy of the heating systems. **(**Tahsin **and Hepbasli)**

The above study proves that the waste heat recovery methods are good for the industries to bring the cost down and increase the efficiency of the system. The recovery of the waste heat is necessary for cleaner environment as the waste heat contains flue gasses and flue gasses will harm the environment if there are no waste heat recovery systems in place.

1.3 Sources of Waste heat

The largest proportions of total waste heat are from power stations and vehicle engines. The largest single sources are power stations and industrial plants such as oil refineries and steel making plants.

- Power Generation:

  The electrical efficiency of thermal power plants is defined as a ratio between input and output energy. It is typically only 33% when disregarding the usefulness of heat output for building heat.

- Industrial Processes:

  Industrial processes, such as oil refining, steel making or glass making are major sources of waste heat.

- Electronics:

  Although small in terms of power, the disposal of waste heat from microchips and other electronic components, represents a significant engineering challenge. This necessitates the use of fans, heatsinks, etc. to dispose of the heat.

- Biological:

  Animals, including humans, create heat because of metabolism. In warm conditions, this heat exceeds a level required for homeostasis in warm-blooded animals and is disposed of by various thermoregulation methods such as sweating and panting. (Fiala *et al.)* modelled human thermoregulation

Waste heat from the industries can be used to produce fresh distilled water. Qatar is an arid country where 100% of the water is supplied through the thermal intensive energy-intensive thermal desalination process. The country's need for water has reached an all-time high which stipulates finding an alternative way to augment freshwater without adding any drastic affect to the environment. A study showed that around 605 MWh of waste heat can be recovered from studied Qatari chemical industries which resulted in a total daily production of 5078,7 m^3 of freshwater. This water can be used in a wide variety of applications. (Richter et al.)

In another study carried out in Czech Republic, waste heat from the industry was used to produce electricity. This system revolved around the usage of Rankine steam cycle. The study show that waste heat can be successfully converted into electricity using some modifications to the original design of the turbine. The efficiency of the system was around 4.4% net while the classic turbine blade in these low steam parameters achieve about 12.6%. despite the lower efficiency compared to the one which is generally used, the analyzed turbine would be suitable for the operations that have problems with the steam purity as even small droplets can serious damage the conventional blades. (Richter et al.)

Domestic Waste heat applications: Rowe reported that a waste heat based thermoelectric power generator is used in a domestic central heating system with the modules located between the heat source and the water jacket. In this type of setting, the out heat is provided by gas or oil burner which passes through the generator before reaching the central heating hot water exchanger. The generator converts about 5% of the input heat to electrical power and remaining 95% transfers to hot water heat exchanger for its intended use of heating the radiator system.

Thus, it is beneficial for us to recover waste energy and put it to use. Despite it being highly advantageous, there is no simple method to recover heat waste and utilize it. Different technologies are used to recover the waste heat from industries. Some of those technologies and techniques are mentioned below. It was discovered that major heat recovery equipment is mainly categorized based on the temperature range and the type of fluid being recovered in the process and each has a different usage. (Richter et al.)

1.4 Energy conversion technologies

Recovery of wasted energy can be achieved using energy conversion technologies. These technologies can be classified depending on the type of energy input (thermal energy or waste heat, which will be the focus of this document, and other types such as pressure or motion), and on the type of energy output.

Waste heat recovery technologies include: -

- Heat exchangers and heat storage solutions, which do not convert energy but simply transfer it to another medium or store it to make it available upon demand. There are two types of heat exchangers. One of them uses technology based on process heaters and often has two sections, a section where tubes containing sCO_2 are heated by radiation from hot combustion gasses: once the gas is cooled sufficiently, convection is used to further heat the CO_2 in the tubes. Second type of heat exchanger is different than the first one. In this type of heat exchanger, only convection heating is used. These systems are typically like heat recovery steam generators that are used in steam bottoming cycles. These WHR systems generally use finned tubes with the combustion gas flow over the finned tubes. (Harrestrup and Svendsen)

- Heat pumps, which increase the temperature of a heat source. Heat pumps are a promising technology for heating and cooling. Heat pumps are usually used in District heating and cooling systems. They can provide exceptionally high efficiencies compared to fossil fuel combustion. Electric heat pumps are one of the most energy efficient ways to provide District heating and preparation of sanitary hot water. Though it is a well proven technology, but it is yet to get the public recognition and fame. In Europe, some countries like Sweden, Switzerland and some parts of Austria is sustainable market for heat pumps. Due to increase in the price of oil and electricity and recent energy taxes, the market shall show great growth in all of Europe. There are many different types of heat pumps, they are differentiated on which heat source and heat sink they are made for. All types have their own pros and cons as well as environmental impact. (Forsén)

- Steam boilers, that use waste heat to produce steam for use in the plant (widely implemented in industrial processes). The boiler is consisting of furnace and a boiler proper. An air and fuel inlet are used to input fuel to the furnace. Once heat up the boiler proper containing water converts hot water into hot steam which can be used for producing electricity or to be used in district heating. In case of producing electricity, the hot steam from the boiler proper is used to turn the turbine which generates electricity which can be used for different purposes. In case of District heating, the hot steam coming from the boiler proper is carried out through the pipes to the national grid to supply heating for the domestic uses. The modern boilers require high quality water to operate efficiently but such water cannot be obtained from any natural sources as it contains certain impurities. In order to use the water in the boiler to achieve good efficiency, the water is pretreated using various techniques before being fed to the boiler.

- Classic thermodynamic cycles, based on the phase change of a fluid, to produce electricity with a turbine or directly drive a rotating machine in the plant.

- Alternative technologies to produce electricity without rotating machines and phase change fluids. One of the common examples of such a process is Thermoelectric process. Thermoelectric process is such a process in which the heat is used to produce electricity. The heat is created by temperature difference between electric voltage. One of the methods used is Seebeck effect. It is conversion of heat directly into electricity at a junction of different types of wire.

1.5 Waste Heat from Industry

Waste heat recovery is not uncommon practice. Industry sector utilizes waste heat for many different purposes. The waste recovery heat can reduce the dependence on the primary or fossil fuels. Some industries like Glass and Cement produce high emissions and hence it makes sense to use the waste heat recovery systems and technologies in those industries. Usually, the waste heat coming from the glass and cement industry are of high temperature and the technologies are available to collect the waste heat from them. The waste heat coming from wood and paper along with food and beverage industry is usually low temperature heat. The systems for recovery of the low-temperature waste heat needs to be developed and the potential of WHR in those industries are big. Some of the successful examples of the WHR (Waste heat recovery) systems effectively utilized in the practical world are given below.

1.5.1 Glass Manufacturing:

The Glass industry consumes about 300 TBtu/yr, some of the sources estimate that as much as 70% of this energy is used in glass melting and other processes for refining at high temperature furnaces. The temperature required for melting a glass is varied due to the type of the glass. The theoretical minimum energy for melting a glass is only about 2.2 million Btu per ton however this estimate is very conservative as some of the furnaces can consume up to 20 million Btu/ton. The use of regenerators and recuperates are very common for waste heat recovery in the glass industry. Glass melting is a high-temperature operation and providing ample opportunity to recover and utilize the waste heat. The temperature for the glass melting is always as high and sometimes can exceed up to 1314℃. As mentioned earlier the recuperates and regenerators for combusting air preheating are most common methods for the waste heat recovery. Method to recover the waste heat in the glass manufacturing company always include preheating batch and cullet material and using the waste heat boilers for the electricity generation. The waste heat is at high temperature, but the mass of the exhaust gases is much lower leasing to lesser waste hear loss as percentage of fuel input. The recovery of the waste heat in the glass industry is a common practice in the United states. Pre-heating batch material is a cost saving measure and it is used in only one of the United states glass manufacturing company but most of the European industries do use the preheater because the cost for preheating batch material is much higher in Europe. (Agathokleous, Agathokleous, et al.). Glass manufacturing can be used for providing the District heating to the residents of the nearby areas. One such example is found in Italy. Where Heliex Genset utilizes the steam which is generated by the waste heat recovery boiler using exhaust gasses from the furnaces. The furnaces are used in the glass making. The plant is generating about 400 kW of electricity and providing 4MW heat which is supplied to the locals using the conventional networks. At 111 °C, the steam available after the Heliex system is the perfect temperature to produce hot water for the local houses. (Heliex Power)

1.5.2 Cement Industry:

Cement industry consumers about 550 TBtu/yr to produce about 110 million tons of cement annually in US. Mining of the material and refining of raw material which is mainly limestone and chalk are the important part of the cement industry. Crushing and grinding materials in the preparation of kiln, clinker production and cement milling are part of the process. The use of Rotary kilns is common and there are two different types of rotary kilns. One is the wet process and other is dry process. In Wet kiln, the moisture content is about 30-40% and requires high temperature and energy for evaporation of the water. Exhaust temperature without the heat recovery is about 450℃. Heat can be recovered from the exhaust by using the preheating and power generation. This recovered heat can be used again for the higher efficiency and reducing the fuel cost. While the heat recovery from the cement kiln is a common procedure but it is estimated by the paper that about 83 TBtu/yr of the medium temperature waste heat is not recovered from the kiln. These waste heat losses can be reduced further by using the cogeneration technologies. (Agathokleous, Agathokleous, et al.). in 2014, Gas-oxy furnace was installed in Estonia for the recovery of the waste heat. The main benefit for using the gas-oxy furnace that it converts the outputs into the inputs which benefits the extraction process. The process will be able to extract as much energy as possible. (Owens-Illinois)

1.5.3 Skjern Paper Factory

Skjern is a paper factory which is located in West Jutland in the Denmark. The Area has open lands and peat bogs and heaths. It is home to around 8000 people. The paper factory started the initiative of providing the district heating facility to the inhabitants of the West Jutland region. It used a large heat pump. The capacity at the start of the project was 3.9 MW but with the passage of time and after realizing the advantages, another heat pump was installed in the paper factory and raised the capacity of the paper factory to 8 MW. The temperature of the factory is usually around 28℃ to 33℃ and condensate at 70℃. The Project is providing the district heating to 60% of the city of Skjern. The paper factory is not only providing the district heating to the region but also bringing down the Co_2 levels. 8200 tons of CO_2 was saved from getting released into the environment. (Petrović and Karlsson)

1.5.4 Nutrex Food company

Nutrex is a company which is based in the Switzerland. The company is one of the leading manufacturers of the vinegar production and sales. The company vinegar production involves two processes. One of the process is named as Fermentation and other is called Pasteurization. The processes are a perfect match for heat pumps and serve as a source and sink. Fermentation of Vinegar is an exothermic reaction and stops working when the mixture is too warm. To stabilize the process, it is required to keep the temperature at 30℃ and large tanks to be cooled. The need for this method met with innovative idea. The cooling demand of the large tank was met by installation of heat pump with capacity of 136 KW and heating capacity of 194 kW. Besides the processes, the waste heat generated is used as a source for district heating in laboratory and building. The use of the heat pump in the Nutrex factory has brought down the CO_2 emissions by 310000 kg/year and it is saving 65000 liter of fuel per year. (Zuberi et al.)

1.5.5 Swiss Krono's chipboard factory

The production of the chipboard is a high energy consumption industry. The processes involved in the process consumes high levels of energy such as electrical processes which are consuming greater than 200 GWh and thermal processes can take 1300 GWh. The processes such as slicing of tree trunks and drying of woodchips and forming wood chips from them. The cogeneration plant is producing and recovering about 2MW o the waste heat. Hot water is used to dry the entire amount of wood chips which can consume up to 12 MW. Swiss krono company has installed two heat pumps to separate the waste circuit of the power plant from heat pump. This helps the transfer of heat to the source side of the heat pump. The heat pump is currently working at the COP of 4.5. Based on the data collected from the industry in

2016, the results showed that the industry was able to save 32 GWh and 6700 tons reduction in the CO_2. (Milkov et al.)(Zuberi et al.)

1.6 Waste heat to Electricity

German industry releases 200 billion kilowatt-hours of thermal energy a year into the environment as unused waste heat – roughly equivalent to the entire energy consumption of the federal state of Hesse. BILSTEIN GmbH & CO. KG in North Rhine Westphalia processes steel strips for use in the furniture, tool and automotive industries. The strips must be heated and then re-cooled so that they can later be formed and further processed. The waste heat generated in this recrystallisation process is used to produce electricity, with the aid of an innovative Organic Rankine Cycle (ORC) system. Unlike conventional procedures, ORC can make use of the relatively low temperatures of the waste heat for the generation of electricity. Not only does the company save electricity through the efficient use of waste heat, it can also use the heat for heating buildings and accelerate production thanks to faster cooling times. Another notable German waste heat to energy plant is The Gebr. Wiesböck & Co. GmbH Portland cement plant in Upper Bavaria produces cement for the construction industry. The required raw materials are heated together with various additional materials in a rotary kiln to produce cement clinker. The 400°C exhaust gases from the rotary kiln contain dust and are used to preheat the raw and additional materials for the firing process. At the same time, they are also fed into a special waste heat boiler to produce steam. The steam then powers a turbine which produces electricity via a generator. In this way the power plant can generate 30% of the electricity it needs and save the equivalent of 80,000 tons of CO2 a year.(Agathokleous, Bianchi, et al.).

1.7 Waste heat barriers:

There are many barriers which are related to waste heat implementation. Some of them can be interrelated. Even after good knowledge of value of heat and it can bring advantages, some industries are just not interested to put in an effort and utilize that heat. Following are some of the barriers that are listed. Waste heat recovery systems are frequently implemented. Most of the unrecovered waste heat is at low temperatures. While low temperature is waste heat has less thermal and economic value than high temperature. Some of the losses that occur from non-traditional sources are difficult to recover but have significant value.

1.7.1 Practical Barriers:

For an industry that is already up and running, it is hard for them to install waste heat recovery systems in the industry. First issue is the equipment will be replaced and the materials and working SOP of the industry will change. The industry cannot afford to shut off the industry to install big equipment and set up heat recovery system. This will incur losses to the industry which nobody wants to bear. Shutting down processes can be at a great cost and most of the industries are not willing to take that risk. In small or medium size commodity, the installation of the waste heat recovery system can be more problematic as there is not much space available for the installation. In some industries, buildings are old and are using different roofs.

1.7.2 Structural Barrier

If the waste heat is to be used internally then there must be an additional heat demand near to the waste heat generation plant. This is a barrier because the long-distance heat transport is not much profitable and heat pipes are needed to be properly insulated for longer distance. Heat can also be exported to local community nearby, but the heat sink should be close to the consumer. The heat must be saved if it is not required and when it is required then it should be utilized.

1.7.3 Financials and Logistics barrier

The installation of the waste heat system is a costly affair. The payback time is about 3-4 years in installing such a system. The profitability of the system depends on the buyer of the waste heat that is recovered. This can be avoided by making long term contracts as if there is no consumer for the heat then the system will eventually go bankrupt. Most of the companies prefer the short payback time and if the payback time is many years then the investor will not be investing a hefty amount in the system or at least the investor will be hesitant. The risk assessment should also be taken into consideration as global warming can wipe out the need for the heat of consumer. This problem needs practical approach to create win-win situation for both customer and investor. (Pehnt et al.)

1.7.4 Technological Barriers

Even though Waste heat is a mature technology but there is still vast room for improvement. The need for technology to convert low grade heat into electricity is a big factor. Heat recovery from hot products and special materials can prove to be game changer for the waste heat. It is quite possible that in near future these technological advancements are met and demand for the waste heat recovery systems will increase. The market is available for the waste heat energy systems, but the system needs some advancements.

1.8 Type of Industry and System Installed

The temperature coming out of the waste heat stream has an important role on which process will be employed by which industry. Basically, there are two types of systems available that convert waste heat to power. These systems are Stream

Rankine Cycle (SRC) and Organic Rankine Cycle (ORC). Over the period, new technologies may also emerge. These technologies include Kalina cycle which has started to be employed in some industries and super critical CO_2. SRC and ORC are commercially viable and available technologies. The table below represents the type of industry and the type of system that is installed in it. (Elson et al.)

Table 1 Type of Industry and system installed.

Type of Industry	Type of Waste heat recovery system
Oil and gas extraction	ORC
Mining except oil and gas	ORC
Food Beverage and Tobacco	SRC
Wood	SRC
Paper	SRC
Printing	SRC
Pipeline transportation	ORC
Waste management	ORC
Primary metals	SRV
Machinery	SRC
Colleges	SRC
Chemical	SRC
Non-metallic minerals	SRC

Two ORC systems were employed in two Steel making industries. The aim was to improve the energy efficiency and sustainability of their primary and heat-based processes. It was installed in Singapore where generally the demand for the heat is less so more viable option was to convert it into mechanical or electrical energy by using the ORC System. The other system was installed in the Riesa, Germany which had nominal capacity of 2.7 MW. The industry employed ORC system to recover the waste heat which otherwise would have wasted. The plant was commissioned in

2013 and working on daily basis. The advantage of using the ORC system is that it can work with many different fluids. Steel making industries are a high temperature industries and ORC is used to recover the waste heat and then utilize the waste the for DH, Mechanical or electrical work. (Steven et al.)(Foresti et al.)

ORC system was employed in Belgium Electric Arc furnace to capture the low temperature heat from the furnace and to use it for other purposes. The Electric arc furnace had two parts which had issues. First, the flue gas was available before the dryer cooler and the temperature range for the flue gas was between 80℃ to 140℃. Only flue gas was considered in this study because of the low temperature. The study concluded that the average heat transfer rate was about 8.8 MW. This result was based on cooling flue gas to 90℃. (Steven et al.)

A study conducted by Milewski and Krasucki compared Kalina and ORC cycles. The Study was based on the usage of both cycles in the steel and metal industry. The study showed that the results where Kalina cycles are used for the temperature range of 180℃-220℃ was more suitable for waste heat utilization. The performance of the system depends on many factors which are carefully controlled in order to get the desired results from the Kalina cycle. The study revealed that the Kalina cycle operates well under the ambient pressure for both the evaporator and for the condenser as well which give it an extra edge over the ORC Systems. The Kalina cycle can be preferred over the ORC where the temperature range is above 200℃. (Milewski and Krasucki)

2.0 Methods to Estimate Heat Potential

There are three things that should be considered before we start to make analysis. The scale of the study should be taken into the consideration and how the data was collected. We should also be aware of the accuracy of the data provided or collected. There are two different approaches that we can consider. One is bottom up approach and the other is Top-down approach. It depends on the analyst which approach to choose.

Study scale can be from a single company, to a town or a region to a whole country. The scale of the study depends on the analyst. It can be one single company or a group of companies performing similar or different tasks. For example, it can be either a cement manufacturing company or glass manufacturing company. If the study scale is large enough then it can be differentiated based on country or countries.

Approaches:

- Bottom-up Estimation.
- Top-down Estimation.
- Data Acquisition
- Bottom Up Survey (Questionnaire)

2.0.1 Bottom-up Estimation:

This is an approach where small piece of information is considered to give result on a bigger scale. In other words, a single case study is carried out to give out the general results. Mostly, the surveys conducted by anybody or organizations are a bottom-up approach as the outcome of the surveys is always a general idea about certain issue. A bottom up approach is piecing together group of information to give out the big picture. When starting a project bottom-up approach can be disadvantageous as total cost of the project will be unknown. It is an advantage in the fact that going piece by piece in a project, cost can be estimated. Bottom up estimation technique has been used by many countries like Germany, UK and USA.

In a city of Germany which is Baden-Wurttemberg, University conducted two studies for estimating the waste heat potential in the region. The results from both the studies showed three different temperature levels. The temperature level under 100℃ was considered low and between 101℃-500℃ was considered medium temperature while anything above 500℃ was considered to be high temperature. (Economics et al.) estimated that the waste heat potential in the four cities of the Baden-Wurttemberg is about 14.9 GWh/y due to a foundry that releases up to 10 GWh/y. Another study was carried out by the same university in the same area, but it was more thorough study. The study revealed that the waste heat potential in the region is about 8 TWh/y. (Blesl, M.; Ohl, M.; Fahl)

Similar Estimation was done for the UK for waste heat potential. The results provided by Mckenna(McKenna) in the study was based on the temperatures that were divided into five different categories. The categories were <100°C, 100°C-500°C, 500°C-1000°C, 1000°C-1500°C and >1500°C. The temperature which are more than 1500°C are found in industries such as cement factory, iron factory or steel factory. The estimation showed that the potential of waste heat is in the industries such has steel, iron and cement which have high temperature which is assumed to be recoverable. After Mckenna, Hammond carried out the similar research and he split the temperature into further shorter ranges. But even after splitting the temperature range the results were somewhat similar. (Hammond and Norman)

2.0.2 Top-down Estimation:

This is an approach where a big piece of information is considered to give result about the specific problem. A top-down approach is breaking the information piece by piece to analyze certain problem or method. Usually Top-down estimating technique is used in industries to estimate the cost of the project used by other companies, which means a cost of a project is estimated based on the cost of the similar project which has been accomplished. Top down approach is an advantage when starting a new project and it can be used if there is not much information is available. It does not complicate things early in the project and cost of the project is known from starting point of the project. The disadvantage of this technique is accuracy. When excluding so many minute details at the start of the project, the estimated cost of the project can rise.

In 2010, Germany carried out the study for the waste heat potential in Germany using the top-down estimation method. The results from the study showed that the Germany have waste heat potential of about 88 TWh/y above the 140°C. However, the potential for a low-mid range temperature was found to be around 44 TWh/y. the highest waste heat potential was found to be in the iron steel mills. (Arens)

Another top down estimation was carried out by the Germany. The amount of waste heat that can be recovered was estimated to be around 40% of the industrial processes. Using this factor to the country makes the recoverable heat about 280 TWh/y. (W.D. Glatzel, O. Langniß)

2.0.3 Data Acquisition

Data Acquisition can be done using two methods. Either the data is collected using the survey or it can be collected using the questionnaire. Surveyed data can be measure data or from the official reports or online databases. Estimated data is usually more accurate but in order to gather the data using the estimated approach, it can be time consuming. In Germany, different techniques for the data acquisition were compared between estimating the heat demand for a single company by using the energy factors based on the company type and efficiency. It should be mentioned that the data coming from the high temperature facilities might not be accurate as they can be easily disturbed by radiation or any other factor. (Economics et al.)

2.0.3 Bottom Up Survey (Questionnaire)

In this type of study, A data is collected from the companies and then the result is calculated based on that company for other companies. This is a bottom approach since one company data is collected and then it is spread over to the other companies. One such study was carried out by the Norway. Data from about 72 companies were taken into consideration which involved companies for Food, wood, chemical and cement. The data also included the data from the incineration plants. A total of 4 incineration plants were considered and then the estimation was done about how much is the waste potential can be generated from the Norway companies. It was estimated that 19.4 TWh/y can be generated though waste heat potential and the data was true for temperatures above 24℃ . (Brueckner et al.)

2.0.4 Potential assessment using ORC cycle:

Waste heat potential can be estimated using ORC and following points.

- Selection of Industry (Cement, Glass, Rolling mills, clinker)
- Capacity of the industry is calculated through hourly or daily data available (PCP)

- The value of PCP to be detected for every industry like Cement, Glass, Rolling mills, Clinker
- From the data available, Specific power, ratio of ORC power over value of its PCP to be calculated.
- r_P to be calculated through a formula mentioned below

$$r_P = \frac{1}{n_A} \sum_A r_a$$

- For the *i*-th plant, the installable ORC power $(P_{ORC})_i$ to be calculated multiplying the corresponding value of PCP for the value of r_P related to the considered process:

$$(P_{ORC})_i = (PCP)_i \,.\, r_P$$

- The operating hours (h_o) of the industrial process to be estimated: a minimum value of 5000 and a maximum of 8000 operating hours per year were considered.
- Energy recovered for the i-th plant to be calculated as:

$$(E_{rec})_i = (P_{ORC})_i \,.\, h_o$$

2.1 Energy Conversion Technologies.

Energy conversion technologies are of many types. They are usually used when there is a need to convert the energy from one form to another form. Energy can be described in many ways and it can be converted in many ways also. Usually, we convert the energy form for getting some type of mechanical work. The waste heat that can be recovered and use to move turbine which is then used to produce electricity. Some of the energy conversion technologies for the waste heat are listed below.

2.1.1 Regenerative and recuperative burners.

This is a technology that employs the heat exchanger and it enhances the efficiency. This technology is used to capture the waste heat from the hot flue gasses which are released during the combustion process. Two burners with a separate control valves are employed which is further connected to the furnace. This technology is commercially used in Cement manufacturing. The gasses are guided from the exhaust to the case which contains material which is aluminum oxide. The exhaust gas heats up the aluminum oxide and heat energy from the exhaust is recovered and stored. When the system reaches the required temperature then the direction of the exhaust is reversed forcing the stored heat back into the heating chamber. (Jouhara et al.)

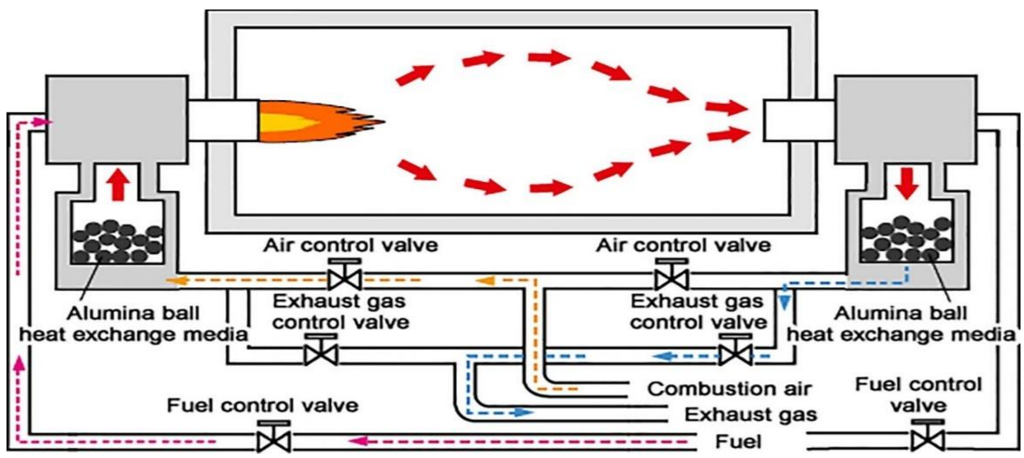


Figure 1 Mechanism of burner

2.1.2 Economizers

Economizers or finned tube heat exchangers that recover low to medium temperature waste heat are mainly used for heating of liquids. The tubes of the Economizer system is covered by the fins which are made up of metallic material which helps in maximizing the surface area of heat absorption and heat transfer rate. These are made up for strong materials such as carbon, Teflon, and stainless steel.

Condensing Economizers is a technology that is used to recover both the latent heat and the sensible heat from the flue gasses. This technology is able to increase the boiler efficiency up to 90%. This condensing economizer can help to reduce the temperature of the flue gas by up to 10%. The working temperature range for the HPCE is 70℃-500℃ which is good for industries which uses mid-temperature

to high-temperatures. (Vandariff)

The theoretical heat from the Condensing economizer can be calculated using following equation

$$Q = V \rho \Delta h$$

Where

V is the air volume [m^3/s]

ρ is the density of air [1.202 kg/m^3]

Δh is the enthalpy difference [kJ/kg]

2.7 Waste Heat Boilers

In this type of technology, the waste heat boilers are aligned parallel to the direction where the waste heat is leaving the system. The Waste heat boilers are used to recover medium to high temperature exhaust gasses. The exhaust gasses which is recovered through the boilers are further used to generate steam as an output. The recovered steam can be used to generate power, or it is directed back into the system for reuse. For example, as mentioned by Berkeley, the heat generated in the coal power plant has temperature of about 1000℃. The use of the waste heat in boiler in this case allows the recovery and utilization of heat of flue gas to vaporize the fluid which will generate the steam. The steam can be used for energy generation through turbines and generators. (Berkeley et al.)

2.1.3 Air preheaters

Air preheaters are technology that is used to recover the waste heat from low to medium temperature range. It is different from other methods mentioned earlier as it deals with the system in which contamination must be prevented and avoided. Air preheaters can have two different designs, the plate design and the heat pipe type. As we can imagine from the name, Plate type design has several plates that are placed perpendicularly towards the incoming cold air inlet. Hot air is derived into the channels between the plates which eventually transfer the heat to the plates. These plates once heated then cold air is passed through them which releases the hot purified air. The heat is captured and then the cycle is repeated. (Modi et al.)

2.1.4 Plate heat exchanger

Another method to recover the waste heat is Plate heat exchanger. This method is also used when the contamination in the system is needed to be avoided. The method uses thin plates which are having different patterns. The air is passed through the inlet and captured by the thin plates that are aligned. The plates which are used in the system have differently pressed patterns and it has gaskets which can be used to avoid or stop other fluid from getting into the system. In this way both hot and cold fluids pass each-other and in the section of heat exchanger. The fluids exchange the heat but does not get contaminated. It is reported that there are only 3 types of the heat exchanger available which are either single pass or multi pass. The efficiency of the multi pass arrangement is better. (Srihari and Das)

2.1.5 Stream Rankine Cycle

it is a vapor power cycle that utilizes heat to generate work. It utilizes the heat energy contained in coal, oil or natural gas. It then converts it into mechanical energy or electrical energy which can be used in our homes. One of the best definitions of the system is it closely describes the process of stream turbine systems which are derived from the carnot cycle. The power is dependent on the temperature difference between heat source and cold source. The working fluid in the stream Rankine Cycle is water. The stream Rankine cycle uses the exhausted steam coming out through the pipes and feed it into the boiler. The stream turbines are in use for over 100 years now. These are mature technology. The capacity of the Stream Rankine Cycle can range between 50 kW to several hundred megawatts in Waste heat production applications.

2.1.6 Organic Rankine Cycle

It is similar to the earlier mentioned SRC systems. The difference between SRC and ORC is that instead of water as a working fluid, in ORC the working fluid is hydrocarbons, hydrofluoro or ammonia. There are parts of the ORC include a boiler, turbine, preheater, condenser and regenerator. The working fluid has a low boiling point than water which allows ORC to work at a lower temperature as compared to the SRC. Working fluid used is often chosen on the basis of the heat source. ORC system was employed in Belgium Electric Arc furnace to capture the low temperature heat from the furnace and to use it for other purposes. The Electric arc furnace had two parts which had issues. First, the flue gas was available before the dryer cooler and the temperature range for the flue gas was between 80℃ to 140℃. Only flue gas was considered in this study because of the low temperature. The study concluded that the average heat transfer rate was about 8.8 MW. This result was based on cooling flue gas to 90℃. (Steven et al.)

2.1.7 Kalina Cycle

In this type of cycle, the working fluid is both water and ammonia. It is regarded as an upgrade to the Rankine Cycles. These systems have good energy efficiency compared to the SRC/ORC. In SRC/ORC the temperature of the system remains constant as only water or other fluid is used in the system which has same BP but, in this case, the working fluid is water and ammonia, and both have different boiling points. Hence the temperature cannot remain constant. The temperature is higher during evaporation process which is better for thermal matching with the waste heat source. The first Kalina plant was installed in the state of California, USA in 1992. Since then, several of such plants are in operation in USA and different parts of the World. Countries like Japan, Iceland, Germany, China, Taiwan and USA has employed Kalina Cycle for different purposes. Japan has 3 Kalina cycle plants and total output MW is about 11.4 MW. (Ogriseck) Germany has two of such plants and output is 4.1 MW. Japan's Sumitomo metals is using the Kalina cycle for Waste heat recovery and also the Fuji oil which was installed in Japan in the year of 2005 is helping Japan recover the waste heat. The total output of Fuji oil is about 3.9 MW. One of the Kalina plants is installed in Pakistan in cement factory named" D.G Khan Cement". it started the operations in 2013. In a study conducted by Milewski and Krasucki, they concluded that the Kalina cycle should be preferred over the ORC systems when the temperature range is above 200℃ (Milewski and Krasucki)

2.1.8 Super critical CO_2

In this type of Rankine cycle, the working fluid is not water or ammonia or both combined. In this variator of the system, it uses the carbon dioxide in place of water or ammonia. It is simple and most advanced form of the Rankine Cycle. The main parts of such a system include heat exchanges, condenser, system pump and turbine. This system has many advantages over the previous systems. It is much more compact then other systems and has better sustainability. This system provides superior economy and is also very compact compared to other systems. This system can work with high temperature heat sources such as Nuclear power, combustion chambers and Solar plants. In 2002, Duarte and Alarco carried out a study to use Super critical fluid in the Food processing industries. The Co2 was employed as a working fluid as it is non-toxic and non-flammable gas. The results were encouraging but no further study or research was followed up with it. (Duarte and Alarco)

3.1 Energy Policy and legislation in Estonia.

EU energy and strategy union has set out goals for short term and long term for the EU energy. The focus of the strategy is to reduce the dependence on the Fossil fuels and decarbonization of the homes. More than half of the total energy in EU is used for heating or cooling. Secure, affordable and sustainable energy for every citizen of EU is the main goal for the EU Energy policy. A number of different steps and strategies are developing to fulfil the aim. EU energy commission wants to become leader for the clean energy transition. The aim for the EU is to cut down on the carbon dioxide by at least 40% till 2030. This will be huge step towards the sustainable environment and to bring down the carbon levels to minimum by 2050. There are three main goals that EU has set for itself. Energy efficiency cannot be ignored and should be at the forefront, becoming the leader in world for renewables and providing fair and equal amount of energy to the masses. Some short-term goals and some long-term goals which are up to 2050. Since the development of the Energy policy, EU has made several packages and committees which regularly keep the progress of the roadmap. The implementation of the plan is keenly monitored at every stage. As a part of the policy, the main points which were the highlights were Efficiency of the buildings needed to be improved. The buildings should adopt different tools and techniques or mechanism to support the sustainable and efficient heating and cooling. Supporting energy efficiency in industry. The commission was in view that all building sectors which include residential houses, industries and services have significant role to play in order to reduce the energy demand. Increasing the energy efficiency and shifting to renewable energy sources is the only way forward. Policy can be implemented only when the citizens take the ownership of the program so in this case the consumers should be at the core part of the policy. They should be informed and given guidance on why they are shifting to renewables and what are solutions that they can adopt. (Kuldna et al.) District heating and cooling in EU is still dependent on the fossil fuels. Around 75% of the heating and cooling demands are fulfilled using the fossil fuels. Use of the renewables is growing rapidly but at the current its only 18% of the total share of energy needs. Policy was in view that local governments should be given support and incentives to shift to the renewables.

In October 2014, EU agreed on the target set by the policy makers to cut down on the greenhouse gas emissions by 2030. The Paris agreement vindicated the Policy as it is part of the EU. To make sure both the consumers and the shareholders are on the

Policy there are certain directives that were ordered which were to be followed by both consumers and shareholders.

- Setting the framework for improving energy efficiency
- Improving energy efficiency in buildings.
- Improving the energy performance of products and giving knowledge to consumers.
- Financing the energy efficiency with smart finance for smart building proposals.

3.1.1 Action Plan for Baltic countries 2050:

The Baltic countries in the EU are Estonia, Latvia, Lithuania. EU has set an ambitious target for the 2050. The plan and target is to cut the CO_2 emissions level by 80% to 95% in the year 2050. In order to achieve this goal, all members of the European commissions must act as a well-functioning body to achieve this target. These are the countries which have Baltic sea in their territory. Usually Baltic countries name refers to Estonia, Latvia and Lithuania. Some of the directives for the Baltic countries are listed below.(Blumberga et al.) While reducing the GHG emissions special consideration should be taken into place for maintaining a sustainable and reliable electricity supply along with energy security and economic growth in the EU. The ambitious program cannot be achieved without the input from all the stake holders. There is evident increase in the literature that is focused on the potential impact of different scenarios in the roadmap. Most of the studies focus on the reduction of the emissions and only handful of them are focusing on the market impact of such measures. The goal of 2050 cannot be achieved without the complete decarbonization of the industry sectors. The decarbonization of the industry sector needs a lot of technology measures as well as financial backing. Some of the key points of the goal to 2050 are mentioned below.

- Enhanced market integration of RES and best practice sharing. Lead: Latvia.

- Promote measures to develop the usage of sustainable biofuels. Lead: Latvia.
- Promoting energy efficiency measures. Lead: Latvia. Deadline: 2015.

3.1.2 Action: Towards a well-functioning energy market:

- Monitor the implementation of the Baltic Energy Market Interconnection Plan (BEMIP). Lead: Lithuania. Deadline: Progress report July 2013.
- Sharing best practices of regional cooperation of BEMIP with EU Eastern Partnership countries. Lead: Lithuania. Deadline: Progress review November 2013.
- Extend the Nordic electricity market model to the three Baltic States. Lead: Latvia. Deadline: 2013.
- Potentially: Investment in infrastructure in the Baltic Sea Region. Lead: Denmark.

The roadmap for the 2050 is to reduce the emissions by 80% to 95% as compared to the levels in the 1990. The main objective is to provide a well-functioning society which is beneficial for human life as well as for the environment. The main challenges following the target is mainly arising due to staying competitive and able to provide the employment to the youth along with security of energy supplies. The decarbonization will be playing a major factor in saving the environment and moving towards a better future. A future which is not only technologically advanced, but it should be good for the environment. The practical side of the coin shows us that the goal set by the EU for 2020 will not be achieved as there is very slow progress in this regard. The 2050 goal will not be met and according to the estimation, EU will be able to reduce the emissions by 40% to 50% in the year 2050. This not only shows the difficulty of the task but also shows that we still must go a long way before we can make significant change in our society. This cannot be done by curbing down on the industries and factories, this target needs unanimous effort from all the segments of the society which includes people, industries, factories, transport and other factors. EU is also aware of the fact that investment in the EU is key for progress. EU just cannot impose certain strategy, and this will cause uncertainty and uncertainty will stop the investments. If the investment is delayed the costs of the business will rise and eventually wipe off the investment.

3.1.3 Estonia Energy Policy.

Estonia is a country which has huge oil shale reserves. About 2 decades ago, Oil shale was the source of energy for Estonians, even today the oil shale is one of the important players in Estonia energy sector. Apart from the Oil Shale, Estonia also posses' natural reserves such as coal and gas. Oil shale is big factor for emissions in Estonia. 90% of the power supply in the Estonia was delivered by the oil shale industry. This Oil shale has highest rate of emissions and Estonia was using it most. Estonians have formulated a policy to cut down the usage and dependence on the oil shale and seek other sources as producing the energy. This policy will ensure that fossil fuels are less utilized and the dependence on the fossil fuels will be reduced. Oil shale is also expensive as compared to other fuels, so it will be good for Estonians to reduce some costs.

The focus of the Estonian government is to provide energy to the country at the lower possible price and they are making efforts to increase the efficiency of the systems in order to save more energy which can be used and bringing the cost down. Decentralization is also a big factor in this policy as giving more authorities and power to the local government will benefit the investment and boost the confidence of the investor too.

The energy policy was designed and implemented to cut down the usage of oil shale and as well as dependence on the oil shale. The Policy incentives were accepted by the industries and the investors which resulted in the increase of renewable energy. 12.7% increase in electricity generated from the renewable is a good indicator for a successful policy. The same electricity generated in 2007 was only 1.5% from the renewables. (Kuldna et al.)

With the successful implementation of the policy, Estonia is well on track to become the first Eu nation to achieve the target of producing and generating 20% of the energy from renewables.

GHG gas emissions in Estonia is 88.74% (2017) and the biggest contributor to this percentage is production of Energy. Since 1990, Estonia have made a remarkable reduction in the GHG. The percentage of the reduction since 1990 is about 48.52%. Estonia tactfully transformed from the planned economy to the market economy and it was fruitful for Estonia. Agriculture is another significant contributor to the GHG and in Estonia it accounted for 6.6% of the total GHG emissions. Estonia have reduced the agricultural GHG emissions by 49.16%. The third major contributor to the GHG emissions was industrial processes which was contributing to about 3.08% of the total GHG emissions in 2017. Since the base year of 1990, this value has been reduced by 33.5%. Mainly, the reduction of these GHG emissions was due to planned and carefully implemented policy. The results are speaking for themselves. The Estonia plan to reduce it furthermore for a friendlier environment.

3.1.4 Estonia District Heating Bill:

In 2016, Estonian government passed the bill for the development plan which was aimed at using more safe, cheap and user-friendly method of producing district heating. The main aim of the bill was to provide the consumers with Lowest and most stable price of heat energy. The Bill is proposed to have plan up to 2030 but it will really setup the country for 2050 target achievement. Estonia is planning to reduce the greenhouse gas emissions up to 80% as compared to the levels in 1990. This will be a huge achievement, if Estonia manages to meet the target of 2050. Estonia is already working on the proposal put forward by EU. They have achieved some success over the last decade.

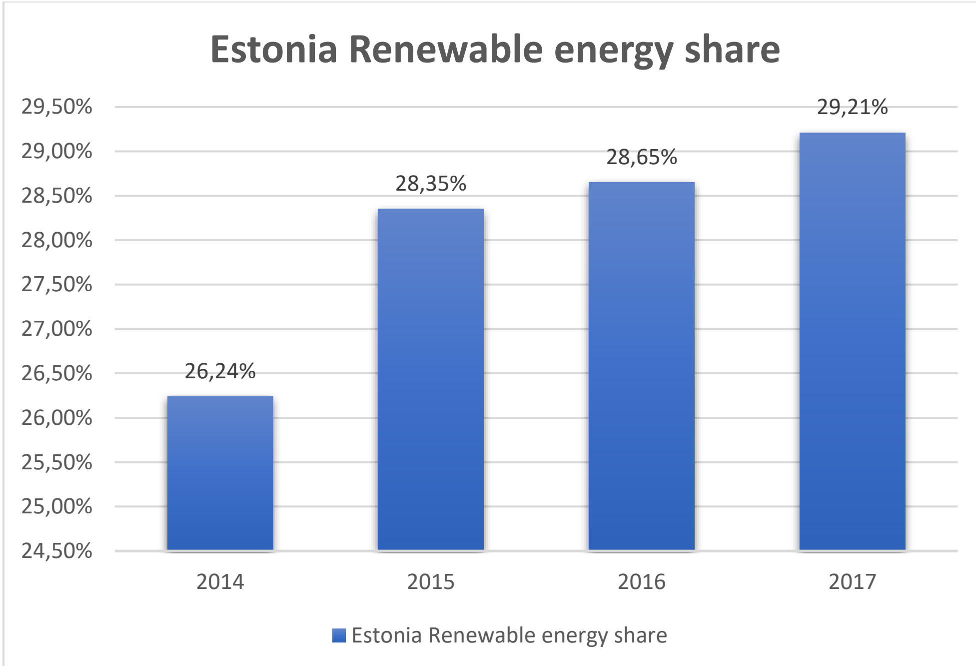


Figure 2 Estonia Renewable energy share. Source: https://www.stat.ee/57169

3.1.5 Estonian Energy regulatory bodies:

Estonia energy is regulated by following bodies:

- Sustainable Development Act.
- Electricity Market act.
- Natural Gas act.
- District Heating Act.

3.1.6 Cost of Heat Generation:

There are number of factors involved in determining the cost of the heat generation in a building. Some of them are listed below.

- The Distance of the boiler facility to the building the heat is supplied to.

- The energy efficiency of the building. If the building efficiency is lower the demand of the heat will be high and hence increasing the cost and if the efficiency of the building is high, then less heat is required, and cost is decreased.
- The cost of delivering heat also depends on the grid losses.
- Availability and access of Bio mass.

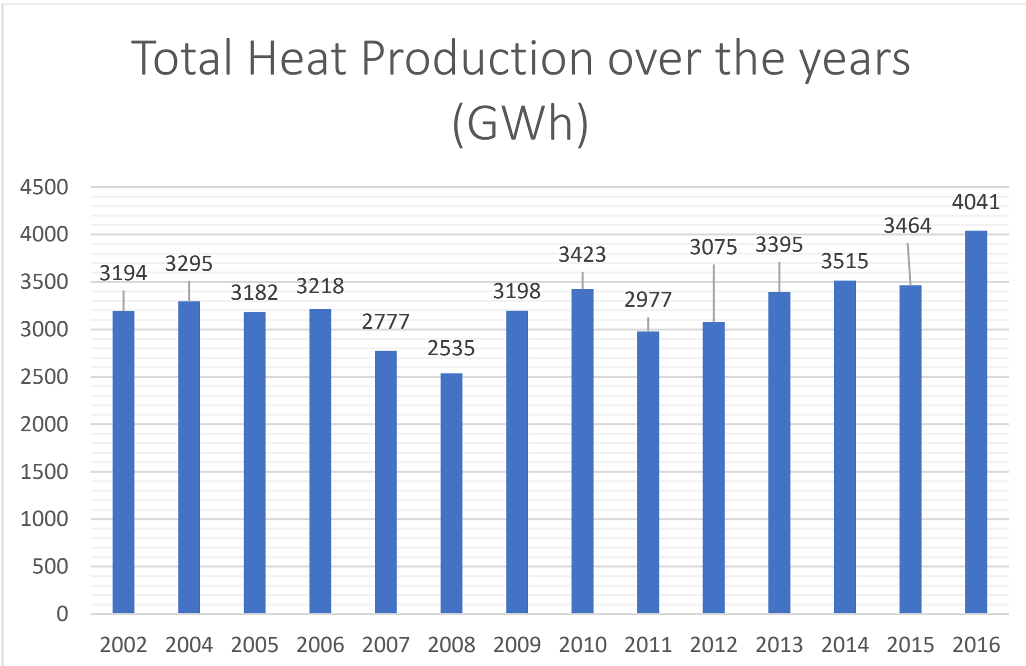


Figure 31 Total heat production over the years in GWh. Source: http://pub.stat.ee

3.2 District heating in Estonia.

Heat in District heating can be generated using various methods. District heating is a mature technology which is around for over centuries. The biggest advantage of DH network is that it can provide safe and reliable heat to households and buildings spread across the area or city. The specialty of a DH system lies in its versatility. The DH network can be run using different fuels and different techniques. Heat generation is required in houses for domestic purposes and for heating of houses during the winter season. Winters in Estonia are particularly harsh where temperatures can slump to minus 25℃. In order to tackle such low temperatures, DH network is one of the most formidable force because of its ability to work under different circumstances and it can use various fuels. DH network is reliable technology throughout the world. In EU, it is of importance because of its environment friendly nature and good ability to provide the heat. There are 200 or more areas in Estonia with district heating network. The winters in Estonia are usually very cold and temperatures can plunge to -25°C in winters. The Estonian household need heating system and District heating is one effective and efficient method to fulfil the need of Estonians. The District heating system is successful in the areas which are densely populated because it is easier to lay the pipes required for the supply of heat. It is friendly solution for domestic needs and it is very reliable as well. It is eco-friendly solution and does not contain any flue gasses. The main medium of the district heating is water which is heated using the boiler and then pumped out through pipes to the consumer. District heating is also beneficial as it provides energy security and we can use different fuels for generating heat. Cogeneration plants are available that can provide us with heat and electricity at the same time. Most of the natural gas coming to Estonia is provided by the Russians. Estonians are deliberating on the fact that the taxation should be based on the calorific value of the fuel used. The prices for the renewable fuels are stable for few years now and there is not much fluctuation in the prices. One of the main directives of the EU to Estonia is to have near-zero energy buildings by 2050. The changes are already taking place in government and state-owned buildings. A research was done by the Taltech University in 2016 said that buildings that are based on renewable energy and cogeneration can meet the goals set by the EU for near-zero energy buildings. District heating is flexible approach in terms of the fuel that can be used in it. District heating is using a central heating plant which have boilers. The boilers can burn different type of fuels and the usage of fuel is optional and the plant management can use which fuel is most economical at any given time. The usage of the biomass fuels such as woodchips and other low-grade wood for the generation of the heat has benefitted the district heating a lot. In this way , the usage of the primary energy is reduced and the dependence on the primary energy is also reduced. The usage of the renewables is good for the long-term sustainability and also it is helping to bring the cost down.

District heating continue to grow in Estonia and in 2016, more than 40 energy projects were funded, and main Course of action was to switch from the fossil fuels to the renewable fuel sources.

Figure 4 Estonian thermal power plants and CHP plants. Colors-separated power: Green - 0… 1.9 MW; yellow - 1.9 to 20 MW; red - 20… 195 MW source: energiatalgud.ee

District heating is widely available to use in Estonia. There are around 226 municipalities in Estonia and out of 226 municipalities 149 are using District heating. The rest of the municipalities are using local heaters to produce heat. There is network of around 1430 KM of heat pipelines in Estonia.

Heat can be generated in DH using following methods:

- Boiler houses
- CHP Plants
- Heat Pumps
- Geothermal pumps

3.2.3 Boiler Houses

Tallinn has over 500 boiler houses. Majority of the boiler houses belong to the AS Tallina Kute, AS Erakute and Fortrum Termest AS. These producers supply Tallinn with 70% of the heat. The capacity of the boiler houses has already exceeded 100 MW. The number of boilers have different production range. Some of them working at a capacity of over 10 MW which includes Taltech university boiler house and BLRT group AS. More than 100 of them operate at a capacity of over 1MW. The boiler house located in Mustamae and Kadaka areas supply heat to the western part of the Tallinn which includes districts like Mustamae, Haabersti, Kristiine,. Kadaka boiler house is modern day boiler which is meeting the requirements for the EU for the environmental issues and flue gas emissions. The main fuel of the boiler house is gas. Mustamae boiler house can use oil fuel as stand by. AS Utilias is another company which is operating in the capital city of Tallinn. The company is providing 4076 buildings with heat and has 454 km of managed thermal energy. The company is operating about 17 boiler houses in the capital city alone. The AS Utilitas Eesti is not only operating in Tallinn but other cities like Haapsalu, Jogeva, Keila, Kardla, Rapla, and Valga. The company is using about 76 KM of district heating network which includes insulated pipes. 11 boiler houses, and out of which 8 are generating heat for district heating and 3 are local boiler houses.

3.2.1 CHP Plants

Currently, there are 17 CHPs are working in Estonia in different parts of the country. CHP generate electricity which is about 1000 GWh/y and it accounts for the 11% of the total generation in Estonia. Majority of the CHP employed in Estonia are steam cycle CHPs which have low power to heat ratio. As mentioned earlier, CHP produce about 11% of the electricity in the country along with 30% of the heat is produced by using these CHPs plants. The efficiency of the CHP is low and hence the heat to power Ratio is about 1:3.

About 56% of the heat is produced from the local fuels. Overall efficiency for the heat production is 82% which is good enough. The DH system has some of the network losses which account for 15%. Share of the Natural gas is 41% but the issue is that is 100% imported from the Russian Federation. In 2016, Production of the electricity was dominated by the oil shale power plants. Network losses in the production and supply of the electricity is 17% which might be due to the export concentrated production and old network equipment. Efficiency of the Power production was 34% in 2016 which have major potential for improvement with implementation of more CHP plants.

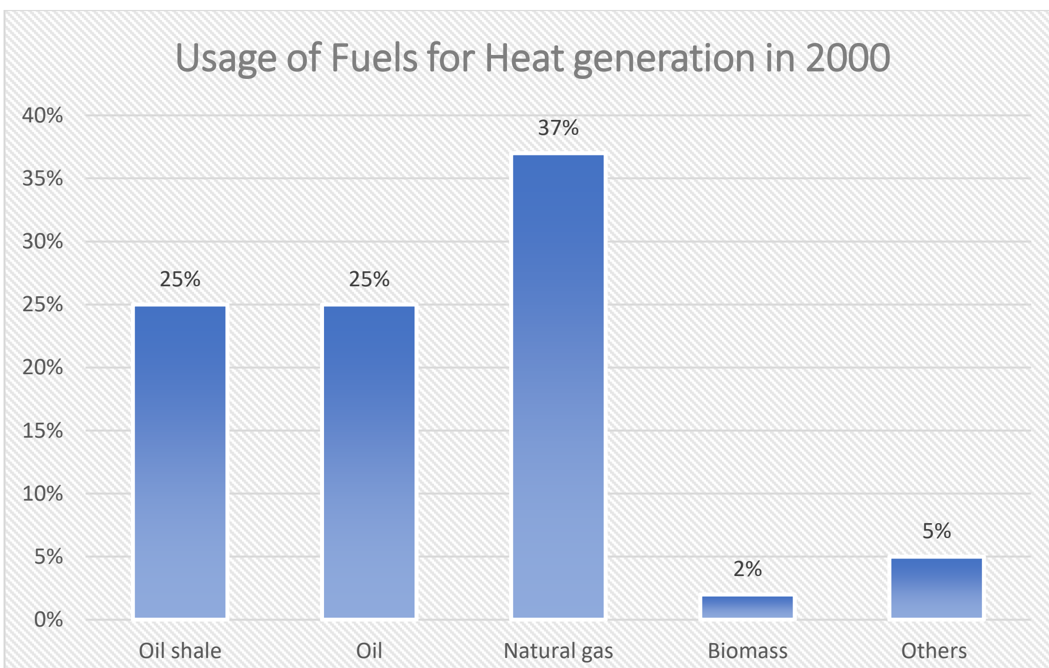
3.2.2 Network Losses

Network losses in the DH system plays an important role in determining the overall efficiency of the system. In 2001, the average losses in the 14 biggest Estonian networks was around 21%. 21% of the energy in the system that should have been provided to the consumer was getting lost in the system. In order to prevent the network losses in the system, new measures were taken, and results were fruitful as the losses began to decrease. The losses from the year 2001 to the year 2005 was reduced by almost 4% which is marked improvement but this 4% of the losses was still is a huge energy leak. From the year 2001 to 2014, the losses in the system was brought down from 21% to 17% in 2014. In 2001, the estimated amount of network loss was about 958 GWh and in the year 2014, the losses were 678 GWh. Which means a reduction of about 280 GWh.

One of the reasons behind the price drop in DH systems are the investments that are pouring in recent times. The investments are made to reduce the network losses, increase the efficiency of the system which in turn decrease the prices that consumer will have to pay and it will create more competitiveness among the players. Investments are coming in to refrain from using the primary fuels and use more environment friendly and more renewable fuel for the generation of heat. As the focus in the DH system has switched towards the usage of the Biomass fuel which is much cheaper than the Natural gas or oil shale and have better efficiency also.

Estonia was heavily dependent on the use of oil change, oil and natural gas in the early 2000s. this dependence was supposed to be reduced as EU had announced a policy to switch to renewable energy which should be clean and environment friendly. As Estonia is part of the EU, they had to also look for other options to create the sustainable development. Estonia was producing about 25% of the heat using the oil change and 25% using the oil. A big part of the heat generation in the year 2000 came from the natural gas which was imported from Russian federation. Natural gas was a dominant player in producing heat and it accounted for 43% of the total heat generation in 2000.

As the requirement for the Heating increased and oil shale had low efficiency and oil and natural gas were primary sources of the energy, Estonia had to look for alternative way of producing heat which is clean and environment friendly. Estonia started using Biomass and reduced the usage of oil shale, oil, and Natural gas. Natural gas is still a big contributor for production of heat, but its usage has been reduced considerably. In 2014, Biomass was the biggest contributor towards the production of heat with 37% of the share as compared to only 2% in 2000. The usage of the natural gas has been reduced by almost 10% over the period of fourteen years and now the share of natural gas for the production of the heat is 33%. The usage of the less environment friendly and lower efficiency fuel oil shale has been reduced to only 10% . It was one of the key drivers for the heat generation in the year 2000 with 25% but it has been reduced to 10% only, a reduction of 15% over the period of 14 years. The usage for oil has seen a significant and welcome slump from 25% to 6% in 2014.



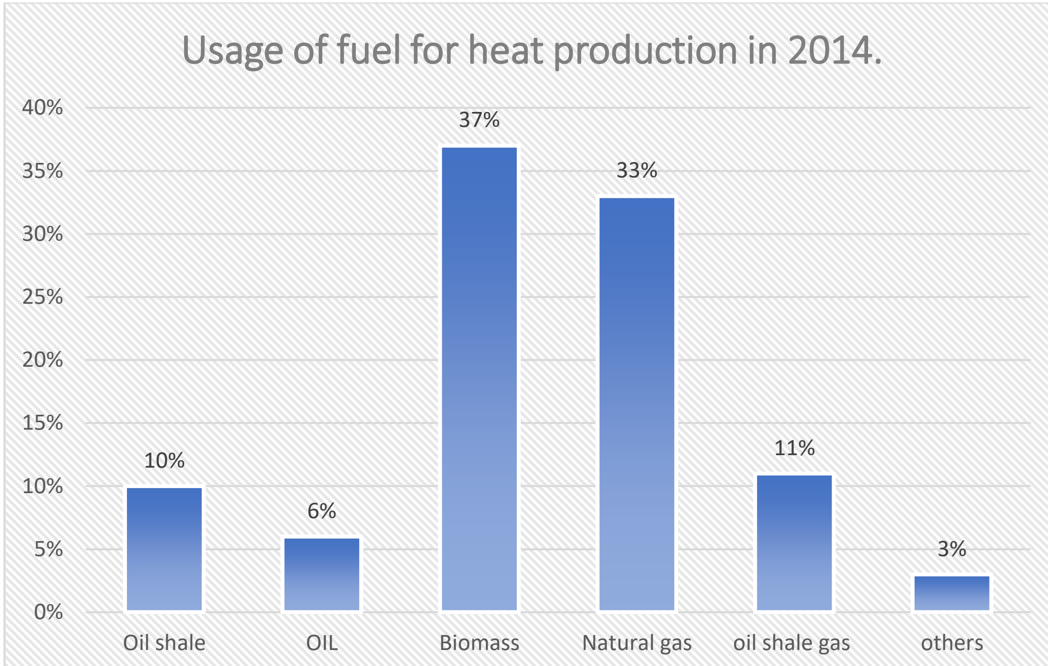


Figure 5 Usage of fuels for heat in 2000. Source: https://www.konkurentsiamet.ee/

3.3 Industries in Estonia.

There are many industry sectors that are working in Estonia. Estonia is a small country but have many industry sectors working and working successfully. Energy consumption in those industry sectors are based on the type of the industry. For example, the three most energy consuming industry sectors are Paper and pulp, Wood and wood products and Food and beverage industries. These consume most energy from the Estonian national grid. While wood products are highly exportable item for Estonia and it is very important factor in the for growth of the country as exports depends on it. Food and beverage are the commodities that cannot be ignored, and Estonians are self sufficient in production of food. No country can flourish without industry sector doing well and same is the case with Estonia. The GDP (Gross domestic product) of the Estonia was 3.4% in the year 2016 but the growth of the GDP increased by 1.2% and in 2017 the GDP growth was 4.6% which is a indicator that the country is growing. Some of the industry sector which consume most energy are briefly mentioned below.

3.3.1 Paper and Pulp Industries in Estonia

There are some paper and pulp industry working in Estonia namely Horizon Pulp and Paper Ltd, Rapina Paper Ltd. AS Estonian cell, Ralex industry. Estonian Cell is working in many different European companies and it is part of the Heinzal group which have many different industry sectors including the pulp and paper industry. The mill is located about 110 KM away from Tallinn in a location named Kunda. In a press release by Estonian cell in the year 2006 they claimed that to have produced 7.7mn m^3 of biogas in 2016, compared to 5mn m^3 in 2015. This was termed as remarkable achievement by the company. The achievement proved to be significant one as it replaced nearly 50 GWh of natural gas by bio gas. The growth of the industry is expected to increase further in coming years. The expansion of the company is already planned and underway. The company invested about 17 M-Eur to the expansion of the factory in 2013 and it is expected to grow further. The company is a modern pulp producing industry and have set high standards for the environment friendly processes. The company is using state-of-the-art methods in the manufacturing processes and making sure to keep the environmental affects to minimum. Horizon pulp and paper industry in Estonia is another pulp and paper producing company which started the company about 75 years ago. The Company is producing high quality grade paper using modern day technologies and producing wide range of 100% virgin unbleached sack kraft papers. The company renews its environmental policy every year to ensure the EU laws and regulation are being followed and in order to improve the technologies and improvement of the products. The company is expected to grow further with high demand of pulp and paper in Estonia and in Europe. Rapina paper and pulp industry came into being in 1728 when Peter Gustav started the operations. The Mill is still standing and using the modern-day technology which results in high-quality production. Rapina pulp and paper industry is the largest manufacturer of packing corners in the Scandinavian countries. The company only uses waste paper collected from Estonia as a raw material. The raw material is collected through the packaging and printing industries. The year

2005 proved to be game changes in the manufacturing of paper and paper products as the investment poured into the sector. After 2005, the growth stalled due to economy compression. 2010 saw increase in the growth again. A decrease in emissions was observed in the 2013 which was about 12% decrease compared to the previous years. However, in 2015 a big increase in emissions occurred. The emissions increased 279.1% compared to the previous year. The relative growth was quite large; however the absolute growth is quite insignificant compared to the overall emissions of Estonia. The increase took place mostly due to the increased usage of natural gas. In 2016 GHG emissions increased yet again, 81.6% compared to 2015. The increase was caused by increased consumption of natural gas.

Emissions in Paper and Pulp industry sector is an interesting read. The emissions kept fluctuating between high and lows. The emissions in the 1990 for paper and pulp industry sector was very minimal and since the year 2006, it is on constantly between the 7 kt CO_s to 15 kt CO_s. The year of 2015 and 2016 were interesting as the emissions of GHG rose incredibly and it crossed the record for all previous years. The GHG emissions recorded in 2015 were 14 kt CO_s which was twice as much as the previous year. The constant check on the GHG emissions were hoping to reduce the negative trend of increase but in the year 2016 the GHG emissions rose further and it was recorded to be 26 kt CO_s. This was more than twice of the previous year. The reason for such a sharp growth was usage of the natural gas. A graphical representation of the years in mentioned below.

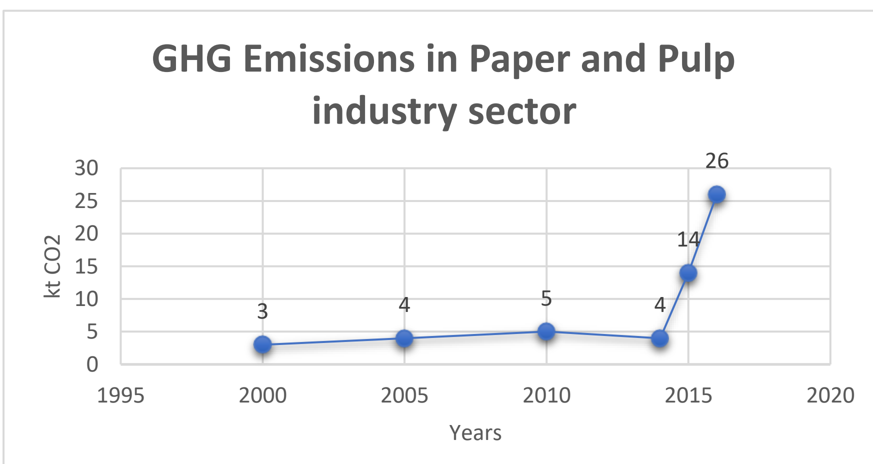


Figure 7 GHG emissions in paper and pulp industry sector

3.3.2 Food, Beverages and Tobacco industries in Estonia

Estonia is a small country, but it has enough resources to be self-sufficient for the production of food. Population density of Estonia is about 30 residents per km^2 but this data is generally taken from the main land area. Estonia have last agricultural area which is about 1003,505 ha. Estonian climate and natural environment are perfect for animals' husbandry and also for the growing grains. The dairy sectors are one of the most revenue generating industry in Estonia. The dairy milk is exported to many different European countries. The milk is considered to be Estonia's "White Gold" as it brings revenue for the country and is primary export item. About 17% of the total exports done by Estonia is milk.

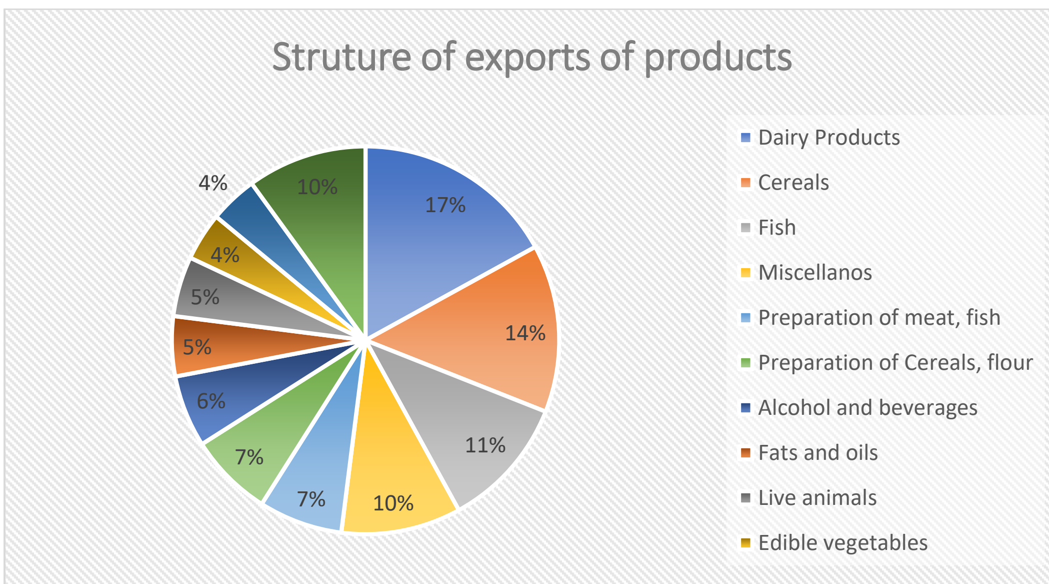


Figure 8 Export products of Estonia. Source: Statistics Estonia

The biggest buyers of the Estonian food products are Finland, Latvia and Lithuania. Most of the Estonian food and agricultural export items are imported by these three countries which are also neighboring countries of Estonia. According to Estonian Statistics website, these three countries import about 51% of the total exports of Estonia. In 2010, the total cost of production of food and beverage industry was around €1115 million and the amount according to Statistics Estonia has increased to

€1408 million. An increase of about €300 million is a huge indicator that the food and beverage industry is thriving, and it is expected to grow further as well. Comparing the other industries with the food industry reveals that the food industry is one of the stable ones. Even in the tough economic conditions the supply and demand for the food and beverages showed a stable growth. This is due to the fact that the population is growing the food products as the basic commodities.

GHG emissions in the food and beverage industry is one of the more stable ones as compared to other industry sectors. The Food and beverage industry GHG emissions is constantly reducing since the base year 1990. The decrease is due to more efficient systems being in place. The GHG emissions from this industry sector can further be reduced using the waste heat recovery systems. A graphical representation of the GHG emissions over the years is shown below.

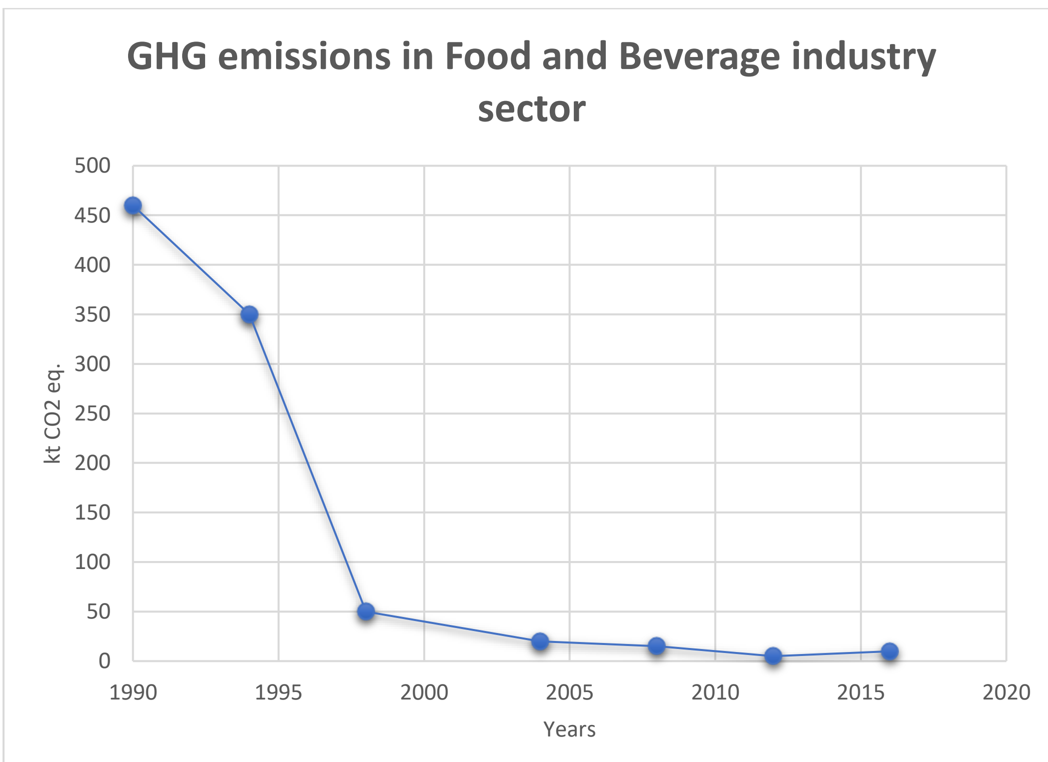


Figure 9 GHG emissions in Food and beverage industry sector

3.3.3 Wood and Wood Products.

Forests is one of the most important things in the culture of Estonia. More than half of the Estonia is covered with the Forests. Forest coverage is about 51% if Estonia's total land which is about 6th in the EU. Only countries who have more Forests in the country are Finland, Sweden, Slovenia, Montenegro and Latvia. Most common trees in the Estonia's Forests are pine 42,0%, birch 30,7%, spruce 20,2%, aspen 3,6% and grey and black alder 3,2% and others. Estonia is one of the biggest exporters of the wooden houses in EU. The target market of Estonia is usually Germany, South Korea, Japan. The Estonian timber industry is thriving and stands at highest level of all times in terms of production and sales. Estonia has huge number of wood companies operating in it who are processing and manufacturing the wood and wood products. Nearly one thousand companies operate in wood processing and manufacture of wood products in Estonia. And the furniture industry in Estonia is a sector with long traditions. More than 500 companies operate in the furniture industry in Estonia.

3.4 Waste heat usage in Estonia

As mentioned above that the waste heat recovery systems have been in use in different countries and different industries across the world. Estonia is no different and there are some of the waste heat recovery systems available in the Estonia which are recovering heat and then delivering it for the use for other purposes. These purposes may include recycling of the waste heat, pre-heating of the water, or providing the district heating to the local or national grid. Some of the examples of such systems are given below. These projects are operational and functional. District heating is an environmentally friendy way of supplying heat to the town. As the name suggests, District heating is providing heat to a town or school or area using one big boiler rather then buildings and houses having their own boilers. The heating in such a arrangement is provided by the central plant.

3.4.1 Tallinn Elektrijaam (The Vao Plant)

The Vao Power plant is also known as Tallinn Power Plant is a Biomass and pear-fired combined heat and power plant in Estonia's capital city of Tallinn. This plant is located at the eastern side of Tallinn in Vao. Biomass is a renewable resource that can continue to grow when it is managed and harvested sustainably. The wood which is not suitable for the furniture or high end products can be utilized as a fuel in Biomass. The power plant has the capacity of 25MW of electrical power and 49 MW of heat. The main fuel used in the Vao power plant is the Wood chips and peat. IT also has 230ft high flue gas stack which was supplied by a Finnish company. After the success of initial power plant, the company went on to install another Power plant which is called Vao-2. The heat capacity of the Vao-2 is 76.5 MW while the electrical output capacity is 21 MW. The power plant will be able to sell about 350 MW of the thermal energy over the year which corresponds to nearly 19% of the total consumption by the remote heating network in the Tallinn city. Both of these power plants are using 90% of the renewable fuels which is cutting costs for the company as well as for the consumers.

3.4.2 VKG- heat from shale oil production

Estonia has rich resources for the oil shale but this resource comes with the environmental impacts. The use of oil shale to produce heat has declined over the period of time and the decline will continue as the additional primary energy is supplied through the Biomass which is fired in the CHP plants. The overall demand for heat continues to decline in Estonia as well.

Though, Oil shale remains integral part of the Estonian energy system and VKG Soojus is another company that is providing the district heating to the Kohtla-Jarve, Ahtme Urban area and Johvi district using oil shale as the fuel. It is the unit that is using long-distance supply and it is supplying energy to over 1310 facilities. Previously, Ahtme heat power station was used to provide the heat to the consumers but on January 1st in 2013, the plant was closed as it was not meeting the EU environmental regulations. The Ahtme and Johvi district switched heating pipeline from this power plant to Kohtla-Jarve. This plant is using oil shale processing. The oil shale usage for the heat generation has steadily declined since 2000. The heat generation coming from the oil shale is only about 2% and it is supplying around 13% of the nation’s heat.

While the share of oil shale to produce heat is decreasing, the overall demand for the heat is also decreasing. It will still take few more years to completely switch to the Biomass from the oil shale as Biomass is much cheaper than the oil shale and has less environment affects. However, Estonia is not only using the Oil shale to produce heat but to produce the electricity. The use of oil shale for the heat generation might become very minimal in future but the oil shale consumption for electricity will still be key player.

In order to calculate the waste potential of the system using the Carnot theorem. The temperature ranges of all three selected industries i.e. Wood and Wood products, Paper and pulp and food, beverages and tobacco industry were analyzed.

3.5 Calculation of Potential

The waste potential and Carnot potential differ with respect to the temperature that the process is taking place in. Carnot potential is measure of highest efficiency that an engine can perform work. Energy is sum of exergy and anergy. The exergy of the system is measure of the energy that can be used to convert into the mechanical energy. According to the results given in (Panayiotou et al.), The Waste heat potential that can be recovered from the low temperature range is about 12.60%. The majority of the process that are taking place in Food, beverages and tobacco industry are under 100°C. So by knowing the temperature used in a process in Food, beverage and tobacco company, we can find the waste heat potential of that industry in terms of energy consumed and in terms of temperature. Similarly, we can also find out about the Carnot potential of the system working under 100°C. Same process can be applied to different industries. In Estonia, the fuel consumption was maximum in the Food, beverage and tobacco, Wood and wood products and Paper pulp industries.

Each of those industries go through many different processes having different ranges. These temperatures were given categorically by the (Forman et al.). The data for the processes taking place in those industries were extracted and is given below.

Paper and Pulp industry	
Name of Process	Temperature Range
Paper production	55℃
Compressor	80℃

Table 2 Paper and Pulp industry temperature range.

The paper and pulp industry are a low temperature range industry. The temperature range of under 100℃ is considered as low temperature range. The Paper and pulp industry fall under this category. According to (Panayiotou et al.) The waste potential in such industries which has low temperature is about 12.60%. The total energy consumption according to the statistics data in Estonia for 2018 is 982GWh. So the waste heat recovery potential of the paper and pulp industry is 123GWh. This calculation is based on theoretical value and there must be some losses and loss of energy occurring in the real environment. The effluent losses were 5% of the total waste heat that can be recovered from a system. Even if the assumption is made on basis of this scenario, the waste heat that will be lost in such a scenario will be about 6.18 GWh. Still, Waste heat that can be recovered will be around 116.82 GWh. The market is expected to expand further as the growth of the industry has been a steady one so if the extraction of about 116.82 GWh is possible then this heat can be added to the national grid and can be utilized further for district heating of the nearby towns of paper and pulp industry. Rising market will increase the energy consumption by the industry and will increase the waste heat potential of the system. More waste heat can be recovered. The market growth of the paper and pulp industry in the last two years is 13%. Though the market is expected to grow but if the modest approach is taken and assume that the market will only grow by 2% in 2020 then the waste heat that can be recovered from the paper and pulp industry can be 119.1 GWh.

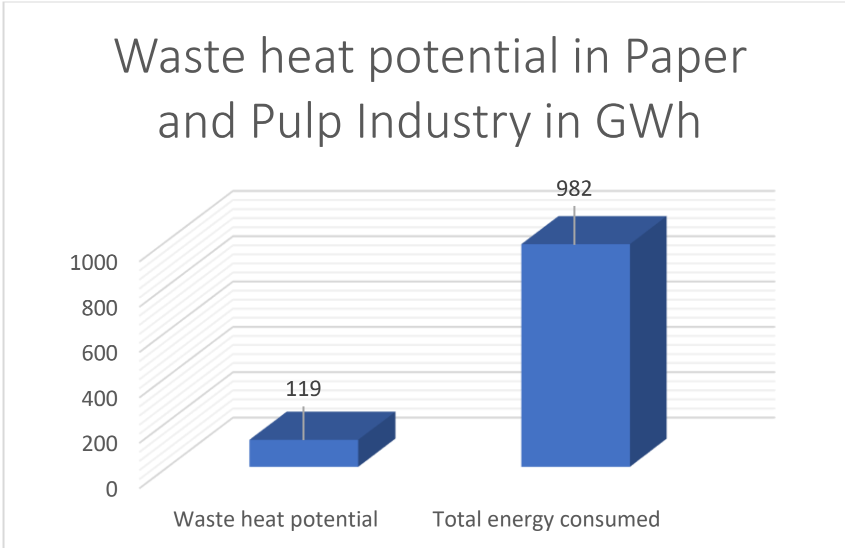


Figure 2 Waste heat potential in Paper and pulp industry

Wood and Wood Products	
Name of Process	Temperature range. ℃
Cutting motor	80
Compressor	80
Lighting and other	35

Table 3 Wood and Wood products temperature range.

These are all processes which took place at the temperature range of less than 100℃. As we know from the results given in the reference(Agathokleous, Bianchi, et al.). The amount of waste heat that can be recovered from these processes are up to 11.40%. The consumption of the energy by the wood and wood products industry in 2017 was 1298 GWh. As it is industry that consumes a lot of energy out of those 1298 GWh, the energy consumed by heat was 799 GWh and the energy consumption of electricity was 499 GWh. In this case, the calculation of the total waste heat that can be recovered from the Wood and wood products industry is 148 GWh. The industry has potential to recover the waste heat which can be converted to provide the district heating in the nearby area by using the pipelines or it can be sold to the national grid. The waste heat that is recovered from the process can also be recycled and used in the same process which will reduce the usage of the primary fuel in the industry. The usage of the same energy for the same process will reduce the usage of primary energy and bring down the cost of the total operation.

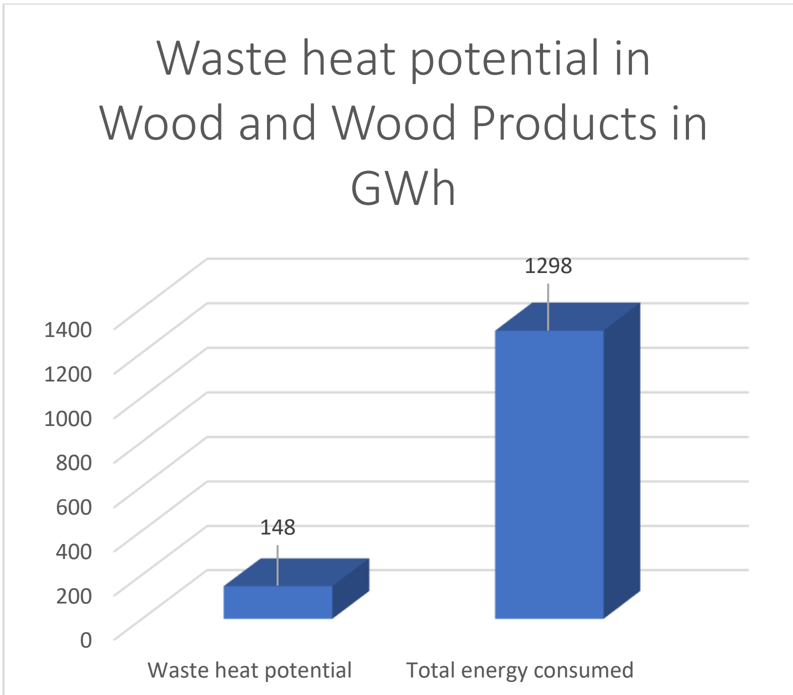


Figure 31 Waste heat potential in Wood and Wood products industry sector

Final Consumption in Food, Beverage and Tobacco	
Electrical GWh	Heat GWh
309	389

Table 4 Final consumption in Food, Beverage and Tobacco Source : Stat.ee

Food industry has many low temperature processes like Pasteurization, Distillation, blanching and sterilization. These processes are all taking place under 100℃. Mostly the process temperature is around 60℃ to 90℃. These processes include many different phases. The energy consumed by these industries is lower than that consumed by the wood industry or paper and pulp industry. This is mainly due to the fact that the Food preparation does not require high temperatures. Sterilization is a food unit operation which is used to eliminate the micro-organisms from the liquids and other processes. Pasteurization is controlled heating process used to eliminate the dangerous pathogens that may be present in milk, meat or other foods. The temperature range is usually around 62℃ to 90℃. The process of pasteurization is not very long and usually finished within seconds to minutes at most. Blanching is a process where whole food is exposed to the temperature of 95℃ for a short period of time. This is done in order to inactivate the bacteria that is present in the food. The blanching deactivates the bacteria and enzyme action so the food will not get degraded very quickly. In 2017, Estonian Food industry consumed 698 GWh of energy for the production of food. Though this number is smaller than what is used in other industries, but this industry is far more important than other industries as these are products that are part of the daily life. Out of 698 GWh, 309 GWH energy from the electrical is used and 389 GWh of the heat consumed. According to the results given in reference (Panayiotou et al.), in a low temperature processes the waste heat that can be recovered is 11.40%. So, the total waste heat that can be recovered from the Food, beverage and tobacco industry is 79.5 GWh. The energy recovered from the industry can be utilized to provide district heating.

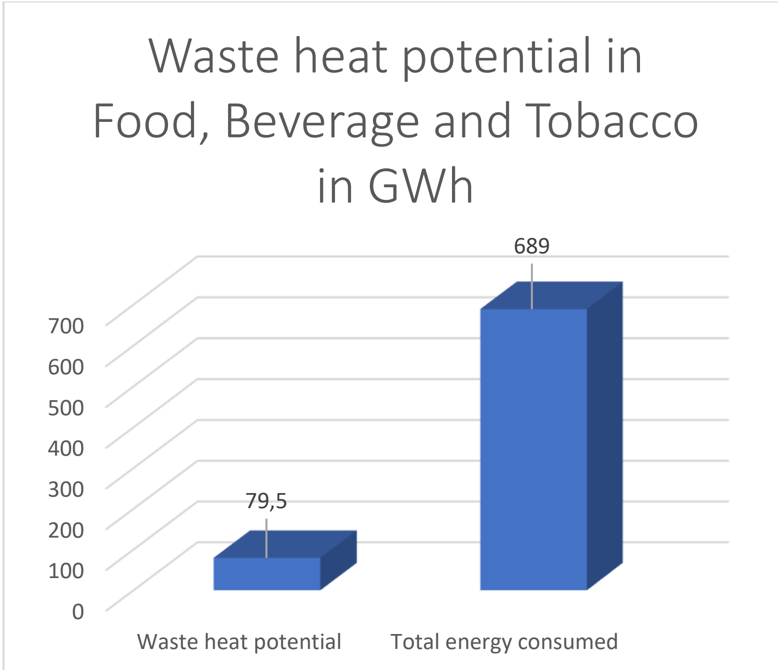


Figure 4 Waste heat potential in Food, Beverage and tobacco industry sector

4.0 Conclusion

The aim of the study was to calculate the potential of the waste heat that can be recovered through the low temperature industry sectors which consume more energy than other industry sectors. Although the results from all three industry sectors above are very much encouraging but all the results are theoretical and based on the data that was taken from different sources. The need of the hour is to create applications and technologies that will help us in recovering the low-grade heat from the industries and companies. The results show that there is significant potential available for the industries and companies to exploit and bring the usage of the primary energy down. The cost of the processes can also be brought down using Waste heat recovery processes and technologies. The next step from this research will be to perform a more detailed and practical analysis of results that will help us move towards a more environmentally friendly approach. The three selected industries utilize about 2978 GWh of energy each year and they have combined potential of 346.5 GWh. These industry sectors can provide up to 346.5 GWh energy that can be utilized for district heat purposes, recycling of the waste heat can lead to reduction in usage of the primary fuel. A visual representation of the all three-industry sector are given below.

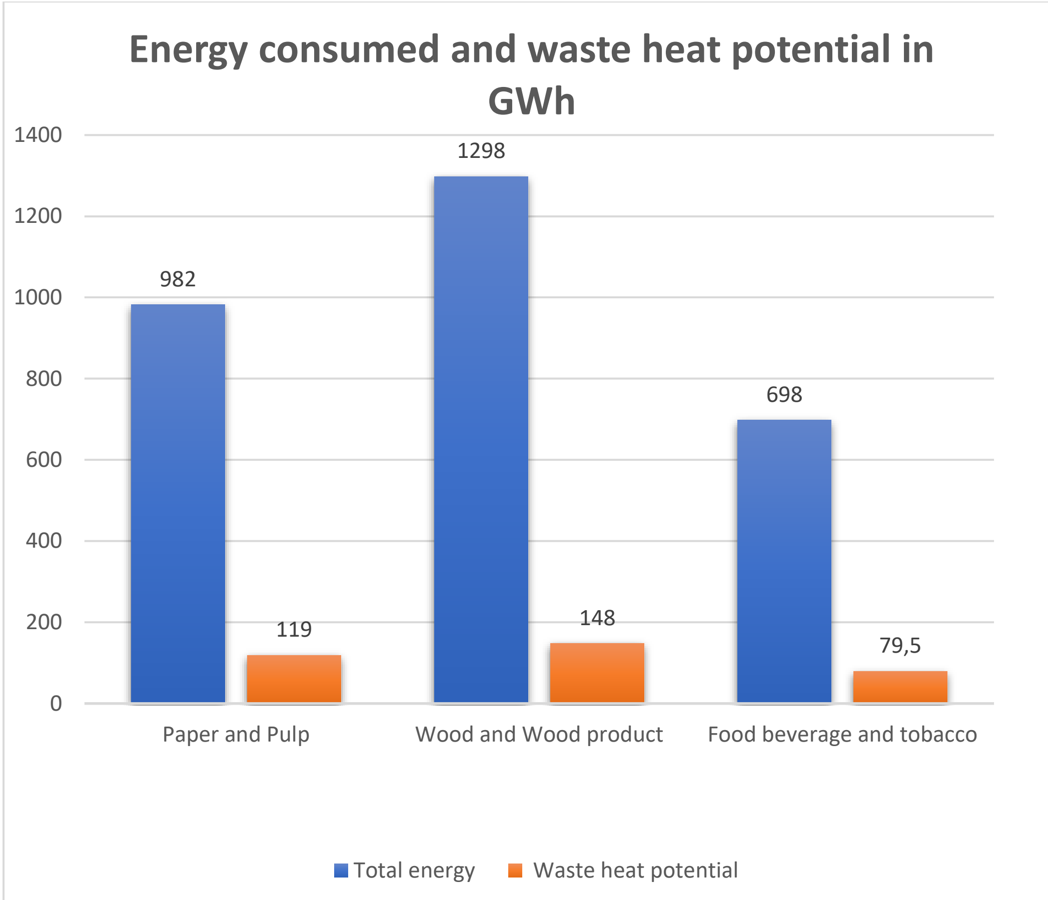


Figure 13 Energy consumed and waste heat potential in three selected industry sectors.

4.1 District heating and waste heat.

It is a common misconception about district heating being a low efficiency technology. Several surveys and reports suggested that it is a highly environment friendly and economical method. In comparison with the individual heating network a district heating system allows many individual consumers to access heat that is produced from the different sources. Out of the 9541 GWh heat produced in the year 2016 in Estonia, about 70% was used in the district heating. The energy efficient way of producing the supplied heat in district heating can potentially cut greenhouse gas emissions to a significant amount. Using the waste heat recovery systems can effectively contribute in saving up to 346.5 GWh of the heat produced per year out of the 6650 GWh which was used by district heating. This corresponds to 5.2% of the total heat that is used by the district heating systems. WHR systems are viable option as it will save cost, reduce GHG emissions and also reduce the usage of the primary fuel. Estonia wants to cut down on the usage of the Natural gas because it is not a local fuel but mostly it is imported from Russian Federation. WHR system can reduce the import of the natural gas as 5.2% of the district heating need can be provided by the WHR systems.

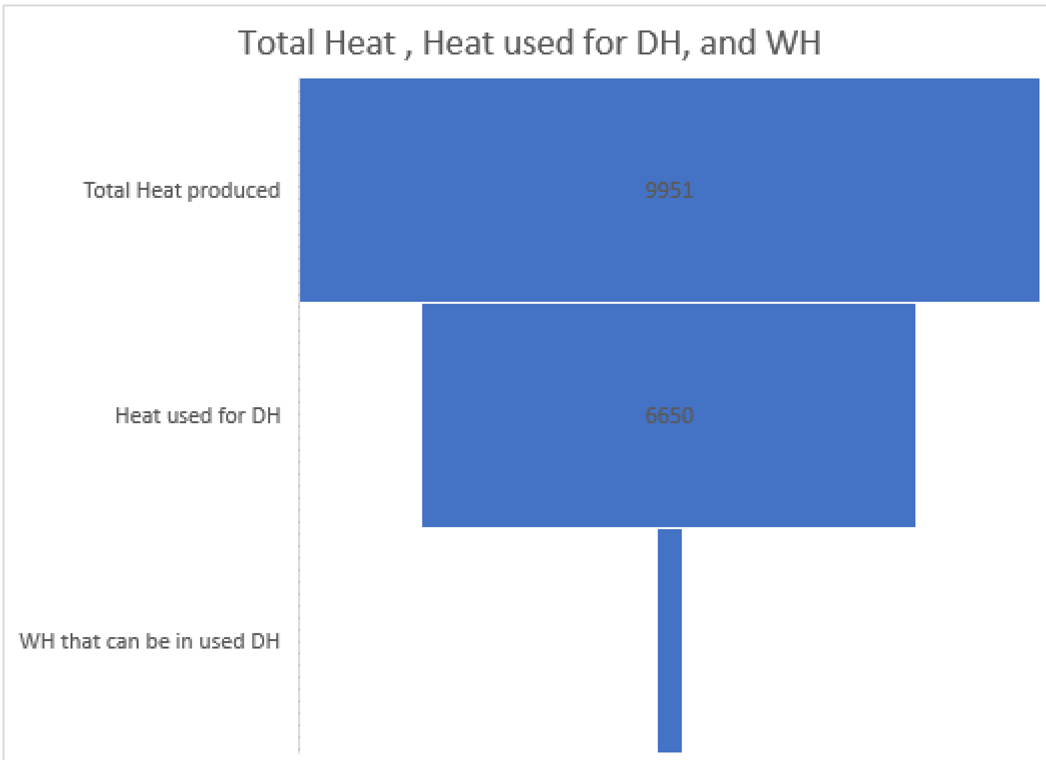


Figure 14 Graphical Representation of Total heat, Heat used for DH, and Heat from WHR (2016)

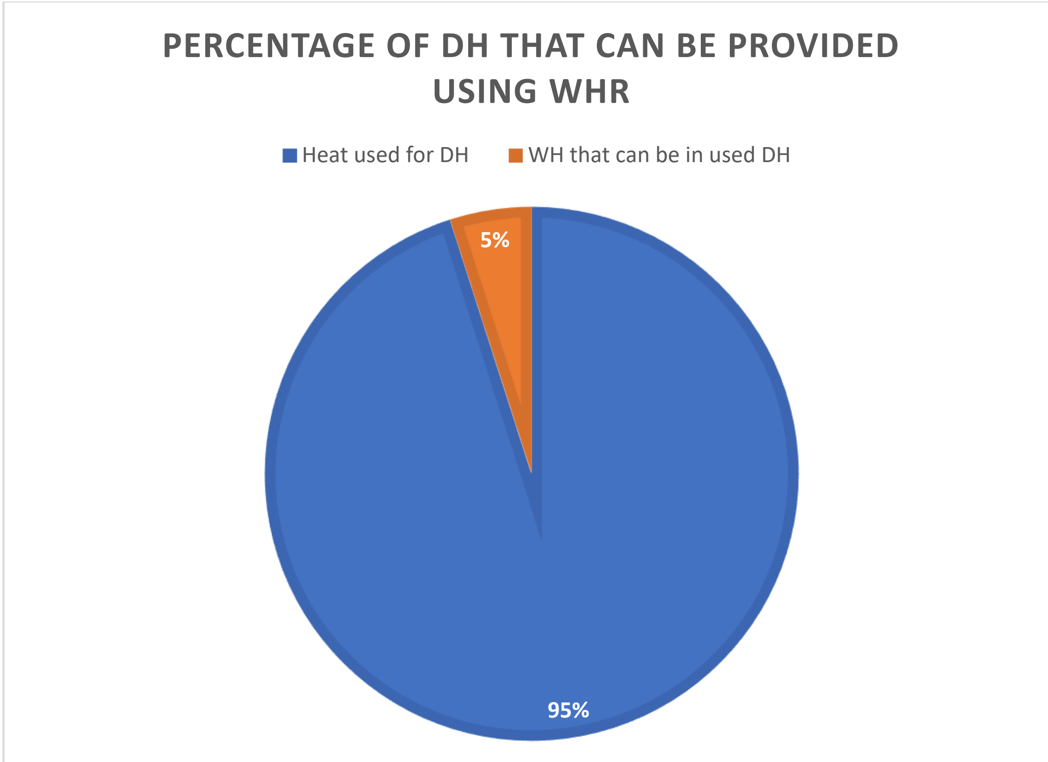


Figure 15 Percentage of DH that can be covered using WHR system in Estonia

Since, we are considering data from only 3 industry sectors then it is worth mentioning that the actual potential can be higher as there are more industry sectors working in Estonia. The actual potential from the industry can be higher and it can differ from the calculations which are mentioned here. As mentioned earlier, these values are based on the estimations from the data which was available. Also, this study contains estimation from the three industry sectors only, so the potential could be higher if we take data from the other industry sectors. The three industry sectors that were chosen in this study was due to the fact that they consumed more energy than other industry sectors in Estonia. Some of the factors that are involved must be taken into consideration. These factors include consumer needs, temperature and demands of the consumer. Also, the location of the consumer can also affect these values as DH works well when the consumer is situated near the centralized heating plant. The actual potential can be lower or higher depending on these factors. The waste heat recovery system can be beneficial for the industry sectors and they are beneficial for the companies who are looking to cut down on the cost of the fuel and also providing safe and clean DH to the consumers. These technologies will benefit environment and industries in the long run as well.

4.2 Waste heat and Emissions savings.

It is estimated that 1 KWh has about 6.5×10^{-4} tons of CO_2 emissions(Yan et al.)(Kuldna et al.). This was taken into consideration and total emissions saving from the use of waste heat recovery was calculated. The total waste heat potential in those three industry sectors was 346 GWh. So, the calculation which was based on theoretical values gave the result that about 5.82 tons of the CO_2 emissions can be saved from getting into the environment. This reduction in the emissions will help Estonia to achieve the target of 2050 set by EU. The target is to reduce the emissions by 80% to 90% from the base year which was 1990. Estonia is also a member of Kyoto protocol and it is a body that is functioning to reduce the emissions from the environment. These steps will help Estonia reduce the emissions for better environment and achieving the goals set by Kyoto protocol and EU. It is worth mentioning that these results are strictly theoretical and actual results might differ from these calculated values.

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