Internship report

Project feasibility

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Preface & Acknowledgements

From the 4th of November until the 28th of February I did an internship at the HOST bioenergy installation company at the city of Enschede. The internship is part of the two year master program in Sustainable Energy Technologies (SET) at the University of Twente. The master consists of a year of courses relevant to renewable energy technologies (Wind, Solar, Biomass and Hydrogen), a three month internship and 9 months of graduation thesis.

With this opportunity I would like to thank the director of HOST, **Herman klein Teeselink**, for giving me the opportunity to do an internship within HOST and to experience working at a business environment. Also I would specially like to thank the process engineer of HOST and at the same time my job coach, **Jeroen Stroomer**, who had the kindness to accept me in the company and guide me through my internship with advices, feedback and tips despite his busy schedule. During this process Jeroen gave me extensive guidance sharing his knowledge and experience as well as make me to understand in depth the working principle of a wood fired CHP (Combine heat and power) plant. The internship at HOST offered me a personal and professional experience and also helped on my personal development by making me more independent. Furthermore, by learning and understanding a different culture, I now have a broader perspective of the world which is a personal gain of this internship.

Besides that, I would like to thank my colleagues that I worked with and spent nice moments at their friendly office environment during my internship, **Saskia Strating**, **Joost Fokkink** and **Melvin Elizen**.

But this internship would never become true without the smart initiative of the **University of Twente** which introduces us on the “real world” during the master program and let us to experience a working environment for three months. Last but not least, I would like to thank my supervisor at the University of Twente, Ir. **Eddy Bramer**, for suggesting to me the HOST as a possible company for my internship.

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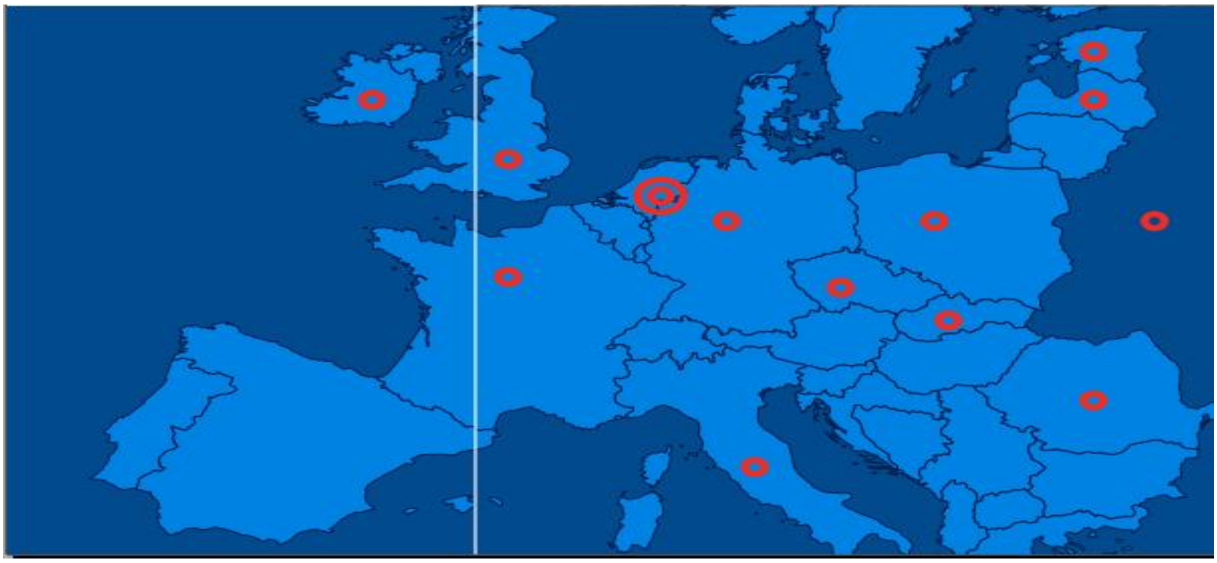
Introduction

Host B.V

HoSt is a supplier of bioenergy systems and delivers complete systems, from anaerobic digesters for agriculture and industry, wood-fired boilers and combined heat and power plants to fluidized-bed gasifiers. In addition to the design, construction and assembly of plants HoSt operates as a turn-key supplier. HoSt also provides a wide range of other services, such as feasibility studies, planning applications, financial support, start-up, supervision of process operations, process monitoring and optimization of systems supplied.

HoSt came into existence as the result of a joint-venture between Holec Projects and Stork, two well-established suppliers of energy systems. From 1999 onwards HoSt has been a fully independent business whose activities focus 100% on the technological development of systems for the processing of biomass flows and the supply of systems for the sustainable generation of energy from biomass. HoSt has built up extensive experience in the processing of diverse waste flows from the food-processing industry and agricultural by-products such as straw, chaff and grass cuttings.

HoSt has designed and constructed more than 40% of Dutch biogas plants. Four out of every five HoSt projects are currently being realized outside the Netherlands. For example, systems have been installed in countries such as Belgium, Poland, Romania, the UK, Latvia, Portugal and Thailand.



Internship objectives & project approach

The main scope of the internship is a financial estimation of Host's projects (mainly wood fired CHP) on different locations. The project result will be used as a tool by the company's agents to determine quickly and accurate whether the project is feasible and allows them to evaluate potential customers.

Different configurations and capacities of CHP power plants corresponding to fuel consumption and cycle efficiencies will be implemented for a better approach to the final result. The outer layer will be economical, which allows the agent to make a quick estimation of the investment level taking as input variable such as electricity, heat and steam prices.

An additional aim of the internship is to provide with technical knowledge and working experience the participant. This experience as well as the knowledge which have taken during the internship can help the intern for a smoothly transition on the working environment later on.

To conclude, the financial estimation will be shown on a format excel sheet which the agents can fill in with respect to the customer needs. For the tool construction the following approach has been applied:

- Understanding the working theory of the possible installations.
- Data collection from HoSt database.
- Technical approach and calculations based on input parameters.
- Financial calculation, analysis and evaluation of the results.
- Optimization of plant capacity based on heat demand curve.

A. BIOMASS POWER GENERATION

This report examines not only the financial benefits and feasibility of a CHP plant but also touches on the technical analysis and function of it. Biomass use can offer many advantages compared to fossil fuels for energy generation. Together with energy cost savings, lower greenhouse gas emissions, waste management or reduction opportunities, biomass can improve security of supply resulting to native economic development opportunities. However, whether or not these advantages are implemented, and to what extent, depends primarily on the nature and source of the biomass feedstock.

Three critical components are important to analyze the use of biomass for power generation:

- **Biomass feedstock**: These come in a variety of forms and have totally different properties that affect their use for power generation.
- **Biomass conversion**: This is the method by which biomass feedstock is transformed into the energy form that will be used to generate heat and/or electricity.
- **Power generation technologies**: There is a large range of commercially tested power generation technologies available that are able to use biomass as a fuel input. However, on this report we are looking only to biomass combustion technologies.

The scope range of this report as well as the tool's is:

- Hot water and steam boiler capacities vary from ***1MWth-19.5MWth***.
- CHP plant capacities range between ***5.3MWth and 19.5MWth***.
- ***Flue gas condenser*** installation option.
- ***Wood chips, straw and husks*** as feedstock sources.

A1. Feedstock

The organic material of recently living plants from trees, grasses and agricultural crops are named as **biomass**. Biomass feed-stocks are high heterogeneous and therefore the chemical composition is mainly dependent on the plant species. The most commonly used feedstock of biomass heating fuels are virgin wood, industrial wood residues, certain crops and agricultural residues. Biomass fuels are mainly delivered as wood pellets or woodchips however can even be in different forms like bales of straw. The characteristics points of a biomass fuel include its moisture content that affects the calorific value of the fuel, and also the particle size. Wood chips that are too large can block the fuel feed system, also the high moisture content and ash, can reduce the efficiency and reliability of the boiler respectively. The following table consist a list of the most commonly used biomass feedstocks in combustion process, as well as their HHV and LHV that corresponds to each one.

	Higher heating value MJ/kg	Lower heating value MJ/kg
Agricultural Residues		
Corn stalks/stover	17.6 - 20.5	16.8 - 18.1
Sugarcane bagasse	15.6 - 19.4	15 - 17.9
Wheat straw	16.1 - 18.9	15.1 - 17.7
Hulls, shells, prunings	15.8 - 20.5	
Fruit pits		
Herbaceous Crops		
Miscanthus	18.1 - 19.6	17.8 - 18.1
Switchgrass	18.0 - 19.1	16.8 - 18.6
Other grasses	18.2 - 18.6	16.9 - 17.3
Bamboo	19.0 - 19.8	
Woody Crops		
Black locust	19.5 - 19.9	18.5
Eucalyptus	19.0 - 19.6	18.0
Hybrid poplar	19.0 - 19.7	17.7
Douglas fir	19.5 - 21.4	
Poplar	18.8 - 22.4	
Maple wood	18.5 - 19.9	
Pine	19.2 - 22.4	
Willow	18.6 - 20.2	16.7 - 18.4
Forest Residues		
Hardwood wood	18.6 - 20.7	
Softwood wood	18.6 - 21.1	17.5 - 20.8
Urban Residues		
MSW	13.1 - 19.9	12.0 - 18.6
RDF	15.5 - 19.9	14.3 - 18.6
Newspaper	19.7 - 22.2	18.4 - 20.7
Corrugated paper	17.3 - 18.5	17.2
Waxed cartons	27.3	25.6

Table 1 : Heat content of various biomass fuels (Dry Basis) [10]

In general most of the feedstocks above can be used on the combustion process, but in our scope two feedstock sources are the most common for power generation, as a result of their high heating value and market availability. Wood chips and straw are getting the primary power source of every biomass CHP plant and therefore the project feasibility is highly dependent by their quality and their market price. The main characteristics that have an effect on the quality of biomass feedstock are moisture content, ash content, particle size and density.

The use of biomass is one of the most cost effective and practical ways to provide space heating with hot water and steam from a source with low carbon content. Moreover, exploitation of biomass for space heating provides more cost-effective carbon savings than for other uses, due to the fact that it offers the highest carbon savings per kg of biomass. [10]

1.1. Wood chips & straw

Wood chips created from wood residues, by thinning and logging operations in forestry and are sometimes referred to as forest wood chips. Therefore the method of making wood chips is called wood-chipping. It is a forest product, not contaminated with any other materials.

On the other hand, straw is an agricultural by-product, mainly the dry stalks of cereal plants, after the removal of grain and chaff. Straw makes up about half of the yield of cereal crops like wheat, oats, barley, rice and rye.[8]

1.2. Natural gas comparison

A well-known and reliable source for electricity and heat production is natural gas. Gas boilers are the most popular type of steam or hot-water-producing equipment. However, biomass boilers are getting more and more popular.

The major differences compared to the fossil fuels are as follows:

- **Significant carbon savings**
  Biomass fuels have much lower net carbon emissions than the fossil fuels from which the majority of heat is produced, because of the lower carbon content which is just about half than the conventional fuel varieties (Coal, Oil, Natural Gas and LPG).
- **Operational cost savings**
  The cost of biomass fuels is typically lower than the fossil fuel. Therefore, biomass heating systems can provide attractive operational cost savings. The amount of savings depends on the price of the fossil fuel being replaced and also

the price of the biomass fuel used that fluctuate mainly by the market availability. Biomass fuels can be cheaper on a unit cost-basis than many fossil fuels normally used for heating. Lower cost on fuel translates into lower operational costs, and hence annual savings which over time facilitate to reduce the payback period of the investment.

- **Reduced fuel price volatility**

  Security of energy supply is a repeated and global concern for fossil fuels. Geopolitical instabilities in gas and oil producing countries can threaten availability and lead to unexpected price changes. While biomass fuels price will be change with time, they are likely to be less extreme than fossil fuels and may also be more manageable / predictable if the biomass is sourced regionally.

- **Resources diverted from landfill**

  Using particular biomass resources as fuels can divert them from becoming wastes and being sent to landfill, at the same time the combustion of them can offer significant financial benefits. [3][9][15]

A2. Biomass combustion

Bioenergy can be converted into power through thermal-chemical processes (i.e. combustion, gasification and pyrolysis) or bio-chemical processes like anaerobic digestion. However in this report we are only looking at combustion process for energy production.

2.1. *Furnace*

A mature commercially available technology is the direct combustion of biomass for power generation. This technology is often applied on a wide range of scales from a few MW to 100 MW or more and is the most typical form of biomass power generation. Around the globe, over 90% of the biomass that is used for energy purposes goes through the combustion route.

Operation

The combustion process is taking place in the furnace where the wood is burned on a moving grate. The wood is transported through the furnace by a hydraulically driven moving grate and is subsequently dried, gasified and combusted. The grate is made from high chromium steel which can withstand in high temperatures. The air feeding below the grate is divided in several independently controllable sections for optimal combustion control. Combustion air is preheated to approximately 150°C. Preheating allows combustion of wet fuels and is based on extracting heat from the flue gases. Only air to the primary two sections of the grate is preheated, because there the drying of the fuel occurs. The other sections do not require preheating even when firing wet fuels.

Flue gas is added to the combustion air beneath the grate (re-circulation) to control combustion temperatures at low O_2 content. This makes it attainable to burn the fuel on the grid on a relative low temperature, ensuring an extended lifespan of the grate bars. It also prevents large amounts of ash agglomeration, especially when biomass is combusted with a low ash melting point.

The temperature in the furnace (above the grate) is controlled between 925°C and 975°C by adding additional secondary air and recirculation of flue gas with the help of multi-cyclone from downstream. Within the furnace the O_2 content is under stoichiometric. After the furnace, in a turbulent section, the excess air is added (tertiary air). The temperature control by flue gas recirculation also increases the efficiency of the process, since the desired quantity of surplus air is decreased. The furnace operates (during normal operation) at 5% O_2 in the flue gas. Low NOx emissions and complete combustion is reached by specially designed stage combustion. [14]

A3. Energy conversion technologies

There are three main biomass generation technologies, combustion, anaerobic and gasification. As already mentioned we tend to not examine anaerobic and gasification technologies but the mature combustion technology of hot water/steam boiler and CHP plant.

3.1. Biomass boilers

Before describing the working principle of biomass boilers it is helpful to look briefly at fossil fuelled boilers operation as an aid to understanding the differences. Most boilers burn fossil fuels such as oil or gas. The fuel is typically fed under pressure through a pipe to the burner where it is ignited by an electric ignition system, ignition is nearly instantaneous. Complete combustion requires enough amount of oxygen to make sure that all the fuel is burned, and all boilers require excess air at the burner for this reason. However, excess air leads to causes disproportionate heat loss via the flue gas and most of the times can lead to increased formation of oxides of nitrogen (NO and NO_2 usually collectively mentioned to as NO_x) and nitrous oxide (N_2O) at higher temperatures. [4]

3.1.1. Hot water boiler

Water boilers operating at up to 95 °C (or higher under pressure) and might be classified by various methods based on fuel type or on the physical characteristics of the boilers. Wood chip boilers are fuelled by an automatic feed/grate of chipped wood, which can be supplied with moisture contents from 15% to 60%. They use a stoker burner for burning fuels with moisture content between 15% and 30%, or moving grate systems for burning fuels with moisture contents above these percentages. Boiler sizes vary from domestic systems of 10–20 kW to medium sized of 50 kW and above to power-station sized boilers of more than 100MW. HoSt supplies hot water boiler with capacities up to 20MW.[4]

3.1.2. Steam boiler

Steam boilers are divided in two categories, the flame and the water tube boilers. A **water tube boiler** is the boiler type where the water is heated into tubes and also the hot gasses surround them. This is the fundamental definition of water tube boiler which has just opposite working principle of flame tube boiler where hot gasses are passed via tubes which are covered by water.

➢ *Water tube boiler*

A water tube boiler is a type of boiler in which water circulates in tubes and heated by flue gasses externally. Fuel is burned within the chamber, creating hot flue gas that heats water into the steam-generating tubes. In smaller boilers, additional tubes are separate in the chamber, whereas larger utility boilers rely on the water-filled tubes that form up the walls of the furnace to produce steam. The heated water rises into the steam drum and converted to steam. In some cases, the steam can reenter the chamber through a superheater to become superheated, which can be used to drive turbines (CHP purpose). Cool water at the bottom of the steam drum returns to the feed-water drum through large-bore called downcomer tubes, where it pre-heats the feed-water supply. In large boiler capacities, the feed-water is provided to the steam drum and therefore the downcomers supply water to the bottom of the water-walls. To raise the boiler's efficiency, exhaust gases are also used to pre-heat the air blown into the chamber and warm the feed-water supply.[16]

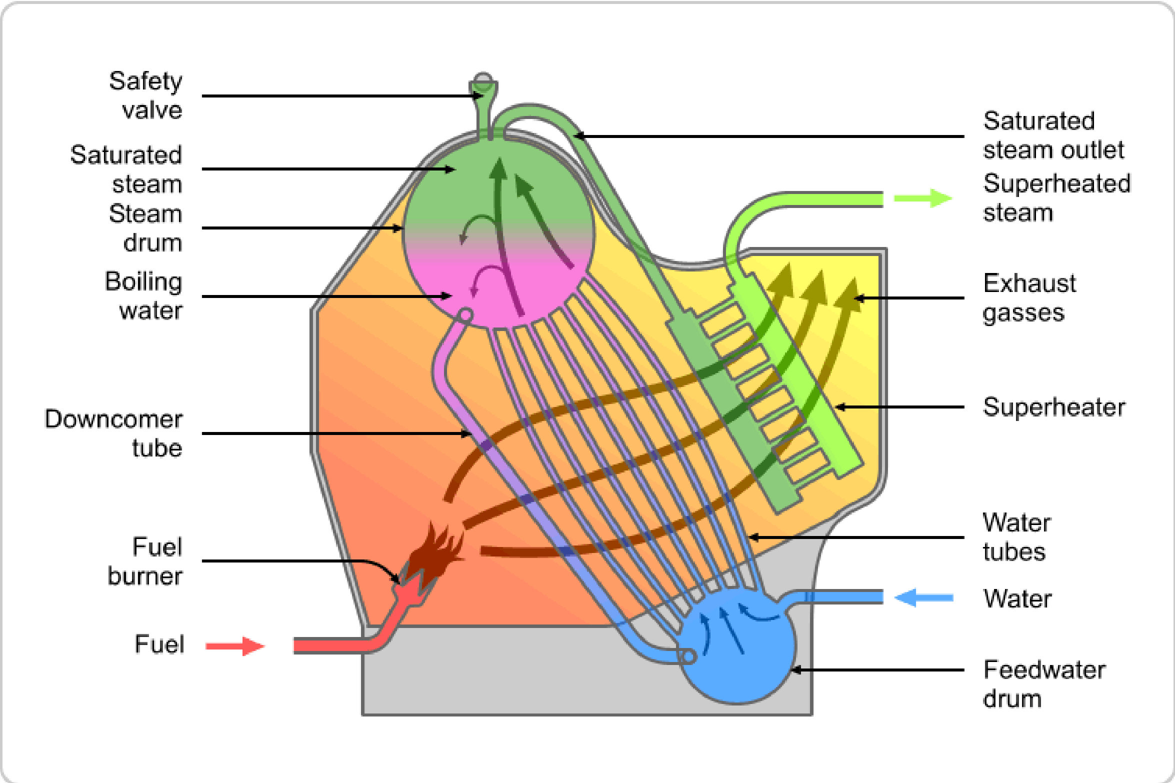


Figure 1: Water tube boiler

➢ *Flame tube boiler*

The working principle of flame tube boiler is as simple as its construction. In flame tube boiler, the fuel is burnt inside the chamber. The hot flue gases produced in the chamber and then pass through the flame tubes. The fire tubes are immersed in water inside the main vessel of the boiler. As the hot flue gases are passed through these tubes transfer heat energy to the water surrounds them. Resulting to the transformation of the water to steam which is naturally comes up and is stored upon the water in the same vessel of flame tube boiler. The generated steam is then extracted from the steam outlet and is used for the required purpose. Cool water is continuously fed into the boiler to replace the generated steam. As the steam and water is stored in the same vessel, it is too difficult to produce steam in very high pressure (25-30 bars) compare to water tube boiler which the steam pressure can reach almost the 56 bars. Furthermore, the investment cost of a water tube boiler is higher than the cost of a flame tube boiler. However if a high efficiency and reliability in a project is required, especially for biomass/waste fuels with known severe fouling behavior, the water tube boiler will be the best choice for the project. [17]

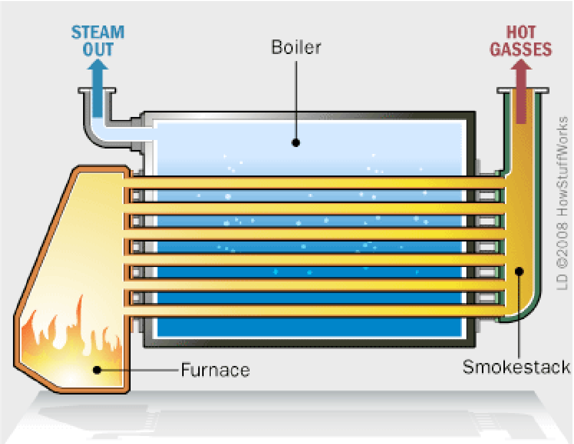


Figure 2: Flame tube boiler [18]

Efficiency

The efficiency of a boiler is measured by the proportion of the fuel input energy that is finally delivered as useful heat output. Main efficiency factors in biomass combustion are the moisture content of the fuel, the extra air flow into the boiler and also the share of un-combusted or partially combusted fuel. Major sources of heat loss from steam boilers are through the flue gas, blow-down and radiation to the boiler's surroundings. When operated properly, all modern boilers are capable of achieving an efficiency of around 80% (based on the quality and the LHV of the source). Higher efficiencies can be achieved by additional installation of flue gas condenser and with economizers. However, the efficiencies by steam boilers are totally different from those available to hot water boilers.

Every type of boiler aims on different needs, water boilers are used for heat production and the distribution of it in centralized locations for residential and commercial use (district heating) and steam boilers are used for steam production and as a result mainly on commercial use. [5]

3.2. CHP plant

Combined heat and power (CHP), also known as a co-generation, is the simultaneous production of electricity and heat from one source of energy. CHP systems are able to achieve higher overall efficiencies compare to the separate production of electricity and heat, when the heat produced is used by industry and/or district heating systems. Biomass CHP plant can provide heat or hot water/steam for use in industry or for space and water heating in buildings, directly or through a district heating network. The feasibility of biomass CHP systems is mainly depended by the electricity price and the market availability as well as the cost of the biomass feedstock. Many biomass sources are available for co-generation nevertheless the highest potentials are located in the wood processing and sugar cane industries.

Biomass power systems have size usually below 50 MW, far smaller than coal-fired plants, that vary between 100- to 1,000-MW. HoSt supplies wood fired combined heat/power installations with an electric power of 1 to 5 MWe and a thermal power of 5 to 20 MWth. Most of the recently constructed biomass power plants are direct-fired systems.

There are 2 basic elements of a combustion–based biomass CHP plant: i) the biomass-fired boiler that produces steam and ii) the turbine that is used to generate electrical energy. The biomass fuel is burned in a water or flame tube boiler to produce steam in high-pressure, then the steam it can be used to power the generator which is coupled on the turbine. In several applications, steam is extracted from the steam turbine before the outlet at medium pressure and temperature and can be used for process heat, space heating, or space cooling. These steam turbines are called extraction steam turbines and can offer high flexibility of operation but at the expense of electrical efficiency. Furthermore, CHP plant overall efficiency can be increased by connecting flue gas condenser device, resulting in additional heat production.

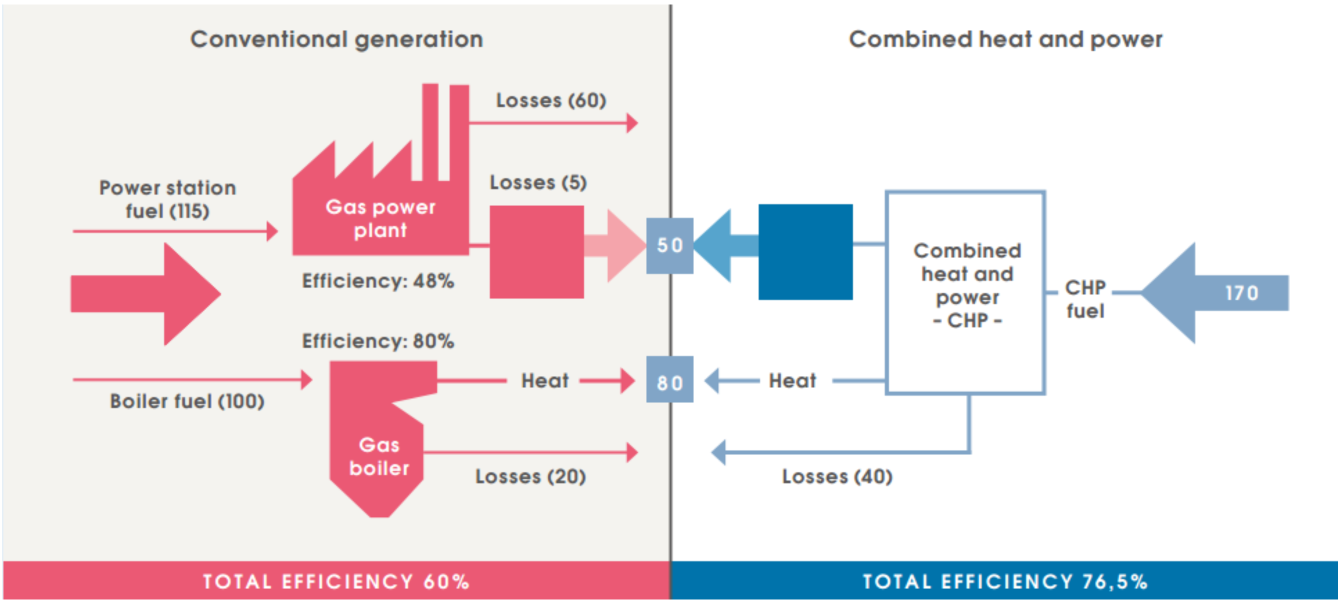


Figure 3: An example of efficiency gains from CHP

3.2.1. *Flue gas condenser*

The wood chip moisture which is mainly used on the combustion process varies between 35%-60%. During the combustion process into the furnace, the fuel is heated up and the water (moisture) from the fuel starts to evaporate. The exhaust gas that produced through combustion processes is named flue gas and its composition rely on the type of fuel and the combustion conditions, the main flue gas elements are (H_2O, N_2, CO_2, O_2, CO, SO_2 and Hydrocarbons). The wet flue gasses carry a significant amount of energy which is apparently released to the atmosphere and is wasted. A part of this wasted energy can be recovered by a device named **flue gas condenser**. Flue gas condenser can increase the boiler's overall efficiency from 8% to 35% depends on the return temperature from district heating and the fuel moisture content. It is also a second flue gas cleaning step. Approximately 50% of the dust passing the multi-cyclone will be separated from the flue gas by the washing process.

Operation

In the flue gas condenser, the flue gas is cooled by spraying cold water droplets into the flue gas. The sum of all droplet surfaces corresponds to the heat exchanger (flue gas condenser) surface. Due to condensation of water vapor from the flue gas, the temperature of the injected spray water is increased. This warm water is collected and pumped through a plate heat exchanger were cold water is heated. The cooled condensate can then be used again as spray water for the flue gas. Depending on the type of the wood chips, the circulated water has to be neutralized to prevent corrosion. The excess of condensate water is led to a cleaning system. After the heat transfer to the water the flue gas is released through the chimney to the atmosphere. The following figure illustrates the flue gas condenser operation and the flue gas route.[14]

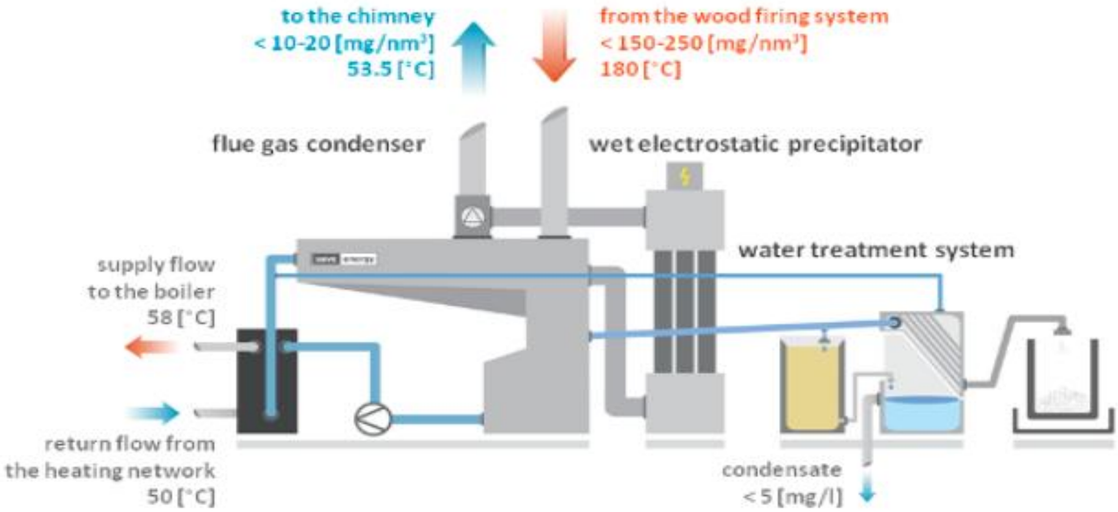


Figure 4: Flue gas condenser operation [6]

Benefits

The more additional heat we recover, the less amount of fuel we need to cover the same heat demand. This is beneficial not only by the district heating company who can purchase less amount of fuel, but also for the heat user who is charged with lower and more stable heat energy cost tariffs. Furthermore, this device reduces greenhouse gasses and dust emissions to the atmosphere, by improving air quality due to a significant reduction of particulate matter emissions (up to 90%). [1] [2] [6]

3.2.2. Steam cycle

To understand the working principle of a CHP plant, it would be wise to be explained the steam cycle. Initially, the steam is produced in a vertical, two draft water tube boiler. The boiler produces steam of 52 bars, and approximately 450°C. The boiler is automatically cleaned by steam soot blowers. Due to this high pressure soot blowing system the cleaning is very efficient, minimizing down time. To increase the efficiency, on the boiler downstream an economizer is installed with soot blowers. The steam is superheated to prevent formation of condensate droplets which can erode the turbine in the steam turbine outlet part. The higher the superheating temperature, the more efficient the steam cycle will be. The steam drives a steam turbine coupled with a generator which produces electricity. The steam from the turbine goes to the vacuum steam condenser where it is condensed by the heating circuit water. The higher the steam temperature that leaves the turbine the more heat is produced on the steam condenser. The water that leaves from the steam condenser goes to the deaerator, where O_2 and CO_2 are removed. From the deaerator, the water is pumped to the high pressure steam boiler by the feed-water pumps. Maximum electrical output is generated by the combination of high pressure steam, an efficient steam turbine and process integration. The lower the hot water temperature is the higher electrical output we gain. This can be explained by the enthalpy difference between the inlet and outlet of the turbine. By reducing the outlet temperature of the steam and the pressure need to be reduced respectively to avoid the steam condensation. This can lead us to extract as much as possible energy from the steam that passing through the turbine. With the same principle the higher heat production on the steam condenser can be explained. If during summer time the heat demand goes down, the system can be running in part load. The steam cycle route and the parts of a typical wood fired CHP plant are illustrated in the following figure.[21]

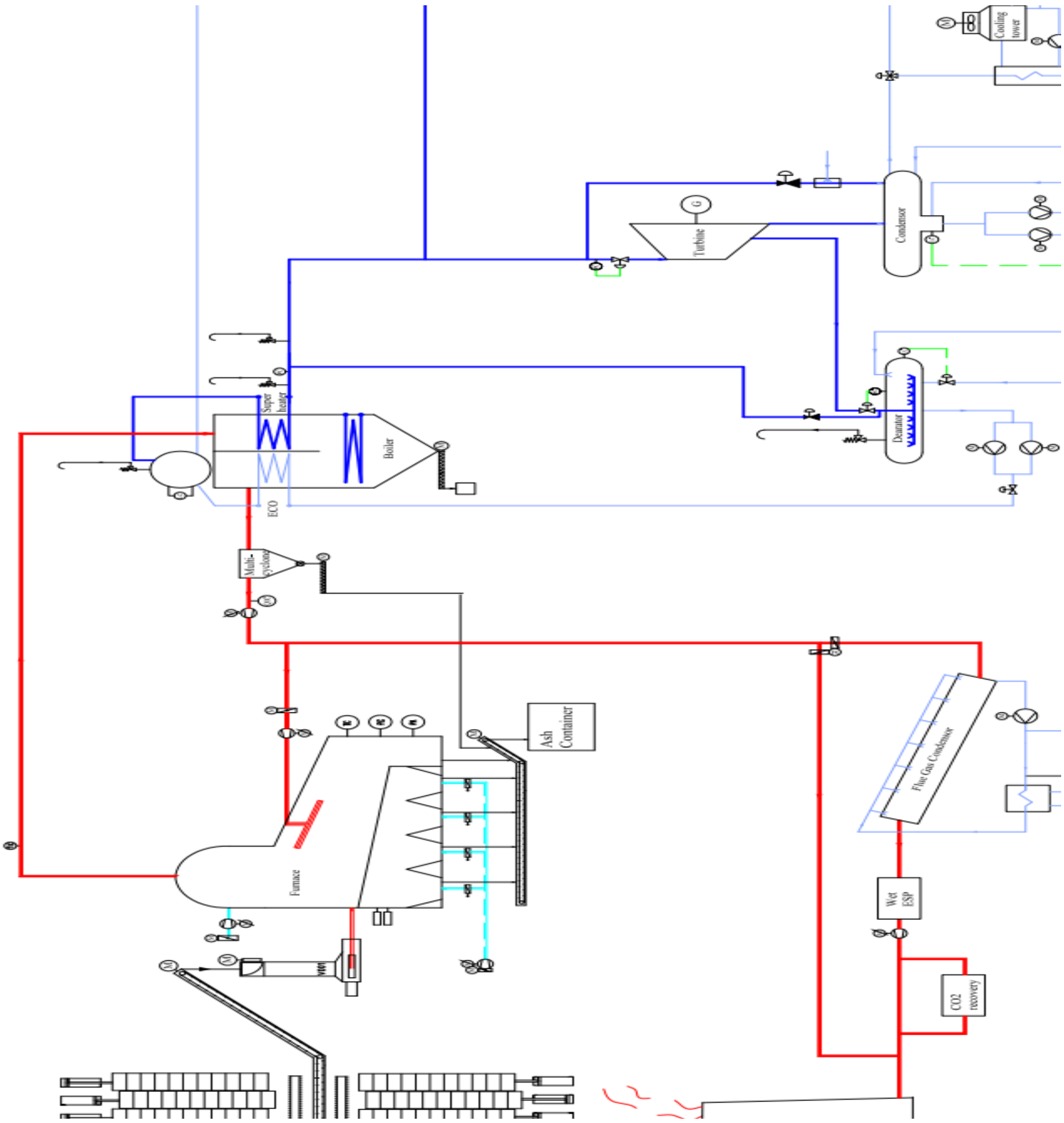


Figure 5: Typical wood fired CHP

B. FINANCIAL ANALYSIS

On the second part of the report we analyze, examine and test the feasibility and profitability of the desired projects with the help of the tool that has been constructed. The financial analysis is mainly divided in two parts, the project input and project results. The input parameters are data that the user can fill in as well as some additional data which are originated by HOST. Regarding the results parameters part, is consisted by formulas which have been used for the financial estimation of the desired project. Also a third part has been added, which includes the heat demand curve and the economic consequences by the wrong boiler size installation.

B1. Project input parameters

The following inputs have been selected for the financial project estimation. However the financial estimation has been implemented with format formulas so it can be adaptable to different countries and situations. In the APPENDIX the financial results are presented with the below data as inputs.

1.1.Cover-page parameters

Installation parameters	*Unit*	*Value*	
Types of installation	-	**CHP plant**	
Type of boiler	-	**Water tube**	
Boiler's Capacity	MWth	**5.3**	5.3
Running hours	hours/year	8000	8000
Flue gas condenser	-	**Yes**	-
Hot water temperature return	°C	35	-
Hot water temperature forward	°C	90	-
Feedstock parameters			
Feedstock type	ton or m3	**Wood chips**	**Dutch Gas**
Feedstock price	€/ton or €/m3	30	0.30
Feedsock moisture	%	45%	-
Market prices			
Price of heat sales	€/MWh	35	-
Price of steam sales	€/MWh	40	-
Electricity price buying	€/Kwh	0.10	-
Electricity price sales	€/Kwh	0.15	-
General parameters			
Interest rate	%	5.00%	-
Dicount rate (NPV)	%	5.00%	-
Inflation factor	%	2.50%	-
Taxation	%	15%	-
Loan share	%	70%	
Depreciation period	Years	10	
Mortgage term	Years	10	-

Table 2 : Input data table of the tool

- ***Installation parameters.*** Consist of information about the project (Type of installation, boiler type, boiler's capacity, running hours, flue gas condenser option) and the temperatures of hot water distribution to the city. CHP plant electrical and heat production are influenced by the hot water temperatures that district heating company provides.

- ***Feedstock parameters***. Referred to the type of feedstock (wood chip or straw) as well as natural gas option between Dutch and Russian type. And the sensitive parameters of feedstock price and moisture content.

- ***Market prices***. The CHP plant is expected to produce electrical and thermal energy in the form of steam and hot water, which can be used to displace electrical-powered heating at nearby facilities. The project assumes the maximum available thermal and electrical energy load to be serviced by the plant, which means that no excess heat and electricity is produced during the year. The market prices consist of heat, steam and electricity sales, as well as the important parameter of electricity purchase for the plant's own consumption.

- ***General parameters.*** The general parameters consist of data that influence the project's profitability during its life span. The interest rate and the loan mortgage term are two of the main parameters that have strong influence on the project's annual profit, with the user to have the option of a direct capital investment, a loan or a combination of both. The inflation factor and taxation percentage are defined to make the financial estimation reliable and more accurate during the years of use. Furthermore, depreciation has been chosen as a factor which is able to determine the installation and equipment cost reduction during the years of use.

However, besides the input data that can be replaced by the user, the tool consists by additional input data which are fixed values and cannot be influenced by him/her. These data are necessary for the financial estimation and mainly originated by HOST.
The data include: *investment cost*, *feedstock informations (LHV, mass composition wt%), electricity consumption, flue gas condenser informations, heat & electrical efficiencies.* Also, some **general parameters** such as: *Unforeseen, contingency and maintenance cost.*

B2. Project operational results

3.2. Operational cost

The operating costs are expenses that are related to the project operations. There are two categories of operational costs, fixed costs and variable cost. For the better examination and financial estimation of the possible project we assume that the operational costs are fixed, so there is no fluctuation on the feedstock, energy prices and all the parameters which can be considered as mutable during the examined years.

2..1. Feedstock cost

For the production of the demanded heat, a specific amount of feedstock required, the following formula has been used for the calculation of it.

Demand (tons/year) = Boiler's capacity (MW)/Boiler's efficiency (%) x Seconds per hour (sec)/Energy content (MJ/kg) x Running hours (hours) *(1.1)*

With the previous formula it is easy to compute the annual expenses for the wood chips or straw purchase, by multiple demands with their prices per ton. It is important to be noted that every country has different feedstock prices which is mainly depended by the availability of it and of course by the forest areas that each country is covered. The price of feedstock is one of the most sensitive and major factors that can influence the feasibility of a biomass project.

Feedstock cost (€/year) = Demand (tons/year) x Feedstock price (€) *(1.2)*

For the estimation of feedstock demand the boiler efficiency and the energy content must be estimated, the remaining parameters are known and can be filled in by the possible user.

Boiler efficiency

The feedstock specie, the moisture and the component content (Carbon, Hydrogen, Nitrogen, Sulphur and Oxygen) are the major factors that influence the boiler efficiency. More specifically, the boiler efficiency is calculated by the enthalpy of flue gas on the outlet of the furnace and the boiler's respectively.

Boiler efficiency= [1-Enthalpy of flue gas after the boiler (Kj/Kg)/Enthalpy of flue gas after the furnace (Kj/Kg) *(1.3)*

We can briefly explain that the total flue gas enthalpy for both cases can be calculated from the sum of each component enthalpy (CO_2, H_2O, O_2, N_2) on the specific outlet temperature by take into account the mass composition of every component individually (wt%).

Wood chips	Weight (%)	Straw	Weight (%)
Carbon (C)	50%	**Carbon (C)**	45.8%
Hydrogen (H_2)	5.80%	**Hydrogen (H_2)**	5.96%
Nitrogen (N_2)	1.50%	**Nitrogen (N_2)**	0.45%
Sulphur (S)	-	**Sulphur (S)**	0.16%
Oxygen (O_2)	41.66%	**Oxygen (O_2)**	40.13%
Ash	1%	**Ash**	7.10%

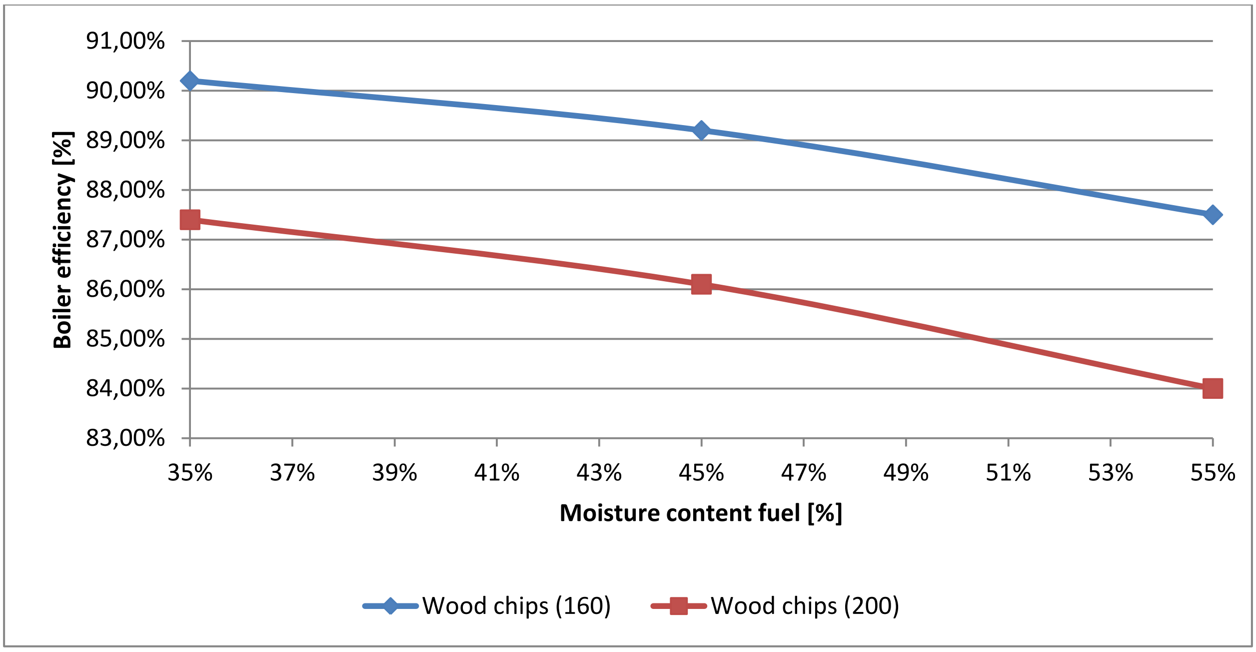
Table 3: Component content of the feedstock

For instance the flue gas weight percentage with moisture content of 45% and 10% for wood chips and straw respectively is presented in the following table.

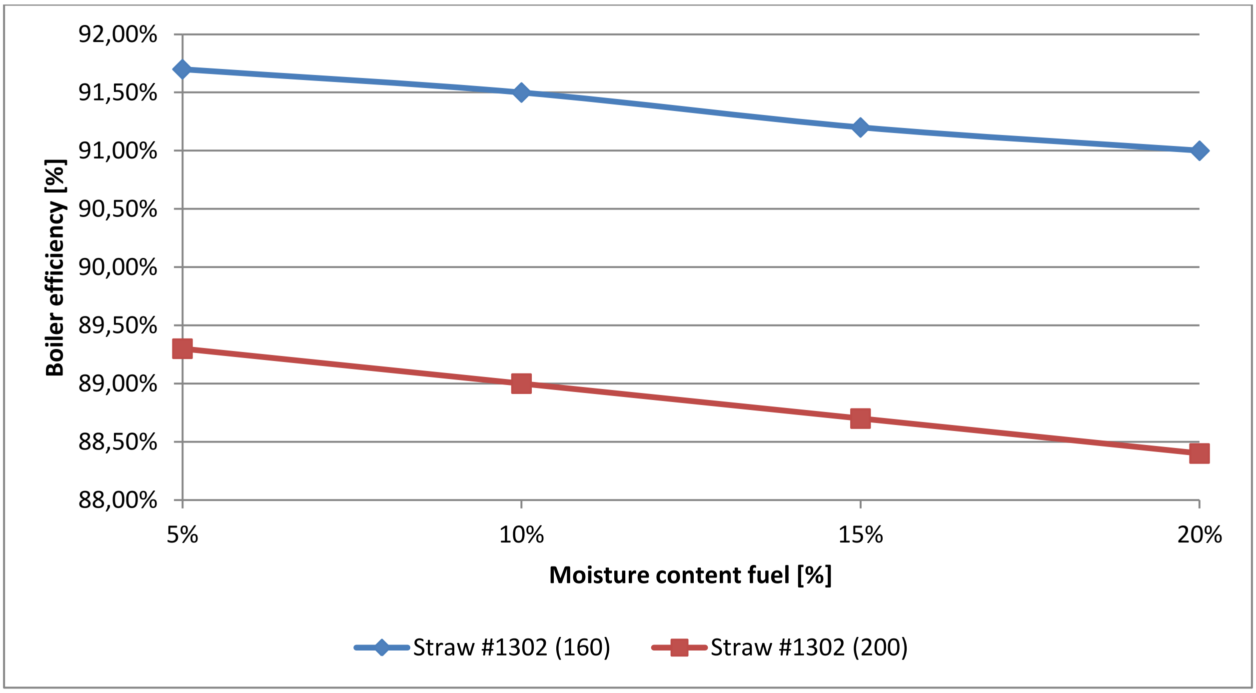
Flue gas Wood chips	Weight (%)	Flue gas straw	Weight (%)
CO2	17.51%	CO2	18.27%
H2O	10.10%	H2O	7%
O2	6.74%	O2	6.61%
N2	65.65%	N2	68.12%
	-	-	-
	-	-	-

Table 4: Component content of the flue gas

The following graph displays how the boiler's efficiency is influenced by the moisture percentage. The two graphs present the boiler efficiency for wood chips and straw combustion in the case of 160 °C and 200 °C flue gas outlet temperature. Small scale boilers (<1MW) cannot drop the temperature of hot flue gas below 200 °C resulting in lower efficiency, due to their limited volume.



Graph 1: Boiler efficiencies for wood chips combustion



Graph 2: Boiler efficiencies for straw combustion

<u>Energy content</u>

Major role on the calorific value of feedstock has the moisture content and the type of feedstock (different LHV per specie). Wood chips with LHV of 19MJ/kg (dry matter) and 0.5% ash and wheat straw with LHV of 18.5 MJ/kg (dry matter) and 7.10% ash are used for the calculations on the financial analysis part. [7]

Using an appropriate formula, it is possible to estimate the amount of energy which has been delivered for every kind of feedstock.

Energy content (%) = [LHV (MJ/Kg) x Organic dry matter content (%)]-[Energy required to dry 1kg of water (2.465 MJ/Kg) x Moisture content (%)] *(1.4)*

Organic dry matter content (%) = [100%-MC (%)] x [100%-Ash content (%)] *(1.5)*

2..2. Electricity cost

The electricity consumption is proportional to the boiler capacity and the installation type. The following table contains the KWe that correspond to each capacity.

	Units	Values			
CHP plant					
Boiler's capacity	MW	**5**	**10**	**15**	**22**
Electricity consumption	KWe	*80*	*140*	*200*	*280*
Hot water boiler					
Boiler's capacity	MW	**5**	**10**	**15**	**22**
Electricity consumption	KWe	*60*	*90*	*135*	*180*
Steam boiler					
Boiler's capacity	MW	**5**	**10**	**15**	**22**
Electricity consumption	KWe	*80*	*100*	*150*	*200*

Table 5: Electricity consumption

If the installation includes a flue gas condenser, it is necessary to add the electrical consumption of it. The following table contains the value of Kwe which correspond to each boiler's capacity.

Flue gas condenser	Units	Values					
Min boiler load	MWth	1	2	4	7	11	15
Max boiler load	MWth	2	4	7	11	15	22
Own e-consumption	KWe	***15***	***25***	***45***	***55***	***100***	***145***

Table 6: Electricity consumption of flue gas condenser

Electricity consumption (kwh/year) = Proper e-consumption (Kwe) x Running hours (h/year) *(1.6)*

Electricity cost (€/year) = Electricity consumption (kwh/year) x Electricity price purchase (€/Kwh) *(1.7)*

2..3. Additional costs

The additional costs are operating expenses which consist of, employees' salaries, cost for insurance, maintenance and possible unforeseen costs during project operation.

Employees' wages

It is assumed that the employee wage will be **75,000 €/year** and for hot water and steam boiler installations only one engineer is necessary. For the proper and stable CHP operation it is assumed that 2 engineers required.

Insurance cost

For the insurance cost estimation an insurance factor of **0.003** has been set. So for the insurance yearly payment the following formula is used.

Insurance cost (€/year) = 0.003 x Total investment (€) *(1.8)*

Installation cost

The total installation cost of the project is presented in detail on the following table. However, the amount of total investment cost is multiplied by a contingency factor **(0.05)** for the final estimation. Contingency is referred to the unexpected situations during the project installation which can cause a cost increase.

Installation cost	**Units**
Investment Turn-key cost	€
Civil works (building, pavement, fences, weighbridge, etc.)	€
Electricity Grid connection	€
Cooling tower/dry cooler	€
Utilities (telephone/internet, drink water, sewer, compressed air)	€
Other project costs	€
Flue gas condenser cost	€
Total investment	€

Table 7: Project's installation cost

Unforeseen cost

The unforeseen cost is the unpredictable situation during the project operation that can affect the total amount of operational costs. An unpredictable situation can be, from a broken heat pipe or a delay due to the feedstock supplier, to a flooding or earthquake which can affect the stable plant operation.
The 5% of total investment cost has been set as the unforeseen yearly cost.

Unforeseen cost (€/year) = 5% x operational cost (€/year) *(1.9)*

Maintenance cost

There are two types of maintenance, corrective and preventive. Both types are included in the maintenance cost and a factor of 3% has been chosen to express the cost of corrective as well as preventive maintenance. The yearly maintenance cost for every project installation is estimated as follows.

Maintenance cost (€/year) =3% x Total investment (€) (*1.10)*

To summarize, the total operational yearly expenses are estimated as follows:

Operational costs (€/year) = Feedstock cost (€/year) + Electricity cost (€/year) + Additional costs (€/year)

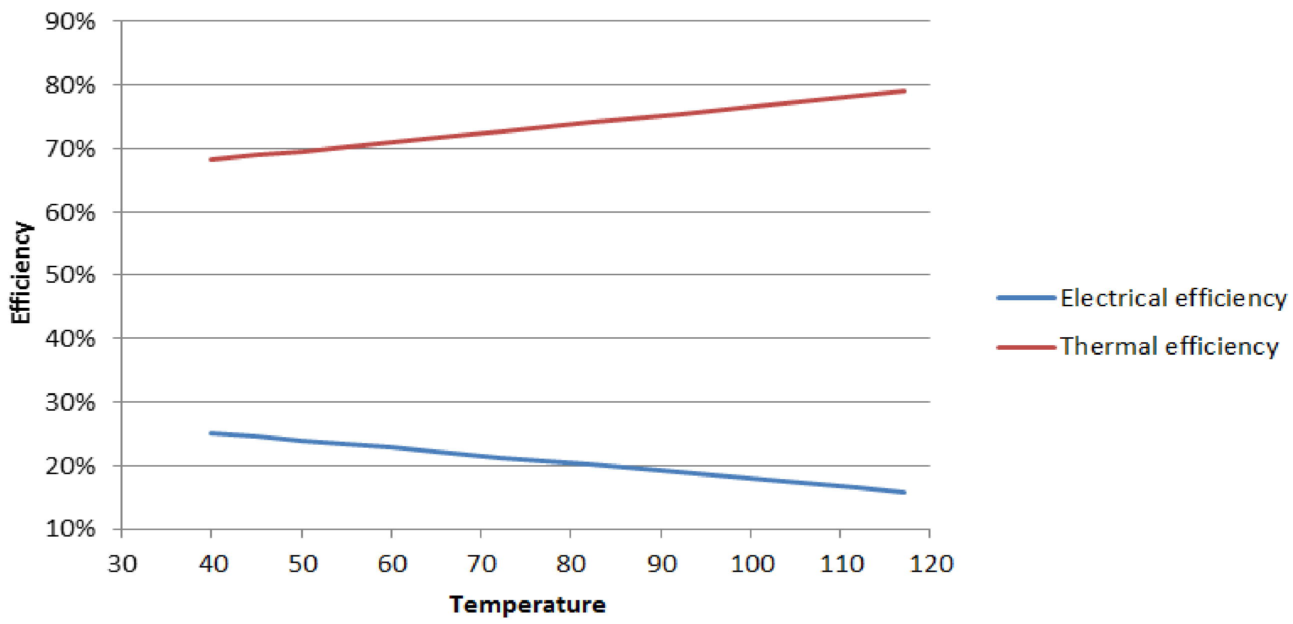
3.2. Production & sales

Every different installation project type focuses on different energy production. It is already noted that the CHP plant is expected to produce electrical and thermal energy and the remaining two installations types, hot water and steam boiler, are able to produce only thermal energy with the form of hot water or steam. The calculations of production and sales of hot water, steam, electricity have been made by taking into account that the project's overall production is distributed to the grid and there is no energy wastage. Furthermore, it should be noted that in the case of CHP plant all the amount of steam production is driven to the turbine and it is not extracted before or during the electricity production process for a different scope.

For the electrical and thermal energy production on the CHP plant project the following table is used. The table's efficiencies have been estimated based the energy input of boiler and not the furnace. The reason is that the tool receives data for the boiler's capacity and not the furnace (see inputs table), so it is necessary the thermal and generated capacity to be depended only by the boiler's capacity. The water and steam boiler efficiencies are depicted on the feedstock cost part (Graph 1 & 2). Their placement on the feedstock cost part was considered more reasonable due to the strong influence from the feedstock moisture. Also it is assumed that steam and water boiler efficiencies have the same values for the same feedstock type and moisture content.

Forward temperatures	Electrical Efficiency	Thermal efficiency
40 °C	*25.21%*	*68.22%*
50 °C	*24%*	*69.61%*
60 °C	*22.78%*	*71%*
72.2 °C	*21.29%*	*72.70%*
82.1 °C	*20.09%*	*74.08%*
92.1 °C	*18.87%*	*75.47%*
102 °C	*17.65%*	*76.86%*
112.1 °C	*16.41%*	*78.28%*
117.2 °C	*15.74%*	*79.05%*

Table 8: CHP efficiencies correspond to forward temperatures



Graph 3: CHP plant efficiencies vs Forward temperatures

1.2.1. Thermal & Electrical energy

The thermal energy can be extracted from the steam and flue gas condenser. It can be estimated by the following formulas for different project type.

Steam/Water heat production (MWh/year) = *Boiler capacity (MW) x Running hours (h/year)* *(2.1)*

CHP heat production (MWh/year) = Boiler capacity (MW) x Proper thermal efficiency (%) x Running hours (h/year) *(2.2)*

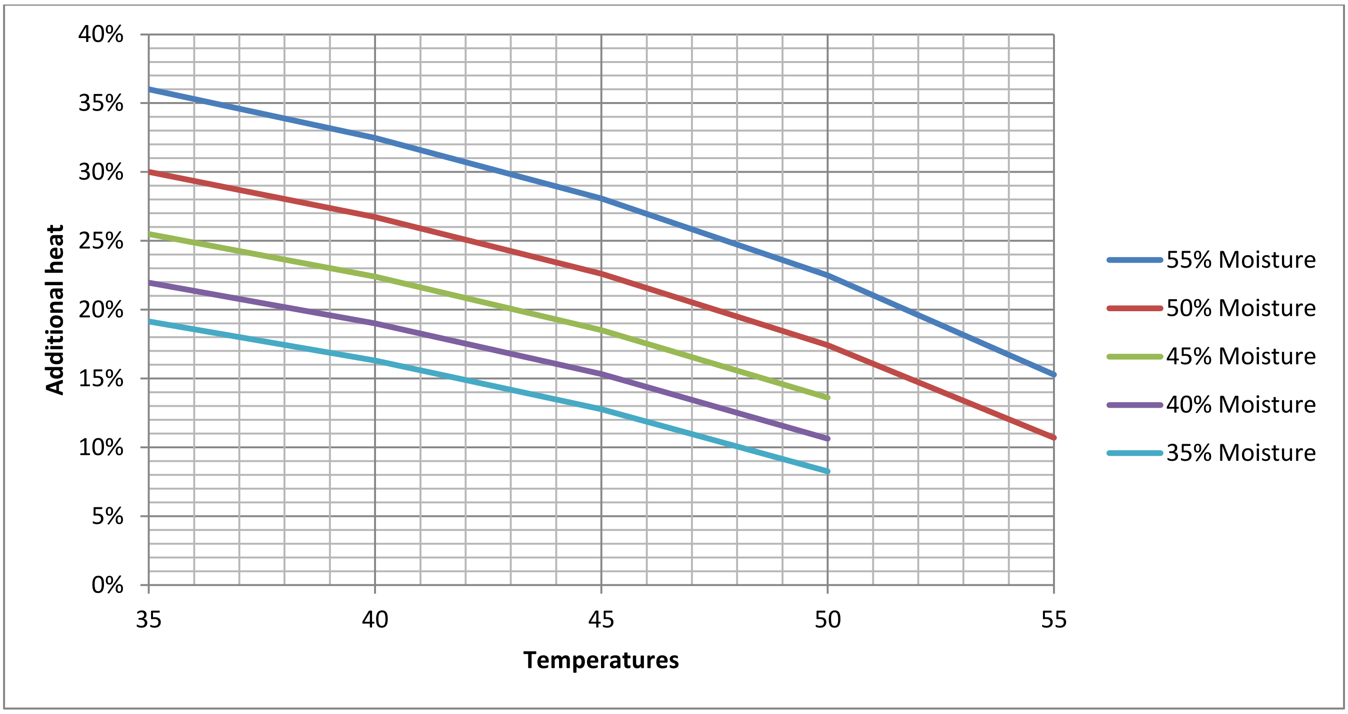
The electrical energy refers only to the option of CHP plant installation. The generated electricity can be extracted from the turbine and it can be estimated from the (table 8) and the following formulas.

Electricity production (MWh) = Boiler capacity (MW) x **Proper electrical efficiency (%)** ***x Running hours (h)*** *(2.3)*

Electricity sales (€/year) = Electricity production (MWh) x Electricity price (€/Kwh) x 1000 *(2.4)*

Additional heat

As has been referred earlier, a flue gas condenser is able to increase the additional heat production up to 35%. However the amount of additional heat production is mainly depended by the return temperature from district heating and the fuel moisture content. The following graph depicts the percentage of the additional heat that the user can receive from the device.



Graph 4: Additional heat from flue gas condenser

It is observed that the higher the moisture content the more heat we gain, resulting in lower wood chips consumption for the same heat demand. Flue gas condenser is not a beneficial option for feedstock with low moisture content as straw or husk.

So for the estimation of the additional heat by the flue gas condenser the following formula is used.

Additional heat (MWh/year) = Boiler capacity (MW) x Proper additional heat percentage (%) x Running hours (h/year) *(2.5)*

Heat/Steam sales (€/year) = Production (MWh) x Heat/Steam Price (€/MWh) (2.6)

3.2. Financial results

Financial results represent the backbone of a successful investment. The financial results contain the annually profit of the business, the payback period and all the important financial parameters of the project which can convince or deter the investor.

2..1. Loan

Most of the costly investments required a loan to cover the possible installation cost. With the help of the tool the total project investment can be covered by some part from a loan and the remaining part by direct capital from investors.

For the yearly estimation of the loan repayment, data from the input table are used, such as, mortgage term and interest rate. Return on investment calculation is based on an 11-year run of the financial model (1 year of construction and 10 years of operation).

For the loan estimation the following formulas are used:

Loan payment (€/year) = Repayments (€/year) + Interest expenses (€/year) *(2.7)*

Repayments (€/year) = Loan amount (€/year)/Mortgage term (years) *(2.8)*

Interest expenses (€/year) = Interest rate (%) x Loan balance (€/year) *(2.9)*

Loan balance (€/year) = Loan amount (€/year) - Repayments (€/year) *(2.10)*

2..2. Depreciation and Amortization

As it is already mentioned in *general parameters,* depreciation is used to determine the installation and equipment cost reduction during the years of use. The calculation relation contains the depreciation period which refers on the life span of the project and the total installation cost as follows.

Depreciation cost (€/year) = Total investment (€)/Depreciation period (years) *(2.11)*

2..3. Operating profit and Payback period

The operating profit is the net annual cash inflow of the project. The estimation of it can be made by taking the savings from energy production and subtracting the yearly operational costs.

Net cash inflow (€/year) = Total sales (€/year) – Operational cost (€/year) *(2.12)*

The Net cash flow does not include the loan repayment, so the actual annual profit from the investment is estimated as follows.

Profit (€/year) = Net cash inflow (€/year) - Loan payment (€/year) *(2.13)*

Regarding the Payback period estimation the following relation is used.

Payback period (years) = Total investment (€)/Net cash inflow (€/year) *(2.14)*

This Payback period method refers to the static Payback period and for many economists not so accurate way of calculation. For that reason some businesses modified this method by adding the time value of money to get the *discounted payback period*. They discount the cash inflows of the project by a chosen discount rate and then follow usual steps of calculating the payback period. The discounted payback period or dynamic payback period can be calculated by the Net present value (NPV).

A different way of evaluating the feasibility of the current project is with the interest rate of return (IRR). You can think of IRR as the rate of growth a project is expected to generate. While the actual rate of return that a given project ends up generating will often differ from its estimated IRR rate, a project with a substantially higher IRR value than other available options would still provide a much better chance of strong growth. Furthermore, IRR can be used to rank several prospective projects a firm is considering. Assuming all other factors are equal among the various projects, the project with the highest IRR would probably be considered the best and undertaken first.

For IRR estimation the following formula could be used:

$$\mathrm{NPV} = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} = 0$$

In which $\boldsymbol{C_n}$ is referred to the cash flow (€/year), the total number of periods ***N*** *(years)* and as ***r*** *(%)* the internal rate of return.

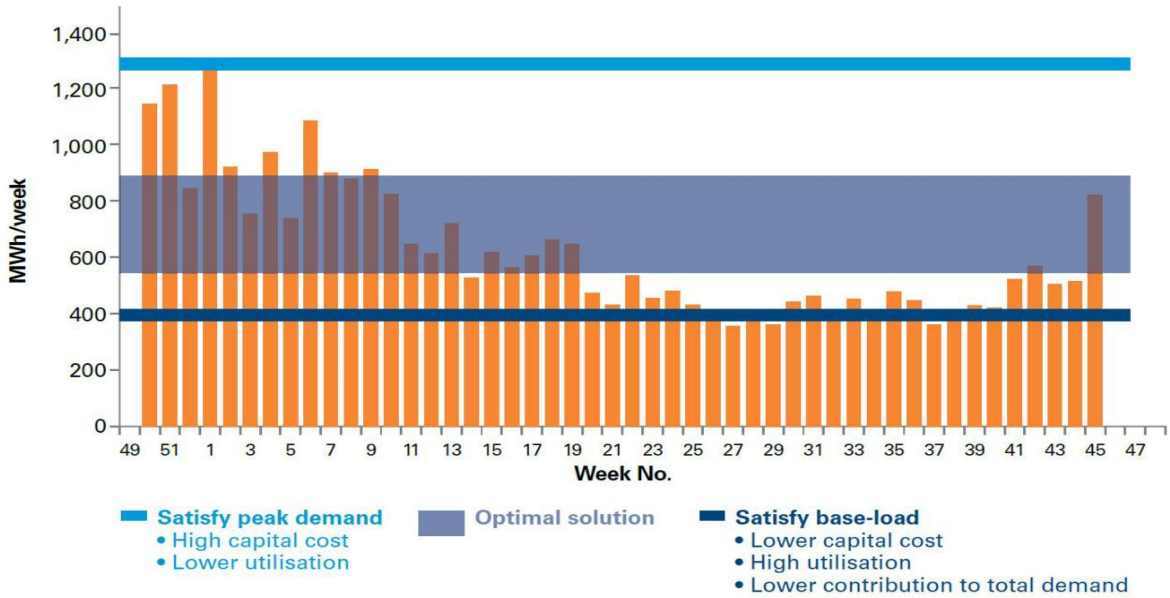
B1. Heat demand

All the previous financial estimation has been made by taking into account the ideal case that all the heat and electricity production will be distributed to the energy users. But what are the consequences if I have excess heat or electricity?

3.1. Proper sized CHP

To maximize environmental and financial benefits, CHP typically needs to be sized to the heat load of a site as this will maximize heat recovery and, therefore, overall efficiency. Any excess electricity generated can then be exported to the grid and any shortage can be imported. If the CHP plant is sized to a site's electrical load, there may be periods during the year of high electrical demand when the heat demand is low and, therefore, some heat will need to be expelled to atmosphere. This wasted heat lowers the overall efficiency of the CHP.

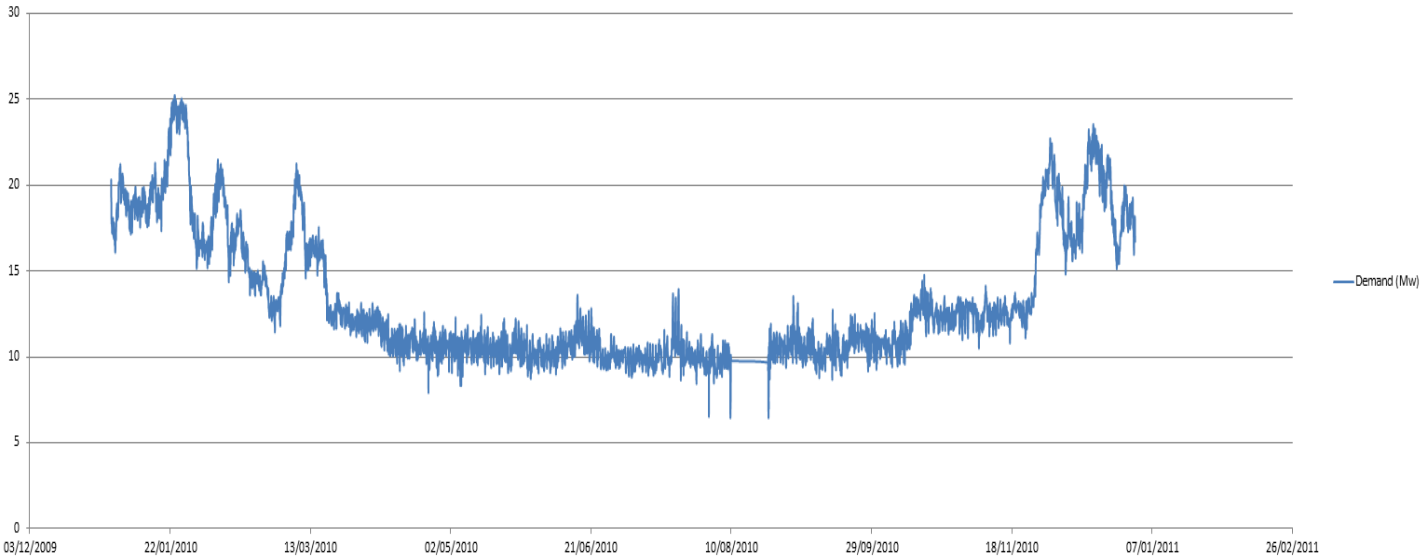
Usually, the most economically viable unit is one that is suited to the buildings/city lowest average heat demand (base-load) with the CHP acting as the lead boiler. Any further heat demand would be picked up by the secondary boilers (buffers). This standard configuration also allows the buffers to act as standby boilers when the CHP is down for maintenance. In theory, a decent CHP system will aim to use all the heat and power produced. [19]



Graph 5: Heat demand curve and optimal size CHP [20]

3.2.Heat curve approach

For the proper estimation of the CHP size it is necessary the heat demand curve during a year for the specific location which it is planned to be constructed. An accurate demand curve can be designed from the district heating company data (forward and backwards temperatures). The following graph depicts the yearly heat demand of an area with the peak demand to be 25MW on January and the baseload approximately 10MW. The straight horizontal line is created due to the fact of the summer CHP function.



Graph 6: Heat demand curve during a year

For the heat curve construction it is required the forward and backwards temperatures difference, as well as the hot water flow rate (Kg/s). For the hot water flow rate estimation it is assumed that the heat demand is 15 MW and the forward and backwards temperatures are 80 °C and 40 °C respectively. Also it is known that the specific heat of the water is 4.18 (Kj/Kg*°C).

Flow rate (Kg/s) = 15000 (Kj/s)/ {[80 (°C) – 40 (°C)] x 4.18 (Kj/Kg*°C)} = 89.71 Kg/s

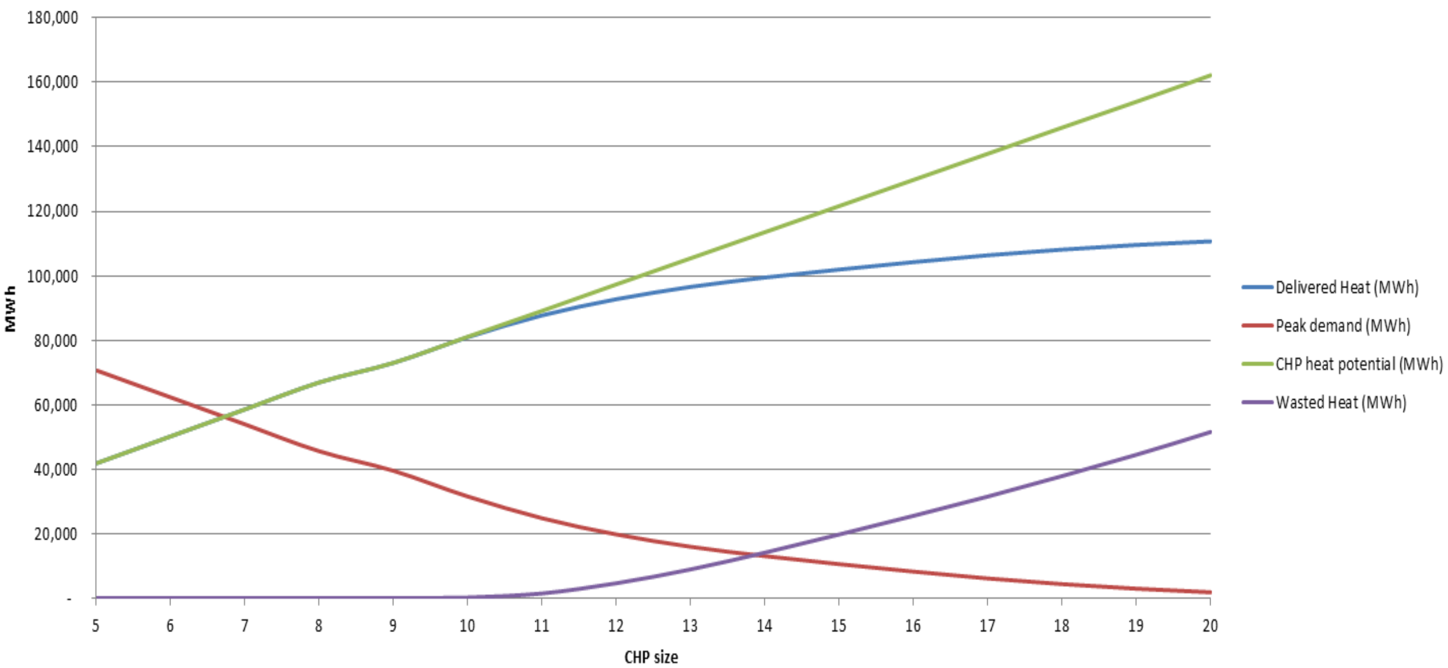
So by estimating a stable flow rate and knowing the specific heat of the water 4.18 (Kj/Kg*°C) and the temperature difference of every hour we can estimate the demanded heat (Kj/s). The following formula shows the heat demand calculation method and with it we can design the heat demand curve (Graph 6).

Demanded heat (Kj/s) = [Forward temp. (°C) – Back temp. (°C)] x 4.18 (Kj/Kg*°C) x Flow rate (Kg/s)

The heat demand curve represents the hourly demand during a year, so the total heat demand in MWh/year can be estimated. Additionally, with the help of excel and the tool we can calculate the yearly heat which is delivered from the installation. This can be made by drawing a horizontal line which corresponds to the CHP plant capacity, thus we can estimate the usable heat energy for every different CHP size.

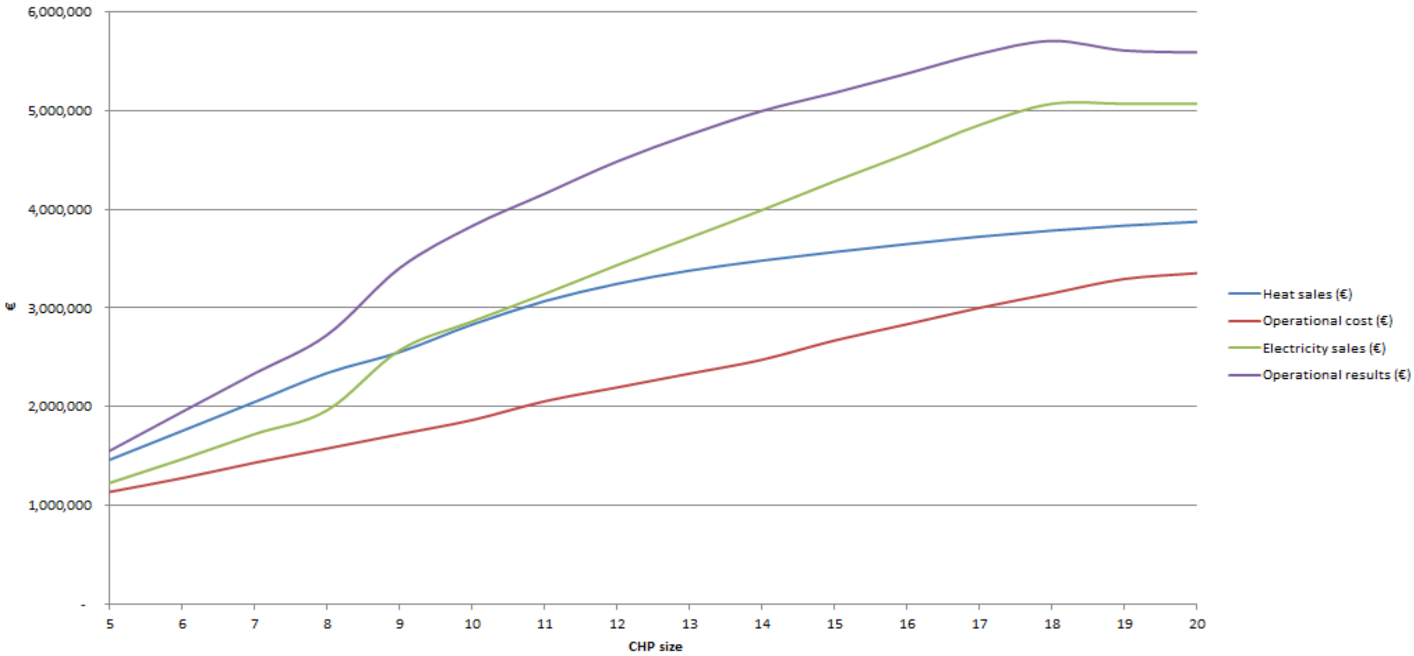
For instance we can take all the heat advantage from a boiler with size between 5MW-10MW for the specific heat curve, resulting in no losses during its function. However, a small boiler installation can be beneficial for the company's profit but cannot be beneficial to reach the actual needs. Furthermore, it is evident that a size between 20MW-25MW for this specific demand it is not the optimum solution, due to the large heat amount that is wasted. So only by the curve observation the optimum CHP size can be easily placed between 10MW-20MW.

The results with all the previous assumptions as well as the important assumption that the limit of generated electricity is 4 MW are presented in APENDIX. However, the graphical display of the results helps us to understand the behavior of every different CHP plant capacity and is illustrated in the following graphs.



Graph 7: Graphical display of the APPENDIX heat production results.

- ***Delivered heat.*** It refers to the delivered heat that corresponds to the boiler's capacity. It is the sum of the hourly heat demand of the year. We can observe that from 5MW until almost 11MW boiler the *CHP potential line* and the *Delivered heat line* are identical, which means that no excess heat is produced.
- ***Peak demand.*** It refers to the demand that cannot be covered by the installed boiler. It depends from the heat demand curve and the boiler size. The area below the *peak demand* line is the demanded heat power in MWh that cannot be covered by each different plant capacity. The larger the CHP size the lower the peak heat demand losses.
- ***CHP potential.*** It is the amount of heat that the boiler can produce for each specific size. It is estimated by the running hours and the CHP size.
- ***Wasted heat.*** It is the heat which is wasted and is apparently driven to the cooling tower. It depends from the heat demand curve and the boiler size. The wasted heat area is the area below the *wasted heat line* and is the same as the leftover area between the *CHP potential line* and the *delivered heat line*.
- ***Operational cost.*** It is estimated by the tool for every different CHP size between 5MW-20MW and it consists of *feedstock required cost, el. own consumption cost, employees' wages, insurance cost, maintenance cost, unforeseen cost.*



Graph 8: Graphical display of the APPENDIX financial results.

It is noticeable that the optimum CHP size for the specific heat demand curve can be placed at 18 MW.

Conclusion & Recommendations

To summarize, the report presents the results that are estimated by the tool use as well as the feasibility of every chosen project that HOST provides (steam/water boiler, CHP plant). It also touches and briefly explains the working principle of the possible installations as an aid to the user.
After evaluation of the financial analysis results, the tool proved that is capable for a first estimation regarding the project feasibility. However, after the initial estimation, it is necessary a further investigation from the company's engineers. These are able to provide the investor with more accurate operational and financial results by taking into account parameters that are matching on the specific installation conditions (Heat/Electricity curve).

Some recommendation and improvements regarding the tool could be:

- ***Manual feedstock.*** To give the possibility to the user to fill in and examine his own feedstock type by adjusting the (components composition, LHV, ash content etc.)

- ***Fossil fuel comparison.*** Except the natural gas comparison, different fossil fuels like coal or crude oil can be added to the tool.

- ***Fluctuation in prices***. The prices for electricity, heat, steam and feedstock are assumed to be fixed for all the running years of the project. Regarding the electricity, heat and steam prices are usually settled by contracts with fixed prices per MWh and are valid from the first operational year till the end of the project function. From the other hand the feedstock prices are changing year by year and can cause economic impacts on the project feasibility. For a proper estimation it would be wise to be assumed a raise every year on the feedstock price.

References

[1] TESTO. (2004). *Flue Gas Analysis in Industry, Practical guide for Emission and Process Measurements.*
[2] http://saveenergy.ch/products/machine-service/
[3]http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,163182&_dad=portal&_schema=PORTAL
[4] Department of Energy and Climate Change and Forestry Commission Scotland (2011). *Biomass heating: a guide to medium scale wood chip and wood pellet systems.*
[5] EPA. Combined Heat and Power Partnership (2006). Biomass CHP Catalog: *Biomass Conversion Technologies*.
[6] http://saveenergy.ch/products/
[7] https://www.ecn.nl/phyllis2/Browse/Standard/ECN-Phyllis
[8] http://en.wikipedia.org/wiki/Straw
[9] CARBON TRUST (2008). *Biomass heating-A practical guide for potential users*
[10] IRENA (2012). Renewable energy technologies: Cost analysis series.
[11] http://www.investopedia.com/terms/c/capitalexpenditure.asp
[12] http://en.wikipedia.org/wiki/Capital_expenditure
[13] http://www.myamortizationchart.com/articles/how-is-an-amortization-schedule-calculated/
[14] HOST. Quotation for 2x10 MWth wood fired hot water boiler plant with flue gas condenser.
[15] CARBON TRUST (2012). *Steam and high temperature hot water boilers.*
[16] http://www.answers.com/topic/water-tube-boiler
[17] http://www.electrical4u.com/fire-tube-boiler-operation-and-types-of-fire-tube-boiler/
[18] http://science.howstuffworks.com/transport/engines-equipment/steam2.htm
[19] CARBON TRUST (2012). *Introducing combined heat and power*
[20] http://www.growsave.co.uk/energy-saving
[21] HOST. Budget quotation for 1000 kWe wood fired combined heat and power plant.

APPENDIX

Optimum CHP size

It is referred to the heat demand curve (graph 6).

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denser (M	Flue gas condenser (I	Electricity production	Total heat output (I	Delivered Heat (I	Peak demand (I	CHP heat potential (	Wasted Heat (I	Operational cost (€)	Heat sales (€)
3.83	1.12	0.97	4.95	41,818	70,627	41,818	0	1,137,767	1,463,616
4.6	1.34	1.16	5.94	50,181	62,263	50,181	(0)	1,277,416	1,756,339
5.36	1.57	1.36	6.93	58,543	53,901	58,545	2	1,433,370	2,049,007
6.13	1.79	1.55	7.92	66,898	45,546	66,908	10	1,577,519	2,341,444
6.62	2.02	2.03	8.64	72,972	39,472	72,991	19	1,721,668	2,554,017
7.36	2.24	2.26	9.6	80,944	31,500	81,101	157	1,865,817	2,833,050
8.09	2.46	2.48	10.55	87,704	24,741	89,126	1,423	2,054,905	3,069,631
8.83	2.69	2.71	11.52	92,723	19,721	97,321	4,598	2,195,339	3,245,318
9.57	2.91	2.93	12.48	96,548	15,896	105,431	8,883	2,335,774	3,379,182
10.3	3.14	3.15	13.44	99,448	12,996	113,541	14,093	2,476,208	3,480,671
11.04	3.36	3.38	14.4	101,922	10,522	121,651	19,729	2,670,761	3,567,270
11.78	3.58	3.6	15.36	104,234	8,211	129,761	25,528	2,836,041	3,648,175
12.51	3.81	3.83	16.32	106,368	6,076	137,871	31,504	3,001,321	3,722,871
13.25	4.03	4	17.28	108,128	4,316	145,981	37,853	3,147,759	3,784,497
13.98	4.25	4	18.23	109,558	2,887	154,007	44,449	3,294,198	3,834,517
14.72	4.48	4	19.2	110,663	1,782	162,202	51,539	3,352,773	3,873,189