MSc Program
Renewable Energy in Central and Eastern Europe

What is the most promising heat concept from an investor's perspective, for a biomass CHP plant in Croatia, considering its technical and economic feasibility?

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
Dipl.-Ing. Dr. Mario Ortner

Ing. Alexander Fischer-Fürnsinn

1326873

Vienna, 15th of November 2015

Affidavit

I, **Alexander Fischer-Fürnsinn** hereby declare

1. that I am the sole author of the present Master Thesis,
   What is the most promising heat concept from an investor perspective for a biomass CHP plant in Croatia considering its technical and economic feasibility?
   124 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

Vienna, 15th of November 2015 ______________________________

Date Signature

Abstract

According to experience from the past, heat concepts for biomass combined heat and power (CHP) plants are necessary. Partially, according to valid feed-in tariff laws, already mandatory. The necessity derives from the economic side, where higher fuel input prices requires an additional income, and from the energetic side. A total efficiency of 25-35% is not state of the art any more.

The motivator for this work, to find an answer to these questions in the master thesis, was a specific project, where an evaluation of different solutions have not been conducted but a high interest about the best solution still exists. The path to come closer to the answer was decided to be from an investor's point of view and to look onto a project through his eyes. For those projects, which are obliged to have a heat concept, the availability of a feasible solution is mandatory to even be able to realize the project. Missing heat concepts could have already hindered the development or implementation in the past.

The core questions to be answered is:

a.) What is the most promising heat concept from an investor's perspective for a biomass CHP plant in Croatia, considering its technical and economic feasibility?
b.) Would the implementation of a district cooling network be feasible in Zagreb? What would be the lowest national electricity price for compressor chiller as alternative solution, to still create a breakeven of heat absorber solution?

Main driver for renewable energy projects are the political frame conditions. These framework need to be analysed first, to form the project basement. Following that, the biomass CHP project need to be described to further define the characteristic of the heat, which should be used in a next stage heat concept.

Beforehand with the investor, the heat concepts to be investigated in this master thesis, were defined. Beside fancy ones, the decision were on realistic possible projects, where also the investor would have an interest in the realization and the project fits to his portfolio.

The pre-selected solutions are:

1. Building up an own district heating system
2. Installation of pellets production plant and use the heat for biomass drying
3. Heat use for cooling networks (Tri-Generation)

To fulfil the criteria of the feed in tariff, minimum 50% efficiency must be reached. Out of the CHP project, the heat supply of 40.000 MWh/a is defined as minimum which need to be used. For each of the heat concepts, the technical solution is developed, investigated through literature research, own sources and experience, and finally summarized and described in this master thesis. To enable the comparison, an economic calculation according to NPV method is conducted. The main aim is a general comparison of the different solutions. According to the result, a detailed analyse need to be undertaken before realization.

The result of this master thesis, as most promising heat concept, the implementation of a pellet production unit next to the biomass CHP plant turned out. The development of a district heating network seems not feasible due to necessary high heat prices to pay back the huge investment costs resulting in a wide village structure. A tri-generation is not possible due to missing heat consumers in Jasenovac coming from to the consumer structure, but would be feasible in a town structure with huge cool energy consumer in a narrow area.

If an electrical driven chiller is compared with an absorption chiller, in case the installed district heating network sells also heat during heating season, the absorption variant serves better economic feasibility. Looking into a comparison of just cooling then the electrical driven solution is better and the electricity price need to be 5 times higher to reach equal feasible results of the absorption chiller.

The conclusion which can be drawn, is that a state of the art biomass CHP plant needs to have a heat concept to reach an efficiency of 50% or higher. In Eastern Europe where a district heating system does not already exist, a heat concept is difficult to realize. However, there are solutions available. For every solution, the focus should be on the affordable energy price for the population, which will offtake the material produced, or the heat supplied. The best solution of a heat concept is the production of a separate good, which is also a renewable energy carrier, easily stored and transported which is needed by Central and Western Europe and can be finally used in the country of origin itself if the demand is created.

Executive Summary

Heat concepts are of major importance due to sustainability reasons from economic and energetic point of view. Projects which are depending on feed-in tariff systems, will probably find an obligation of minimum efficiency criteria in the respective feed-in tariff laws. Finding the best solution from an investor's point of view, is the main topic for this master thesis. A specific project, which faces the problem of using the best solution for a heat concept motivated me to look deeper into this topic.

Climate change being visible to all of us, resulting in hotter summer and milder winter, are results of CO_2 emissions and the greenhouse effects, famous climatologists say. The CO_2 emissions themselves are produced from burning fossil fuel, which was captured during thousands of years, are now released within a short period of time. The EU defined as strategy against climate change, the reduction of energy demand through increasing energy efficiency and the promotion of the use of renewable energy. Interesting private investors to step into that business, stable and attractive frame conditions must be set therefore by the legislation. Hence, the EU defined different directives, which the EU member states turned into national law. The most important law for biomass co-generation plants is the law defining the feed-in tariffs. Most of the laws demanding an efficiency of 50% or higher. So does the Croatian feed-in tariff system. For a specific project in Jasenovac / Croatia where a biomass CHP project is planned, the most promising heat concept should be found.

Beforehand with the investor the heat concepts to be investigated in this master thesis, were defined. Beside fancy ones, the decision were on realistic possible projects, where also the investor would have an interest in the realization and the project fits to his portfolio.

The pre-selected solutions are:

1. Building up an own district heating system
2. Installation of pellets production plant and use the heat for biomass drying
3. Heat use for cooling networks (Tri-Generation)

To fulfil the criteria of the feed in tariff, minimum 50% efficiency must be reached. Out of the CHP project, the demand of a heat supply of 40,000 MWh/a is defined as

minimum. For each of these solutions, the technical solution is developed, investigated through literature research, own sources and experience, and finally described. To enable the comparison an economic calculation according to NPV method is conducted. The main aim is a general comparison of the different solutions. According to the result, a detailed analyse need to be undertaken.

- Building up an own district heating system

The location of the biomass CHP project is Jasenovac / Croatia. It is a small village with roughly 2,000 inhabitants. The structure of this village is widely spread with mostly individual houses. To fulfil the minimum heat demand, with a calculation of the necessary houses to be supplied, was started. This result showed, that the village does not provide enough heat consumer, hence the district heating system is necessary to be expanded to the next bigger city of Novska. Novska has similar structure then Jasenovac but is a bigger city. The design of a district heating system resulted in a heat connection of 26,400 kW and sold heat of 42,240 MWh/a. The district heating network has a distance of 38 km and will demand CAPEX of 19.9 Mio EUR. Calculating benchmarks, the solution slightly exceeds with 1.11 MWh/m the necessary 0.9 MWh/m. To ensure a feasibility for the project, a heat price of 68.5 EUR/MWh is necessary but this price is slightly higher as the households currently pay for their gas fired heat supply and double the price as the wood fired ones. This solution bears the risk to attract the heat consumer to connect to the district heating. The necessary heat price might be higher than the affordable heat price.

- Installation of pellets production plant and use the heat for biomass drying

This technical solution implies the implementation of a pellet production facility next to the CHP project. A market study showed that Europe is a pellet importer and has a lack of pellet. So it is enough space for building up new production capacities. The biomass supply for the pellet production is mainly secured through a long-term contract with the Croatian forest. Production capacity of the pellet factory is 50,000 t/a. CAPEX of 9.71 Mio EUR are calculated and high quality equipment considered to produce A1 pellets according to valid ISO norm. The achievable pellet price was set with 135 EUR/t whereby in parallel in Austria a value of 165 EUR/t can be achieved. The economic calculation presents a positive result of this heat concept.

- Heat use for cooling networks (Tri-Generation)

Cooling as energy service becoming of more importance. Warmer summer and growing wealth enabling the more frequent installation and use of cooling facilities. A calculation of necessary office and/or living space for cooling showed, that within the area of Jasenovac the heat can't be off taken. Trying to consider also the town Novska to be supplied, is not awarded with success because we know already from district heating heat solution that the economic result is not favourable. The result out of the investigation for this solution is, that in Jasenovac area the district cooling network is not feasible. Never the less this technical solution was worth to be further analysed and so the location was changed to City of Zagreb providing the necessary frame conditions. This solution based on the installation of 4 absorption chiller in an area around "Ulica Grada Vukovara" supplying office, block of flats and administration buildings. With the necessary equipment which costs 5.53 Mio EUR, gaining heat and cool energy income. The heat price was put equal the value set by Croatia's energy regulator for the already existing district heating system.

	District heating	Pellet production	Tri generation
CAPEX	19.9 Mio EUR	9.71 Mio EUR	4.72 Mio EUR
Income	2.9 Mio EUR	6.5 Mio EUR	3.29 Mio EUR
Heat price with CHP	15 EUR/MWh	15 EUR/MWh	15 EUR/MWh
OPEX	0.732 Mio EUR	5.064 Mio EUR	1.33 Mio EUR
NPV 12 years	551,907 EUR	2,000,300 EUR	12,648,274 EUR
annuity	67,646 EUR	245,173 EUR	1,550,276 EUR
Return on Invest	14.6%	67%	60%

Table 32: Summary of economic results of the heat concepts (own calculation)

The table above shows the comparison of all three results.

The best solution as heat concept on the location of Jasenovac represents the pellet production facility. It has reasonable investments costs and creates the best return on invest.

Would the comparison be in an area city character like Zagreb, the tri-generation solution could play out its advantage of best economic feasibility, when heat and cooling energy can be sold.

Comparing the electric driven and the absorption chiller solution, a calculation was made by taking the Zagreb City example. From the tri-generation solution, just the cool energy supply was considered and compared with the installation of 4 electric chiller. Through higher investment costs, the absorption solution is more attractive. To achieve equal economic feasibility, the electricity price needs to be 2 times higher. The invest has a higher weight in this calculation than the demand does, due to the low fullload hours.

Since cooling as energy service gets of more importance and unfortunately due to the expected average temperature increase, we all need to concern about energy production and energy efficiency. The energetic efficient use of energy should be our mayor goal. More development and research in high efficient cooling units should be invested. The people who are in charge of development of energy project should more forced, or better have a simple self-conception to include highest efficient solutions into our energy concepts to prevent this world from a collapse.

We have already many efficient technologies available and some will be further developed in the future. We need to use them!

Table of content

List of Tables

List of figures

List of Attachements

Abbreviation

CAPEX	Capital Expenditures
CHP	Combined heat and power plant
COP	Coefficient of Performance
EER	Energy Efficiency Ratio
ESEER	European Seasonal Energy Efficiency Ratio
HERA	Croatian Energy Regulatory Agency
HROTE	Hrvatski Operator Trzista Energiej
OPEX	Operational Expenditures
ORC	Organic Rankine Cycle
PV	Photovoltaik
RES	Renewable Energy Sources

1 Introduction

Electricity is surrounding and enabling our whole life and is unthinkable to live without. On the one hand side electricity in our human body is absolutely necessary. Everything we do is controlled and enabled by electrical signals running through our organism. Our nervous system is sending out signals to brain, brain is sending signals to the hand to act and to the heart to beat. The body uses electricity for communication to keep us alive.

Outside our bodies, electricity also gets more and more of importance. Electricity is the highest value of energy, because out of this universal technology, electricity can provide every kind of Energy Service. Starting with first experiments in electricity in the 17^{th} century of the invention of the electric light, very short after that, the start of the electrical energy carrier began. First electricity was mainly used for lighting, followed by transportation supply and now almost every part we use for work or in our households, is driven by electrical energy. So without electrical energy, live would not be possible.

If we look at Figure 1, the electrical energy demand worldwide increased dramatically in a period of 38 years. Currently fossil energy is the main source for electrical power production, covering the hungry electrical energy demand of the world.

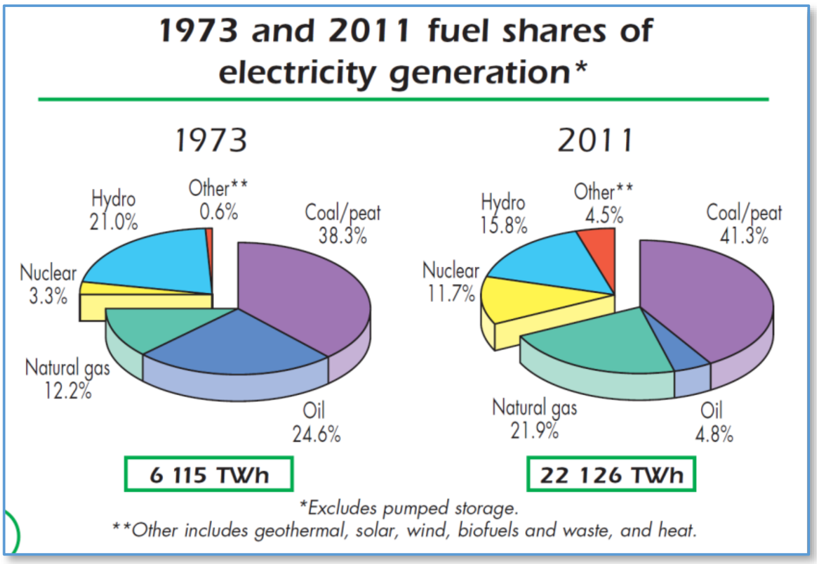


Figure 1: Worlds electrical energy generation; (source: Energy Outlook 2013[1])

[1] International Energy Agency (2013): "*Key World Energy Statistics*", International Energy Agency, 2013

Within a period of roughly 40 years, the world energy demand increased about more than 3 times up to 22 TWh/year. Whereby the world population was about 4 billion people in 1973 and has grown until 2011 to approx. 7 billion people. Hence the electrical demand per capita increased in that period from 1.53 MWh/capita up to 3.16 MWh/capita. That means **doubling the energy demand per world's inhabitant**.

The above figure is showing also, that since 1973 until the last data collection of 2011, for roughly 2/3 of the electrical production, fossil fuel serves the prime energy source. Nuclear power production increased but is now on the way back due to some countries intention of an "Energy change". But, with which energy carrier to substitute? Here renewable energy gets more importance being a reliable alternative to nuclear power.

What does an outlook into the near future of 2030 say? [2]
From the electrical energy demand perspective, we have to face an increase of 2.6% per year, so that we need to cover an electrical energy demand in 2030 of roughly 35 TWh/a. Main prime energy sources will be at that time coal, oil and gas, covering the world's energy demand. Each of these 3 main sources will have a share of 26% and hydropower, renewables and nuclear power will reach each roughly 7% of total energy production. The oil demand will increase until 2030 to about 23%, where the production from non OPEC countries will remain stable. In addition, biofuels and oil sands will cover 5% of the increase. The major rest of the oil production will be supplied by OPEC countries. In the gas sector, the main supplier will be Russia and the Near East to cover the gas demand.

When we look at that future scenario and we take the following credo into account,

"Let us do all we can, that we leave to the next generation, the today´s kids, a world which serves not just only the necessary living space, but also an environment which allows living within and makes it worth living."

(Richard von Weizsäcker (*1920) (English translation by the author))

[2] BP British Petrol (2011): "*Energy Outlook 2030, London Januar 2011*", BP, 2011

we need to rethink our current behaviour of energy use and need to look for energy concepts which are supporting the energy demand and preserving the environment and valuable resources at the same time.

From this perspective seen, some rules can be derived so that all decision makers who are developing or are involved in energy concepts, should respect following considerations: [3]

- *Securing Energy supply*
- *Covering expected increase of energy demand*
- *Reduction on foreign dependency*
- *Relief from balance of payments*
- *Increase of local added value*
- *Using existing ressources*
- *Protection of the environment*

On the other hand side we all know that fossil resources are not endlessly available, so we have to rethink our energy using behavior and go more straight in the direction of renewable energy. **We have to act now!**

1.1 Objective of this Master Thesis

From my perspective sustainable energy production and environmental protection is a global task. Due to the fact, that energy production and prices are influencing all economies around the globe and emissions are not stopping at a border of a country. If we look over the Austrian borders and traditionally orienting the view to Eastern Europe after Slovenia, Croatia joined the EU in July 2013 to connect closer to the EU policy and economy. By doing so, Croatia had to adapt its laws and regulation to common EU laws.

One big sector to be adapted along EU's regulations by Croatia, was definitely the infrastructure and energy. Here the new EU RES directive defines to increase the

[3] Fischer A.: "Nachhaltige Energiekonzepte", from lecture hand-out at University of applied science FH Campus Wien, 2015

RES-share in EU energy mix up to 20% by 2020 and set binding overall RES targets for each Member State [4].

As like all other countries in the EU and also countries intending to join the EU in short time period, National Energy Action Plans have been drafted and adjusted together with the EU to fulfill the overall EU target of 20% Renewable Energy from total energy consumption until 2020.

Enabling implementation of bioenergy projects from private investors, stable and secure conditions must be created to meet frame parameters required by financing institutions. So did the Croatian Government and decided for an incentive system which was implemented. Details will be referred to later in this document. On the other hand side according to experience of other European countries, which have already implemented similar incentive systems and gained also experience on implemented projects, added the request to their incentive systems of achieving a certain efficiency for projects using biomass as prime energy carrier. In Croatia in particular, the feed-in tariff system in the second review, requires now a minimum efficiency of 50%.

1.2 Motivation

The Croatian Government sets the target in its Energy Action Plan for the use of 84 PJ of renewable energy sources in 2020. This goal is further split in a 31.5% portion of this energy produced out of biomass which amounts to 26,46 PJ = **735 GWh/a**. Calculating with 8,000 h/a full load for a CHP plant it results in the installation capacity of 92 MWel .

Goals of Croatian Gouvernment
92.000 kWel from Biomass

Currently, in the area of biomass cogeneration, 4 power plants with a capacity of 7.74 MW have already contracts which allows them to sell green electricity to electrical utility (HERA contract) and are in operation. 23 plants with a production

[4] Resch G.: „Potentials/Economics of electricity generation from renewable energy sources“

capacity of 55.5 MWel have already signed the HERA contract but their plants are not connected to the grid or producing electrical energy yet.
Comparing the installed capacity to the target set by the Croatian government of 92 MWel, enough potential is given for the installation further biomass CHP plants to comply with the target.

Biomass CHP projects – Status Feb. 2015	
Eligible producer with HERA contract also with operation	4 plants
	7.74 MWel
Eligible producer with HERA contract but not in operation	23 plants
	55.55 MWel

Table 1: Biomass CHP projects in operation and planned (source: HERA homepage)

Compared to eg. Bulgaria and Romania, who established quite at the same time incentive systems for the electrical production out of REN, have already over-fulfilled its targets of REN production. Croatia is behind his targets or could not motivate investors to implement projects there especially in the biomass sector.

What are the main reason for it and what are the weak-points?

In my opinion, the political decisions, or political decisions which have been not taken, hindered investments in the past. However, to this topic my Master Thesis is not addressed.
A second main issue from my point of view is the use of the heat produced in co-generation plants. Current status is, depending on the country, 50-60% efficiency is mandatory to be achieved (total energy use of total fuel input). Considering electrical efficiencies related to the chosen technology of 15-35%, a heat concept for the use of heat in addition to electricity is absolutely necessary to reach the mandatory 50-60%. While in other countries like Romania or Serbia district heating systems are available, Croatia does not provide this infrastructure all over the country just partially are cities equipped with district heating systems.

If an investor decides now to step into a project of biomass CHP, which serves in Croatia definitely favourable conditions, he faces the problem to find the right heat concept to its electrical production in the case a district heating system isn't already available.

My motivation for the Master Thesis is the evaluation of the most promising heat concepts for investors who wants to install a biomass CHP in Croatia.

1.3 What is the core objective / the core question?

If we look into possible heat concepts or ask others about their ideas regarding heat energy use out of biomass CHP projects, several ideas are coming up. Some already well known and established, some are really fancy ones. To analyse them all this would overshoot the set frame of a Master Thesis. Hence, some heat concepts were predefined and the objective for the Master Thesis set to evaluate out of this predefined heat concepts

- Building up an own district heating system
- Installation of pellets production plant and use the heat for biomass drying
- Heat use for cooling networks (Tri-Generation),

the most promising one.

The evaluation will be conducted on basis of a specific biomass CHP project and will investigate the technical and economic feasibility. The environmental impact is not analysed as such, because producing energy out of biomass has a positive environmental impact per se.

The scientific questions raised and the answer given through this Master Thesis are:

a. **What is the most promising heat concept from an investor perspective for a biomass CHP plant in Croatia considering its technical and economic feasibility?**

b. **Would the implementation of a district cooling network be feasible in Zagreb. What would be the lowest national electricity price for compressor chiller as alternative solution, to still create a breakeven of heat absorber solution?**

1.4 Citation of main literature

In the biomass field Ingwald Obernberger, Professor at the Technical University in Graz, wrote several books regarding the quality, the differences of biomass and its use (Band 1: „Nutzung fester Biomasse in Verbrennungsanlagen“, dbv-Verlag, 1998) and together with A. Hammerschmid they made different investigation regarding the production of electrical energy out of biomass, its different technical possibilities and cost-benefit analysis. This is written down on „Band 4: „Dezentrale Biomasse-Kraft-Wärme-Kopplungstechnologien“, dbv-Verlag, 1999“. These information of all the books in line with this topic, were presented during several seminars, where the author of this master thesis participated.

Several basic information were gained out of the lecture of Mario Ortner during the current master course.

Further key figures regarding cooling, district cooling and future perspectives could be found and taken out of different reports and studies prepared under the lead of the European Union.

As well as the Austrian Energy Agency published a study of a cooling possibilities and technologies, taken for this master thesis.

1.5 Structure of work

The master thesis starts with background information to the market of renewable energy in Croatia, which sets the impulse for investments in that field. The main framework for a feasible implementation of renewable energy represents a solid feed-in tariff system. Hence, a chapter describes the current situation of Croatia’s incentive system promoting electrical production from renewables including also the requirement of a heat concept, finding the best heat concept from an investor’s perspective is the main topic of this current Master Thesis. The next chapter describes the biomass CHP project itself to give an overview about the technical situation and the parameter of the heat provided, which can be used in the subsequent heat concept.

Following this basics, the different heat concepts, which were previously chosen to be analyzed, are described. For each of the concept, the technical solution was investigated through literature research and own sources and experience. To fulfill the project target, specific frame conditions are required for which description a separate chapter is dedicated. This technical parameter and frame conditions are surfing the basis for the economic calculation, conducted for comparison reasons with NPV method. Finally, all economic results are compared and the best solution presented.

2 Background information

2.1 Croatia‘s Energy Market

The natural environment is the largest economic and social capital of Croatia and one of key elements of its economic development. Therefore, soon upon its constitution, Croatian Parliament adopted the Declaration on Environmental Protection in the Republic of Croatia as well as created an Action Plan.

Some of the basic goals and measures stated in the Action Plan are[5]:

1. Encouragement of energy efficient housing;
2. Reduction of fossil fuel consumption in power stations by using waste and / or landfill biogas
3. Encouragement of innovative projects that promote cleaner production, eco-efficiency, minimize energy consumption, natural resources, emissions, waste generation and overall environmental impact, etc.

For the renewable energy scene, item number 3 is of relevance: the encouragement of innovative projects that promote natural resources.

[5] Source: Croatian Ministry of Economy, National Action Plan for reneable energy sources to 2020, 2013

2.2 Croatia's Feed In Tariff system

In order to achieve the target of 20% and to make investments in the renewable energy market more attractive or even enable them, Croatia's government has established an incentive tariff system for the feed-in of electrical power into the grid generated by green electricity.

On 31st of October 2013, the Croatian Government adopted the law "Tariff System for electricity generation from renewable energy sources and cogeneration", which was further published in the official gazette and defines the following frame conditions:

The law in general divides the production in plants of sizes over 5 MW_{el} and below 5 MW_{el} production.

Plants above 5 MWel production, gets a compensation according to the reference price which is defined daily and hourly from the Croatian Market Operator HROTE (Hrvatski Operator Trzista Energiej doo) and is equal to the unique daily tariff for the supply with electricity. The respective **reference price** is published on HROTE web site (http://www.hrote.hr/default.aspx?id=261). According to the data published for June 2015 the average price was set with 257,9 KN/MWh or **34.02 EUR/MWh**[6].

The calculation itself can be found in

Attachment 1: Average price calculation for October 2015 provided by HROTE

If a plant-size is below or equal 5 MWel, the incentive price differs according to the used prime energy source like wind, solar, geothermal, biogas, hydro, or biomass.

Referring to the experience of other European countries using a feed-in tariff system, the efficient use of the renewable energy source concerns and is important. In the past, projects which have been developed, are producing just electrical power and using biomass. Here, just 20-30% of the energy included in the biomass was used and it finally turned out to be inefficient from an energy and also finally from economic point of view. So Croatian Government implemented this experience and according to Article 4, par. 7, for biomass plants, a total minimum annual plant efficiency is required with **η = 50%**, to receive the incentive price. For other efficiencies following correction coefficient applies:

[6] Exchange rate: from 16th July 2015: 1Kn=0,13189 EUR, www.oanda.com

$\eta < 45\%$ k = 0.9

$45\% < \eta < 50\%$ k = 1.0

$\eta > 50\%$ k = 1.2

The incentive price calculation will be done according following formula:

Ck= c x k

Ck……corrected incentive price

C……..incentive price

K……..correction coefficient

Incentive System 2013	
Incentive period 14 years, paid in Kuna	
Compensation is net production (gross minus own consumption)	
Electric Production > 5 MWel **Incentive price according to reference price**	
Electric Production < 5 MWel **Incentive price:**	
Typ	Price range [€c/kWh]
Hydro power plants	11.46 – 13.93
Biomass	15.63 – 16.93 *
Biogas	15.36 – 17.45
Wind power	9.4 – 9.5
Solar	20.00 – 24.87
Geothermal	15.63
Yearly price increase according to retail price index	

Table 2: Feed-In Tariff System of Croatia (2013), according to Article 5 (source: Feed-in tariff law)

In detail for biomass plants, depending on size and efficiency the feed-in tariffs according to the law are as follows:

Biomass	**C**		**K**		
plant size	kn/kWh	EURc/kWh	η< 45%	45% ≤η< 50%	≥ 50%
			0.9	1	1.2
≤ 300 kWel	1.3	0.1715	0.15435	0.1715	0.2058
300 < x ≤ 2 MWel	1.25	0.1648	0.14832	0.1648	0.19776
≥ 2 MWel	1.2	0.1582	0.14238	0.1582	0.18984

Table 3: Feed-In Tariff System for Biomass use (source: feed-in tariff law)

Feed-In Tariff
Biomass CHP Plant (for 2013)
2-5 MWel and ηk> 50%= **18.98 €c/kWh**

To be able to participate in the feed-in tariff system in Croatia, the project need to acquire the eligible producer status. This status is guaranteed by HROTE (Hrvatski Operator Trzista Energiej), the Croatian market operator, if the project provides 50% overall efficiency. So, beside the economic effect of receiving a higher electrical incentive price, a basic requirement of the project, the usage heat out of the circle to achieve beside the just electrical efficiency of approx. 25-30% the minimum required 50%, need to be achieved.

Heat concept is mandatory to achieve
ηtot > 50%

3 Description of method of approach applied

In addition to the description of item 1.5 where the structure of this current Master Thesis is mentioned, to get to best results and answers to the above defined questions, as first step a **data collection** needs to be performed. Due to the fact of reaching an electrical efficiency of 17 to 34% by available biomass CHP technologies, it will most likely be necessary to use also the produced heat out of the process. Therefore, the **heat demand** of the selected heat concepts needs to be investigated.

As next steps **available technologies** will be collected whereby the data from internet research, literature search and own available data will be brought together. From this bundled information, a technology matrix will be produced out of which the suitable technologies are selected for further analyze, in respect to their energetic and economic performance.

The **energetic** analyze of the selected technologies, the efficiency will be calculated which serves as comparison instrument in between the different technical solutions.

To compare the **economics** of the selected technologies techno-economical models are calculated for each solution according to the dynamic NPV method. The necessary basics for this calculation are collected upfront like biomass price, heat price, investment-, operation- and financing costs.

As final summary the question of point a.) can be answered comparing the results from the above gathered information.
Answering point b.), which is basically related to a variation and comparison with a electrically driven compressor chiller, can be performed after calculating this solution als well. The suitability will be analyzed through technologies available and its investment costs.

4 Documentation of data and data collection

4.1 Project Description

For conducting the analyse and developing the answers to the above defined questions, a specific project was chosen. The project itself is defined as the biggest project possible receiving a feed-in tariff according to the latest Croatia's REN-E incentive system, a 5 MW_{el} Biomass CHP power plant. As the location of the project Jasenovac is selcted. The name of the project is:

5 MWel Biomass CHP Jasenovac

4.1.1 The project location Jasenovac

The town of Jasenovac is situated approx. 145 km South-East of Zagreb / Croatia, at the very south of the province of Slavonia, directly at the border to Bosnia-Herzegovina. The location of Jasenovac has severely suffered during the war time and has therefore been classified as a governmental special development zone with special conditions and support programs for investors (reduced corporate tax for 10 years).

The CHP location is in the industrial zone of the town of Jasenovac on an approx. 1 ha land plot.

The municipal infrastructure works for the industrial zone are already completed. This includes additional road access works, extension of water supply and sewage to name the most important. The road bypassing the town, will be finished during project implementation

Figure 2: Location of Jasenovac, the project location (source: Google maps)

4.1.2 Frame parameters for the project

The project itself is defined from two sides. On the one hand side it is the electrical power which is chosen according the feed-in tariff system. Like mentioned above already, projects with a maximum size of 5 MW_{el} feed into the public grid, will receive the guaranteed feed-in tariff. Plants producing more than 5 MW_{el}, can sell its electrical energy according the reference price (see chapter 2.2). The current reference price for electricity is according to HROTE 34.02 EUR/MWh and no trend seen in the future that this price will increase. This price is not sufficient to successfully run a biomass CHP plant due to the fact that the raw material amounts to approx. 80 EUR/MWh$_{el(produced)}$ and the total OPEX approx. 110 EUR/MWh$_{el (produced)}$ (both values own calculations). When we think about using biomass and having the operational expenditures in mind, a minimum feed-in tariff of 150 EUR/MWh$_{el}$ is needed and the current reference price is not sufficient. So this parameter defines the maximum size of the biomass CHP plant with 5 MW$_{el}$ from an investor’s perspective.

Another parameter relevant for the project, is seen in the biomass source. Biomass is defined as natural grown organism. For electrical energy production, biomass from agricultural source (maize, etc.) or biomass from forests can be used. Considering the size of electrical production with 5.0 MWel power, the sourcing and logistic must be carefully considered. A biogas plant would involve hundreds of different small and medium sized farmers and would also include lots of insecurities in the absolute necessary biomass supply. Another important factor is the storage issue. Feedstock from agriculture can be harvested only one or two times a year, which increases the storage costs for the material at the plant site. Forest biomass is available from state owned forests, operated in Croatia by Hrvatske Sume, to an extent of 600,000 t/year (according to a meeting with Chairman of Hrvatske Sume, Mr. Pavlic).

The biomass demand of Jasenovac project consumes less than 10% of the whole available biomass. In addition to the state own forests, having a share of 80% of Croatia’s forests, private forest owner can also supply biomass to an important amount. So wood biomass from forests can secure a stable and constant feedstock supply for running an REN-production unit.

Considering these frame parameters, an investor will opt for a **wood biomass CHP** showing the most promising technical solution.

4.1.3 Definition of biomass used

For choosing the best suitable plant parts the characteristics of the biomass is of importance and need to be looked into more carefully.

The forest structure of Croatia[7]

Croatia has a total forest area of 2.6 Mil. ha. 78% of that area is owned by the state of Croatia, the rest of 22% is privately owned.

These forests counts 400 Mil. m3 stock of wood of which 320 Mil. m3 in public ownership and 80 Mil. m3 in ownership of private persons.

The sort of wood is split as follows:

Deciduous species		Coniferous species	
Beech *(Fagus silvatica)*	36%	Abies and spruce *(Abies sp. and Picea sp.)*	10%
Pedunculate oak (*Quercus robur)*	12%	Pine tree *(Pinus sp.)*	2%
Sessile oak *(Quercus petrea)*	10%	Other coniferous species	1%
Hornbeam *(Carpinus betulus)*	9%		
Narrowleaf Ash *(Fraxinus angustifolia)*	3%		
Other hard broadleaved species	11%		
Soft broadleaved species	6%		

Table 4: Wood species in Croatia (source: Hrvatske Sume [7])

Annual increment is approx. 10.5 Mil. m3 per year. 80% in state owned forest, 20% in private. Looking into the wood processing, state forest harvests and processes 50% of the total amount with own staff.

Chemical compounds of the used biomass:

The chemical compounds of the solid biomass can be defined according to a conducted fuel analyse as follows:

Compound		
Carbon	C	45.0%
Water content	w	41.4%
Hydrogen	H	6.2%
Nitrogen	N	0.45%
Sulphur	S	0.015%
Chlorine	Cl	<0.01%
Ash content	Ash	1.47%

Table 5: Chemical analyse of solid biomass (own sources)

[7] Hrvatske Sume, 2013, company presentation

See

Attachment 2: Biomass analyse

The heat value of the used material according to analyse

Heat value related to dry material	17.6 MJ/kg
	4.8 kWh/kg

Table 6: Heat value of the biomass (own source)

Biomass characteristics:

According to information from Hrvatske Sume, the biomass will be supplied on the basis of a biomass delivery contract as round wood on the forest road. However, the responsibility for chipping and transportation is on the investor's side of the biomass CHP plant. As chipping equipment different machinery is available. High amount of biomass, demands efficient and cost efficient chipping. For this purpose a chipper in the following category was chosen.

Figure 3: Biomass wood chipper (own source)

This mobile wood chipper produced wood chips of class **P63** according to Norm C 4005 meaning a particle size of 3,15 ≤ P ≤ 63 mm with fine particles ≤ 25%, and ≤ 6% are bigger than 100 mm.

Further, the biomass assortment and biomass specification for the specification of equipment and combustion is defined as follows:

Main classification:	Forest biomass, forest residues	
Origin:	Natural grown wood	

- Without halogen organic compounds
- Without plastic coating
- Without wood preservation agent

Dimension:	Lower Heat value = 2.0 kWh/kg	
	Water content:	max. 50%
		min. 30%
		average 40%
	Ash melting point	1.100 °C
	Weight	200-350 kg/m3
	Particle size max	P100
	Dust	max. 5%

Biomass without any hazardous contents like PVC, chlorine etc., as well as free of any foreign matter, and without any contamination of earth, sand, stones, radioactive particles, etc.

4.1.4 Definition of the different plant components

A biomass CHP plant can be divided into following main parts:

	Main part
1	Biomass feeding system
2	Energy Conversion
3	System of electrical production
4	Water-Steam Cycle
5	Cooling system
6	Air cleaning system
7	Biomass outside storage

Table 7: Parts of a biomass CHP plant (own definition)

This main construction parts will me described in detail in the following chapters.

4.1.4.1 Biomass feeding system

Main parameters:

Wood biomass	P63
Heat value	min. 2 kWh/kg
Weight	300 kg/m3
Fuelpower demand	23,500 kW

see following Balance of heat

Attachment 3: Balance of heat

With this parameters, a biomass demand of

23,500 kW / 2 kWh/kg = 11,750 kg/h = **11.8 t/h = 39.33 m3/h**

needs to be fed into the boiler constantly.

During a period of **12 h** the boiler will consume

11.75 t/h x 12 h = **141 t** or 39.33 m3/h x 12 = **472 m3**

For the feeding of the boiler a daily storage is used. Therefore a wheel loader takes the already prepared wood chips from a bigger storage next to the CHP plant and feeds the daily storage. The storage need to be filled twice a day when dimensioned for 480 m3.

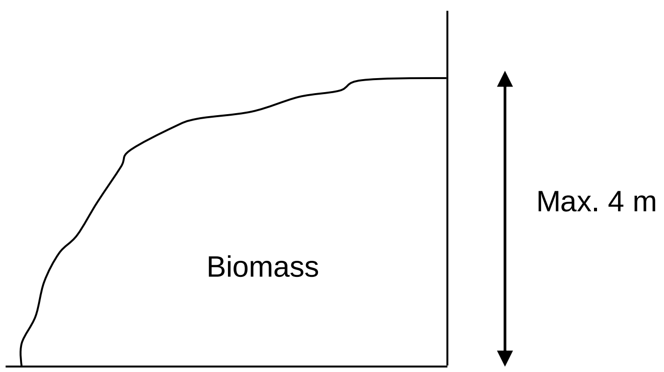


Figure 4: Daily silo dimension, side view (own source)

To enable for the wheel loader the filling from the front side, one length side of the silo is open. The back length side is closed and according to investigation on the market, the maximum height for the biomass pile is 4 m. The limits results from the maximum weight the following hydraulic conveyor can manipulate. Both small sides are also limited with walls. A standard shape of daily silo is chosen which is shown in following picture.

Figure 5: Daily silo (own source)

The chosen width of the daily silo is 8 m. So the calculation of the length is

480 m3 / 4m heigth / 6 m width = **20 m**

Considering the shape of the biomass silo after filling up the biomass by wheel loader and taking the natural dumping angle of biomass into account, just 3/4 of the rectangular shape can be used, which means that the calculated area need to be for about 1/4 bigger.

20 m x (1+0.25%) = **25 m**

For redundancy purposes, I decide for two systems in parallel, so each

13 m long and 8 m width.

The particel size of the biomass is dimensioning the biomass feeding system. For wood chips in general following conveyor systems are available on the market: (Obernberger, 1998, Band 1, p.77 Tab. 3.1)

- Blowing systems
- Screw feeding system
- Vibration coveyor
- Drag chain conveyor
- Push floor conveyors

If we analyse the biomass material carefully, although we have defined the material without stones, in practice it can happen that impurities especially sand, ice etc. is a part of the biomass. Again, from investors point of view the focus is on secure and robust feeding system which is just given with the solution of a hydraulic driven push floor and drag chain coveyor.

Main conveyor

Hydraulic driven push-bar discharge for the fuel discharge from a rectangular silo through alternating movement of the push rods that are equipped with special carriers.

Silo area	2 silos , each	13 m x 1 m
Number of connecting rods		5 pcs.
Max. dumping height approx.		4 m

Figure 6: Main conveyor (own source)

Diagonal conveyor

The main conveyor systems pushes the material from both sides in an approx. 1m lower situatied conveyor, which is designed as drag chain conveyor and transports the material to the boiler. This conveyor is driven by an electric motor.

Fire protection:

Before entering the boiler, to prevent any back-burning of the material into the daily storage, the drag chain conveyor drops the material in a vertical shaft. This shaft stores the material, flattens it for the upcoming combustion, ensures a free space between the conveying system and the stored biomass, as well as is equipped with temperature sensors, which is directly connected to a permanent sprinkler system. In case of a temperature increase detected, which can occur through fire, water floods the whole area and the fire cannot go backwards to the biomass storage.

Push-bar discharge

From the vertical shaft a hydraulic driven push-in bar with cutting device at deferral cone pushes the material to load the fuel coming from the diagonal conveyor into the combustion part of the steam boiler system.

4.1.4.2 Energy Conversion

On the market, there are different kind of technologies available to use solid biomass in a biomass CHP plant. Some of them are in an advanced stage and some just in pilot stage. As expressed already in the headline of my Master Thesis, my used criteria of decisions are from an investor's perspective. The investor has high interests in guaranteeing high security and stabile conditions on the long run from its plant. The focus is further on high efficiency and longest operation time with shortest down time of the plant, low operation costs resulting in maximizing the income, too.

Following technical solution for a thermochemical conversion are available on the market: (Ortner, Lecture, 2014)

1. Combustion
2. Gasification
3. Pyrolysis

The process of gasification and pyrolysis, used in bigger sized plants, are considered to be in a pilot stage. Some projects are available and practical experience gained. A gasification plant in a bigger size is located in Güssing/Austria and reaches around 7.000 operation hours per year, which is published on the homepage of Güssing Renewable Energy[8]. The investment costs of the plant, implemented in 2001, was 10.7 Mil. EUR at that time, the electrical power 2 MW_{el}, [9] so the unit costs amounted to 5,350 EUR/kW.

Combustion technology is a well-known kind of converting wood biomass and has already several decades of practical experience. The technology is used for plants of various sizes and lots of companies are offering good products on the Austrian and European market. So a competition is guaranteed and a reasonable price can be achieved when tendering such a project. According my experience, full load hours of 7,500 to 8,300 h/year can be achieved. The unit costs of the combustion technology are between 4,000 and 5,000 EUR/kW_{el}.

Taking operation hours reached into account, which are much higher than the full load hours, and the specific investment costs, the decision for the project Jasenovac from investor's point of view need to be the **combustion technology**.

Combustion technology can be divided further into (Ortner, Lecture, 2014):

- Grate technology
- Fluid bed combustion

Grate combustion is most frequently used. Lots of producers of grate combustion technology are available, providing a competition on the market and therefore low investment costs, long term experience is available and a wide variety of different biofuels can be burned. The combustion takes place on a walking grate in step shape. The grate provides 3 primary burning zones: 1st primary zone is biomass drying, 2nd primary zone is gasification of biomass, so producing wood gas and on the 3rd primary zone burning of the solid material (oxidation) takes place. The final combustion of the wood gas produced in the 2nd burning zone, is conducted in the secondary burning zone.

This technology can convert a wide range of biomass quality and sizes, whereby a maximum fine content (saw dust) of 20% should be provided and 20% to 60% water content can be processed.

---

[8] Source: http://www.gussingrenewable.com/htcms/de/wer-was-wie-wo-wann/wie/thermische-vergasungficfb-reaktor.html

[9] Sommer Werner; „Biomsse - Kraftwerk in Güssing", article on TU-Wien homepage, source: https://www.tuwien.ac.at/aktuelles/news_detail/article/3436/, 2002

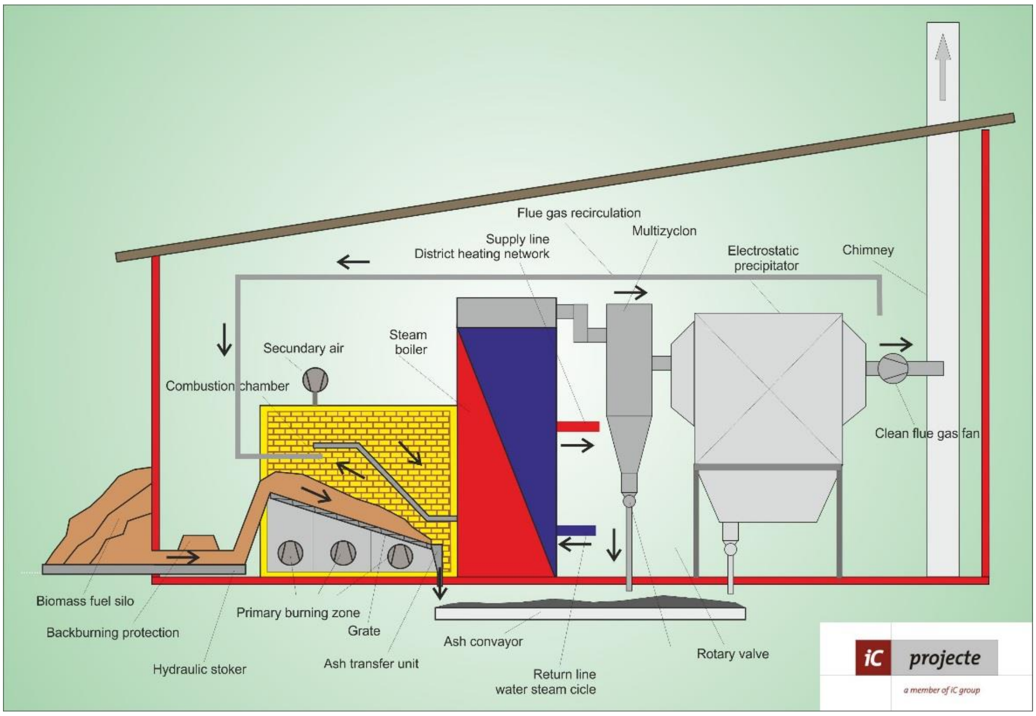


Figure 7: Scheme of grid combustion (own source)

Figure 8: Grate and combustion chamber (own source)

Fluidized bed combustion can be designed as bubbling fluidised beds or circulating fluid bed combustion. The technology was developed and started with waste incineration in the 1960th. Afterwards the technology was re-designed for biomass use. This technology is characterized through a bed material which is normally sand within biomass is mixed. This sand is responsible for transporting heat energy into the new added biomass material to enable water evaporation. A ventilator provides a pressure that the mixture "flies" in the burning chamber. In the bubbling fluid bed the material mix floats and stays in a defined area in the combustion chamber. In the circulating fluid bed combustion, the ventilator produces an airflow, which is that strong that the sand biomass mix circulates in the combustion area upstream and in a back chamber downstream. A cyclone on top of the combustion are separates the sand from the hot flue gases. The sand flows downwards, enters the combustion chamber at the bottom side and is mixed again to the biomass. The flue gases exiting the combustion and are led through the different heat exchanger.

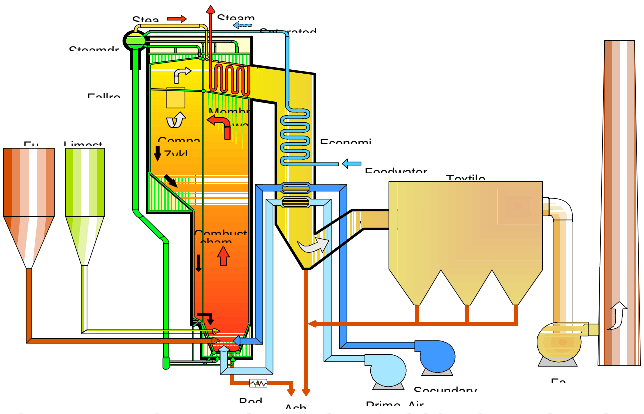


Figure 9: Scheme circulating fluid bed combustion (Source: Foster Wheeler)

These two technologies are available for combusting biomass and suitable for the biomass used and defined for this project.

Considering the investment costs of the technologies, fluid bed combustion has higher specific investment costs. A decision in favour of fluid bed combustion could be if very dry material would be used. In this case this technology would provide advantages compared to grate technology. Ensuring better economic results, the combustion technology was opted for **grate technology**.

Now, the energy which is stored in the biomass fuel, is released through a thermo-chemical conversion in the combustion chamber in thermal energy transported by hot flue gases.

4.1.4.3 System of electrical production

Logically wise at that point, the energy carrier from exhaust gas to the system of electrical production should be discussed, when we consider the energy flow. But to determine this system, we need to know which system of electrical production is used.

The following systems are available on the market (Obernberger, Band 4, 1999, Abbildung 3.1)

Anaerobe gasification, upgrading, liquefying	Thermal Gasification and gas cleaning	Combustion	
Gas engine	Fuel cell	**Steam producer**	**Thermooil producer**
Diesel engine	Gas engine	Steam turbine	ORC process
	Gas turbine	Steam poppet engine	
	Hotair turbine	Stream screw engine	
	Stirling engine		

Table 8: Systems of biomass co-generation (source: Obernberger)

As already mentioned in chapter 4.1.4.2 Energy Conversion, we decided for biomass combustion. However, for this energy production system two main option are available: a steam cycle or an ORC process using thermooil in between. Both systems can supply the requested 5 MW_{el} power. Both systems are Rankine Cycles, named according to the engineer Rankine, which describes a thermodynamic circle.

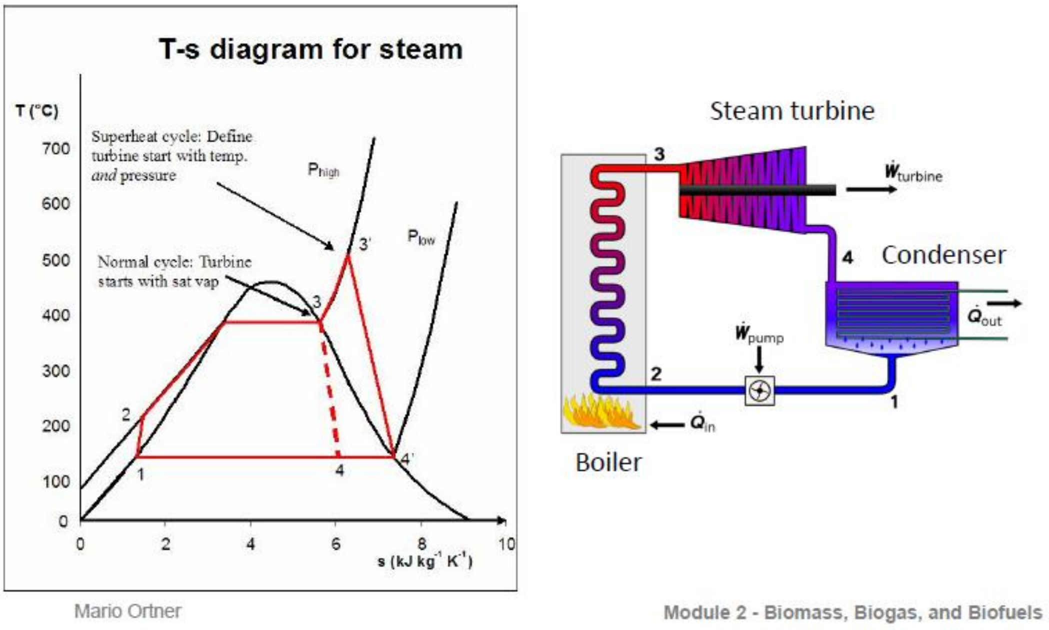


Figure 10: T-s diagram for a Rankine Cycle (Ortner, Lecture, 2014)

The figure above shows a Rankine Cycle of a steam process. Between point 1 and 2, a feedwater pump increases the pressure of the medium. Between 2 and 3 heat energy is added to the water cycle in the boiler and super heater, the steam energy is now converted in kinetic energy in the steam turbine between point 3 and 4, further transformed in the generator coupled to the turbine, to electric energy and between 4 and 1 heat energy is extracted in the condenser.

The ORC process:

The ORC process follows basically the same thermodynamic rules, but uses a synthetic oil instead of water/steam as energy carrier. Compared to a steam process the ORC process operates with two different circles , which are shown in the figure below:

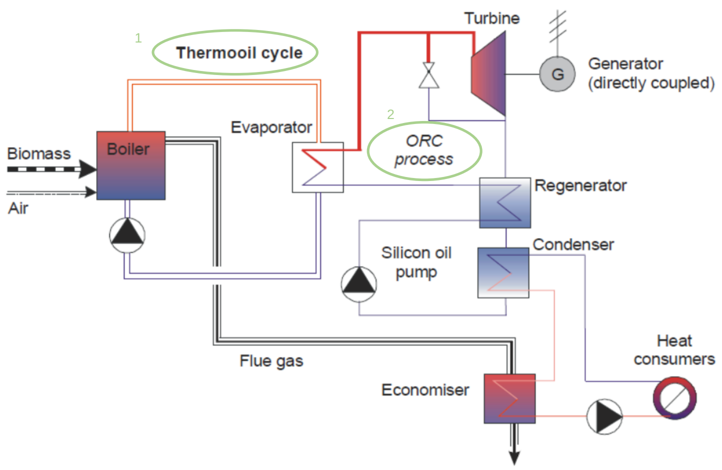


Figure 11: Working principle of the biomass fired ORC process (source: Obernberger [10])

Circle no. 1 “Thermooil cycle” is driven by thermo oil and has the characteristic being still liquid at a temperature level of 350°C. The second circle “ORC Process” is filled with another synthetic fluid eg. silocion oil and is evaporated in the evaporator which finally runs the turbine. This master thesis refrains from further details of description of the process because this would expand the frame of this work.

The most important characteristic is the efficiency of the ORC process. According to the Carnot-Efficiency which represents the quality of a process between two temperature levels, is characterized as follows: (Ortner, Lecture, 2014)

$$\eta = 1 - \frac{Tc}{Th}$$

[10] Source: Obernberger, Report ORC Admond Thermie, 2001

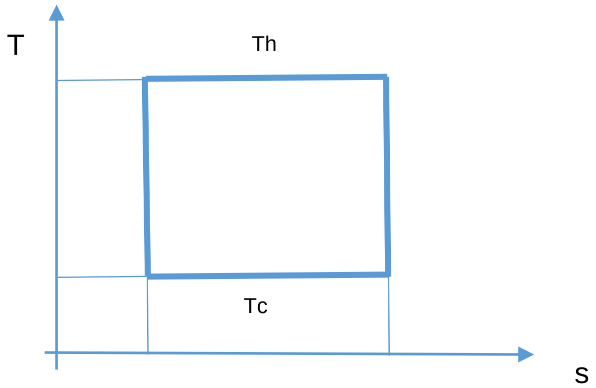


Figure 12: Carnot Process (own source)

Th….Average temperature to the cycle

Ts….Average temperature from the cycle

The thermooil boiler heats up the thermooil to 350°C which is transferred to the silicon oil circuit. In the evaporator the thermooil is cooled down to 250°C. The average temperature Th=(350+250)/2=300°C. ORC process are generally used in combination with district heating systems with a primary flow temperature of 95°C and a return flow temperature of 70°C which results in an average temperature Ts of (95+75°C)/2=85°C. With this data the Carnot Efficiency is:

$$\eta = 1 - \frac{(273 + 252)K}{(273 + 312)K} = 0{,}10$$

T_L ….. Lowest Temperature = 252°C = 525 K

T_H ….. Highest Temperature = 312°C = 585 K

Source: Turboden[11]

[11] http://www.turboden.eu/en/public/downloads/Tabella%20Data%20CHP%20with%20SPLIT%20-%20ING%20LR.pdf

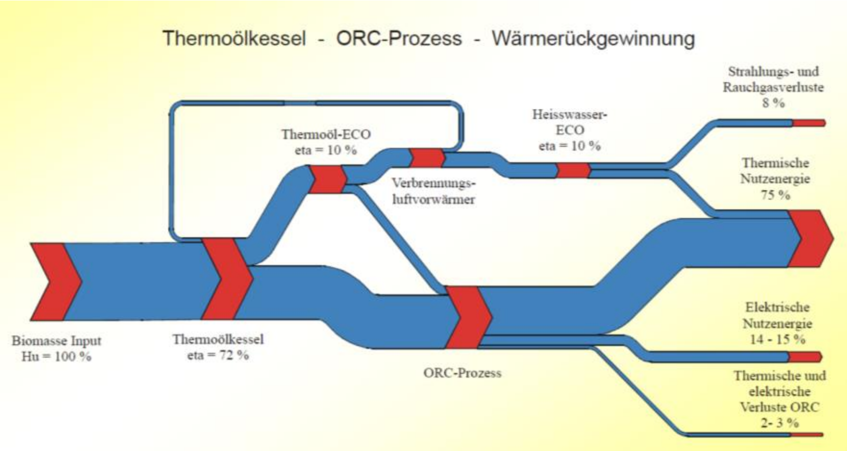


Figure 13: Efficiency flow of an ORC process (source: Obernberger [12])

If we look at the electrical efficiency, in practice around **15-17%** can be achieved.

On the other hand side, operating a thermo-oil boiler in combination with a biomass fired combustion bears a slightly operational risk. The oil used in the circle has a flashpoint of approx. 240 °C (according to safety data sheet UNIL Therm M-300 ISO-VG 32) which means in case of a leakage of the thermooil boiler, the exiting oil is flashed and can harm the combustion or the whole power plant.

Steam turbine:

The steam turbine process is currently the most popular process for electrical production. Previously this process was mainly used for direct coupling to engines to run them, nowadays mostly used in combination with a generator for electrical production (Obernberger, Band 4, 1999).

The turbine can be designed as condensing turbine. Here, the whole enthalpy-difference is used in the turbine and the steam is extracted in the turbine down below 1 bar compared to the other type of turbine construction which is the back pressure turbine. In this cycle, the steam is extracted to that enthalpy which provides in the condenser following the turbine, a certain temperature for the cooling medium (district heating water temperature eg. 95°C, etc.). Because not being in vacuum, always a higher pressure than 1 bar will exist after the turbine. Having in mind out of chapter 2.2 Croatia's Feed In Tariff system, it is requested to use also a defined

[12] Source: Obernberger I., Presentation biomass CHP ORC-EU-demonstration project, 2001

amount of heat to achieve the necessary and mandatory 50% minimum efficiency of our process, a back pressure turbine is in our case the used turbine type.

$$\eta = 1 - \frac{Tc}{Th}$$

Looking through investors eyes, achieving the highest efficiency possible is the target for the plant design. Taking the Carnot-formula into account, lower temperature level is given by the used heat concept externally and can't be adjusted. However, the single variable to increase the efficiency is the temperature on the high temperature side of the process, which provides the energy. This is the task of the boiler, which provides the steam parameters for the turbine.

The steel and material quality of the turbine are limiting here the life steam (steam inflow to turbine) temperature level. Economic feasible materials used, are allowing a maximum steam temperature of 530 °C. Using other materials in the turbine like ceramic, higher temperatures would be possible but this would also influence the investment costs and will probably decrease the economic result (Obernberger, Band 4, 1999).

$$\eta = 1 - \frac{(273 + 65)K}{(273 + 793)K} = 0{,}42$$

T_L ….. Lowest Temperature = 65°C = 338 K
T_H ….. Highest Temperature = 520°C = 793 K

	ORC-Process	Steam Turbine process
Carnot Efficiency	10%	42%
Electrical Efficiency in practice	15%	25-30%
Technology level	+	++
Remarks	Thermooil process necessary	

Table 9: Systems of electrical production matrix (source: Obernberger)

Considering the plant's operation will be full electrical production the whole year and that probably not the whole thermal energy can be used, the electrical efficiency is a main economic criteria, which an investor will focus on. Another issue for a decision

making process is the plant safety. Through hazards, happened in the past in thermooil plants, the investor opted for
a steam turbine process with 520 °C life steam temperature and 65 bar life steam pressure.

4.1.4.4 Water steam cycle

Knowing now that after the combustion the boiler need to produce steam, in general for steam production in combination with a biomass boiler, two different types of steam producer can be used:

1. Water tube boiler
2. Fire tube boiler

Water tube boiler:
These steam producer type consist after the combustion part, of vertical water tubes (water inside the pipes) which are connected to each other with finned walls. Within the tube, water which enters on the bottom of the tube, evaporates when exiting the vertical tube. The water tubes themselves are connected with collectors. All the collectors and steam pipes are bundled in the steam drum, located on the top of the boiler, where the saturated steam is collected. Condensed water in the steam drum, is led through downpipes to the bottom of the evaporation pipes enabling to evaporate again. To get to the required life steam temperatures, saturated steam is transported to the super heater, a heat exchanger located in the exhaust gas system, providing the steam parameter. A further subdivision of this steam producer type can be done into natural circulated systems and forced circulated systems. The difference of the systems is given through the kind of water circulation either through natural flow driven by gravity and pump forced system, the flow provided through pumps. Water pipe systems can provide higher steam temperatures and pressures.

Fire tube boilers:
Following the combustion in this steam boiler type, the flue gases are directed through pipes, which are surrounded by a water vessel. The hot flue gases evaporating the water and saturated steam can be extracted on the top of the vessel. Super heater are located after the boiler. The super heated steam can reach limited life steam parameters, because the flue gases are already cooled down in the water vessel. Efficient super heater are located after the combustion and before the fire tube boiler. This high temperature requires the usage of high performing

steel materials and limits the life steam temperature to 450°C, the vessel construction allows the steam pressure of max. 32 bar (Obernberger, Band 4, 1999).

	Water tube boiler	Fire tube boiler
Characteristics	Water is inside the pipes	Water vessel, exhaust gases are within the pipes
Life steam temperature	< 560 °C	< 450 °C
Life steam pressure	< 180 bar	< 32 bar
Advantage	Lower water content lead to easier star-up and regulation High temp. and pressure possible	Cheaper system Storage capacity of heat Insensitive against load changes
Disadvantage	Regulation in part load operation Expensive, storage capacity of heat	Dust exposition in the pipes Lower efficiency achievable

Table 10: Steam boiler comparison matrix (Ortner, 2014)

Comparing both types of systems and focussing on the parameters required by the high efficient turbine, a **water tube boiler** is chosen.

The necessary connections between the steam producer, the turbine, the cooling system, all heat exchanger, collection tanks etc., are made and construed according to thermodynamic needs considering temperature and pressure characteristics of the required material. It is refrained to describe the water steam cycle more in detail, because this would expand the content of this master thesis.

4.1.4.5 Cooling system

To close the Rankine cycle, which means to go from point 4 to point 1 of Figure 10 heat must be extracted from the cycle. As we already know, we have to use a part of the heat extracted sinfully to increase the electrical efficiency from approx. 30% up to min. 50%. Therefore, a heat condenser is placed in the exhaust steam part following the turbine (back pressure turbine) and extract with this plant part all the heat. According to the heat concept, which will be analysed in the chapters later on, heat on different temperature levels are needed. The temperature level of the cooling medium, or when further used, it is the heat medium for the secondary heat consumer, defines the pressure of the steam in the condenser and influences finally the electrical power of the turbine gen-set or the efficiency of the thermal conversion.

On the one hand side the operation of the plant focuses on a full time electrical operation which means minimum 8,000 h/a, which requires on the other hand side 50% of the time a heat off-taker. For the rest of the time the heat needs also to be extracted out of the cycle. Another reason for installing a cooling system are emergency measures, where in case of a breakdown of the heat user, the biomass CHP plant can fully operate without interruption.

For cooling purposes a

1. Dry cooling system and
2. Wet cooling system

can be established

Having an intense view on sustainability, I personally would step back of an installation of a wet cooling system if not enough cooling water from natural resources are available. In this specific case no cooling water out of a river which can be used, is available. Therefore, the choice is using a **dry cooling system**.

Because a water system will be used transporting the heat from condenser to the heat off-taker already, a table-top cooler system is the suitable cooling device combined with the system.

Figure 14: Table-top cooing system (own resources)

4.1.4.6 Air Cleaning System

The permission from authorities to install and operate biomass CHP in Croatia is coupled to the request, to fulfil the emission limits. Biomass plants with a power of 1-50 MW are according to law NN 21/07 obliged to fulfil the following emission limits (basis: 0°C, 1013 mbar, 13% oxygen):

Emission source	Guaranteed	EU law Directive 2001/80/EC	Croatian law
Dust	20 mg/m^3	20 mg/m^3	150 mg/m^3
CO	100 mg/m^3	100 mg/m^3	500 mg/m^3
Organic C	20 mg/m^3	50 mg/m^3	-
NO_2	200 mg/m^3	250 mg/m^3	300 mg/m^3

Table 11: Emission limits Croatia, EU and guaranteed (own source)

Referring to the Table 11 above, the currently requested emission limits from Croatian government are very high, compared to the EU ones. According to experience, it can be expected that Croatia will implement EU law within in the next years and following, all emission producers need to adjust their equipment to fulfil new regulations. Having this in mind, I would prefer already install equipment, which fulfils higher standards at the beginning results in slightly higher investment costs now, but is less cost intense if the equipment need to be fully replaced within a few years.

Looking at the emission limits, a state of the art boiler producer can guarantee to meet the emission limits if natural grown biomass is used, which is defined for the project herein (refer to 4.1.3 Definition of biomass used). This is provided through a adiabatic combustion in a primary and secondary burning zone and a O2 control. Just dust emission leaving the combustion chamber in a higher amount than allowed. So therefore technical measures need to be installed to reduce the dust emissions.

	Raw dust separation	Fine dust separation	
	Centrifugal separator	**Electro separator**	**Filter separator**
Type	Cyclone separator	Dry and wet electrostatic filter	Bag hose filter
Effect	Centrifugal force	Electrostatic force	Gas permeable membrane
Dust inlet concentration [g/Nm3]	1 – 5,000	0,1 – 1,000 (dry) 0,1 – 50 (wet)	1 – 5,000
Separation [%]	85 - 98	95 – 99.99	99,0 – 99.99
Emission achieved	Max. 150 mg/Nm^3	Min. 10-20 mg/Nm^3	Min. < 10 mg/Nm^3

Figure 15: Dust separator matrix (Ortner, 2014; Fischer, 2015)

Using Figure 15 as the basis for decision, a dry electrostatic filter is chosen. Bag hose filter would achieve higher dust reduction rates but they are not necessary. The 20 mg/Nm3 can be achieved also with the **dry electrostatic filter**. As a pre-cleaning device, a **multi-cyclone** is installed as well.

4.1.4.7 Biomass Outside storage

Considering the profitability of biomass CHP plant, the achieved full load hours are the most important driver. Investment related to its depreciation time, is of minor importance. For a secure and constant operation of the biomass co-generation plant with the goal of highest full load hours possible, high quality plant parts need to be used and some pumps or key equipment need to be installed with redundancy. These measures should be taken from the technical point of view.

Another important factor for a constant operation is the **continuous biomass fuel supply** to the boiler. According to the operation experience, break down of chipping or transportation equipment can influence this constant biomass supply, further restriction in transportation during weekends or holidays lead to necessity of a biomass stock on site.

Using 23,500 kW biomass combustion with a minimum heat value of 2 MWh/t or maximum heat value of 5 MWh/t lead to an average of 3.5 MWh/t and 23.5 MW/h / 3.5 MWh/t = 6.7 t/h, in 24h = 6.7 t/h x 24 h = 161 t/d which means 1,127 t per calendar week.

Figure 16: Biomass transporter (source: Riegler)

Weight of trailer:	9,150 kg (source: company Riegler)
Weight of truck:	9,600 kg
Net weight:	18,750 kg
Max. weight:	40,000 kg
Max. weight biomass:	**21,250 kg ≈ 21,000 kg**

Taken into account, that truck transport and biomass works are just performed during 5 working days, this result further in necessary deliveries of around **11 truck transports per day** or **54 truck transports per week**.

As per biomass definition above, the specific weight of the material is 200-350 kg/m3 (≈ 275 kg/m3). To have biomass demand of one week on stock, a space of 1,127 t/week / 0.275 t/m3 = 4,098 m3 / 4 m pile height x 3 (natural dumping angel) = **3,074 m2** is needed.
Taken all these considerations into account and designing the power plant accordingly, the layout of a 5.5 MWel biomass CHP plant will result thereof which is shown in figure

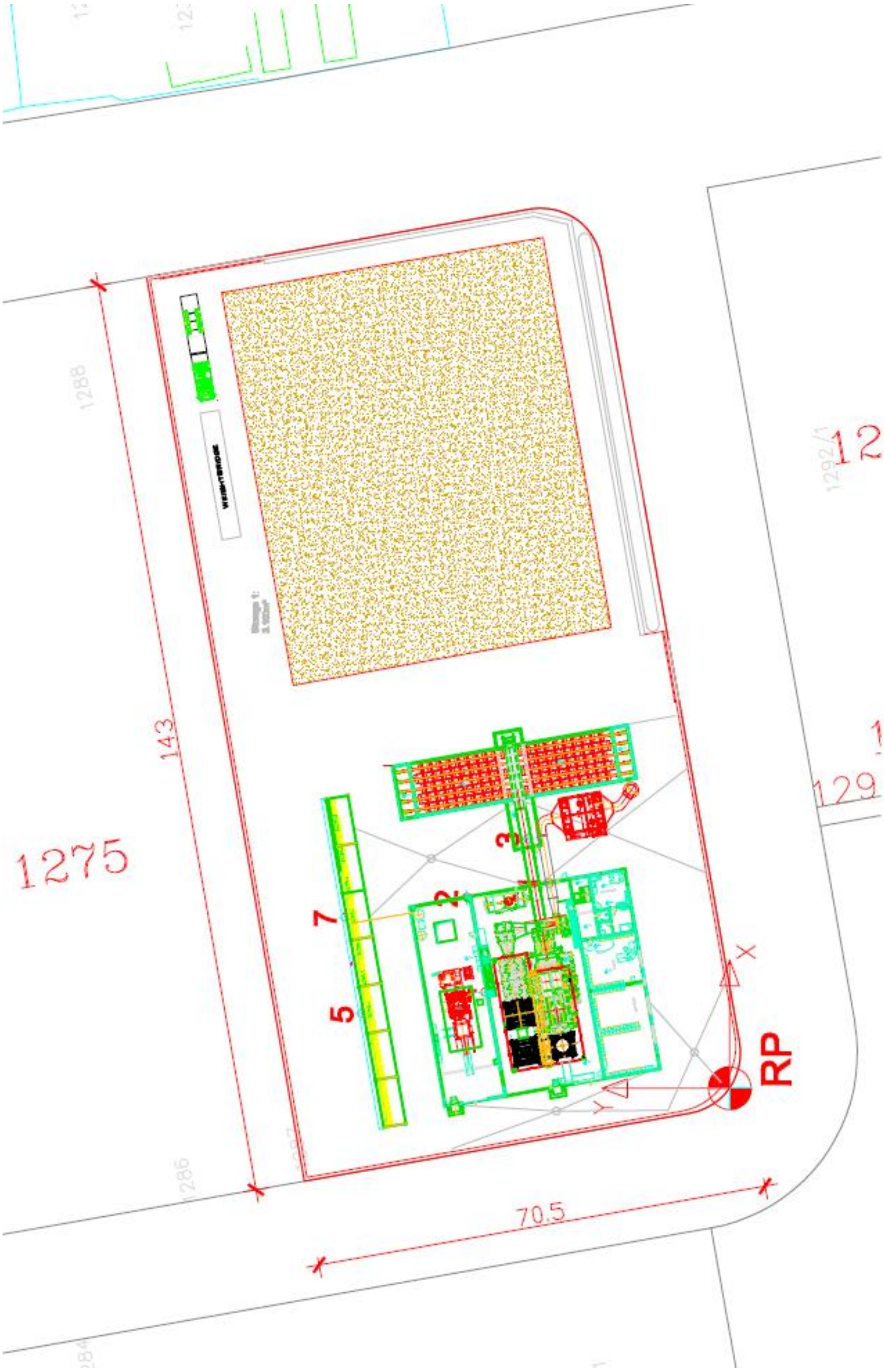


Figure 17: Layout 5.5 MWel Biomass CHP [13]

[13] Source: iC projecte design, 2014

4.2 Heat concept

Chapter 4.1 was dedicated the brief project description of the biomass CHP project. All these factors above are important to define the right and necessary heat concept.

A small side step should be allowed to think about the heat concepts in combination with a biomass CHP plant in general. Main goal of all feed-in tariff systems is the promotion of renewable energy, furthermore in my opinion even necessary to enable the implementation of such plants. Realistically, if the production costs of electrical energy produced out of renewable sources are considered, which I found in a study from Fraunhofer institute shows, that the electrical production costs, covering all investment and operation costs are higher than the current market price of electrical energy.

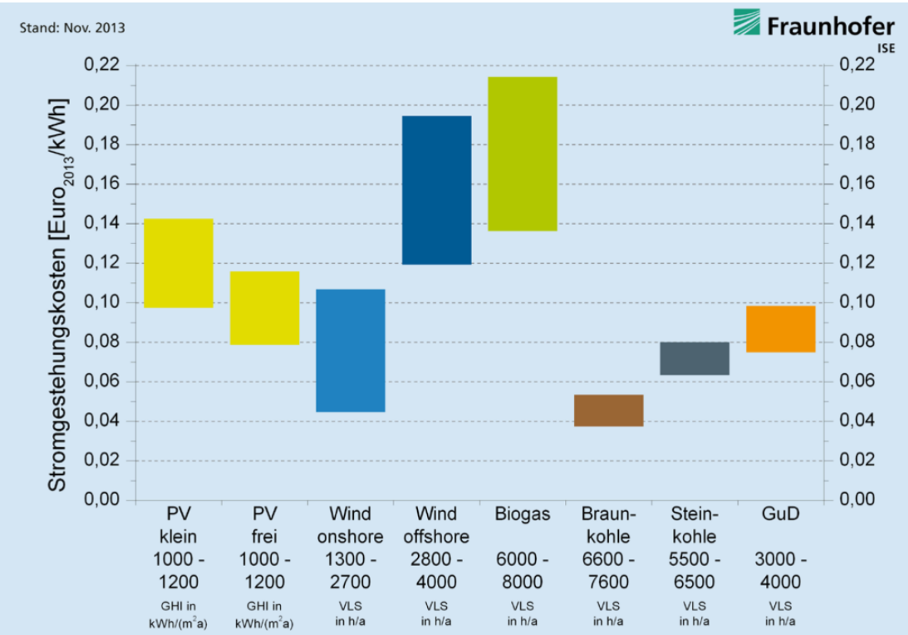


Figure 18: Graph comparison of different costs for ele. produced from RES[14]

In the figure above, biogas is mentioned but I define it equal to biomass, which I am talking about in this master thesis. This means electrical energy produced out of biomass, considering investment costs of 3,000 to 5,000 EUR/kW and no heat use, result in specific costs for electrical energy produced

0.135 EUR/kWh to 0.215 EUR/kWh.

[14] Kost, Mayer, Thomsen, Harmann, Senkpiel, Philpps, Nold, Lude, Schlegl, Studie, „Stromgestehungskosten Erneuerbare Energien“, Frauenhoferinstitut für Solarenergie ISE, 2013,

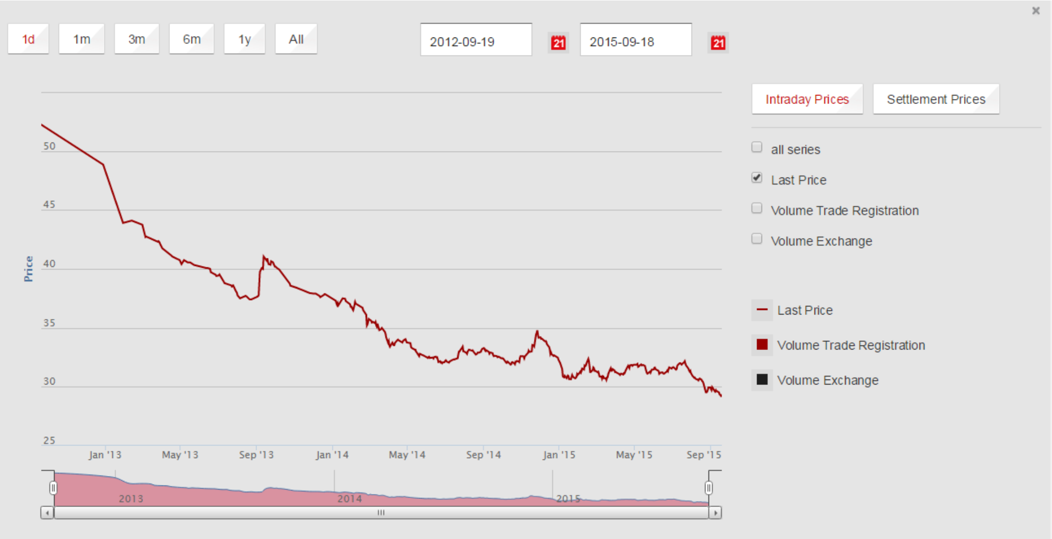


Figure 19: EEX trend curve (Phelix Base Year Future)

Compared hereto, the electrical energy market price is on the one hand by trend declining. As an example Figure 19 shows the trend curve of the Phelix Base Year Future electrical market price taken from EEX exchange on 19.09.2015 and is now approx. at a level of 29 EUR/MWh = 0.029 EUR/kWh. So, a subvention of renewable energy is necessary to even enable the installation of renewable energy production plants or in other words: Electrical energy is currently too cheap!

Following the discussions around climate change and CO_2, the legislator in the Europen Union countries established feed-in tariff laws. Just taking Austria's laws as an example, the first feed-in tariff was granted to projects depending on its electrical power. This led to the implementation of biomass CHP's production facilities either in biomass or biogas plants, just producing electrical energy and not using the remaining thermal energy. Hence, efficiencies of around 30% (Ortner, 2014) in steam turbines were reached. On the other hand side 70% of the energy content of the biomass will be released to the atmosphere. This is from my perspective an energetic nonsense.

But in practice, these concepts worked out until the biomass market regulated itself and the huge number of biomass plants did let increase the biomass price much more then expected in their business plans. Now, lot of biomass CHP plants without heat concept are in financial trouble and will not be able to operate any more, if they ran out of the feed-in tariff which was guaranteed the plant for 12-14 years. Because already the biomass prime reaches:

90 EUR/atrot x 5 MWh/atrot = 18 EUR/MWh$_{fuelinput}$

Efficiency 30% -> For 1 MWh_{el} – 3.3 $MWh_{fuelinput}$ needed

18 EUR/ $MWh_{fuelinput}$ x 3.3 $MWh_{fuelinput/}MW_{hel\ =}$ **54 EUR/MWh_{el} Fuel costs**

exceeds the market price of 29 EUR/MWh_{el} (see above) by far.

However, the actual legislation of feed-in tariffs requests a minimum efficiency. Even so in the Croatian feed-in tariff law with a minimum of 50%. The following chapters,. a comparison of different heat concepts are investigated and compared together which of these preselected solutions would be, from investor's perspective, the most promising one.

The annual efficiency of 50% means the following heat supply:

23.5 MW	fuel energy demand
8,000 h/a	planned full load hours
188,000 MWh/a	annually fuel energy demand on biomass (=Q_{fuel})

The plant itself produces 5.5 MW_{el} power

5.5 MW_{el}	electrical power production
8,000 h/a	planned full load hours
44,000 MWh_{el}	annual electrical production (=Q_{el})

$$\eta = \frac{Q_{el} + Q_{th}}{Q_{fuel}} \geq 50\%$$

$$Q_{th} = 0{,}5\ x\ Q_{fuel\,-}\ Q_{el} = 0.5\ x\ 188{,}000\frac{MWh}{a} - 44{,}000\frac{MWh}{a} = \mathbf{50{,}000}\frac{\boldsymbol{MWh}}{\boldsymbol{a}}$$

What is given by the project itself already, is a heat consumer existing on the neighbouring land plot who consumes already the following heat:

- 5 MWth
- 10,000 MWh/a

The heat concept need to grant a minimum heat energy demand of
50,000 MWh/a – 10,000 MWh/a = **40,000 MWh/a**

The following solutions are subject to further and detailed analysis:
the most promising one.

Heat concepts
1. Building up an own district heating system
2. Installation of pellets production plant and use the heat for biomass drying
3. Heat use for cooling networks (Tri-Generation)

Table 12: Possible heat concepts (own source)

For the heat concepts above the structure of analysis is as follows:

- Description of technical solution each concept
- Evaluation of necessary frame conditions for concept implementation
- Economic Calculation

Which will finally lead to the answer of the scientific questions raised, given through this Master Thesis:

a. **What is the most promising heat concept from an investor perspective for a biomass CHP plant in Croatia considering its technical and economic feasibility?**

b. **Would the implementation of a district cooling network be feasible in Zagreb. What would be the lowest national electricity price for compressor chiller as alternative solution, to still create a breakeven of heat absorber solution?**

4.2.1 Heat Concept: Building up an own district heating system

4.2.1.1 Technical solution of district heating system

Usually district heating networks are supplied with 95°C ex heating plant. Old in-house heat installations are designed for primary flow 90°C and return flow of 70°C. The new installations using floor or wall heating need much lower temperatures of approx. 35-45°C. Finding in Jasenovac old structures requires the plant design for 95°C.

The technical solution for achieving this characteristics is the use of an **extraction condensing turbine**. Depending on the heat parameters, in our case 95°C, the turbine has a regulated extraction in which at a calculated point, steam is taken out of a turbine stage which provided its energy to the turbine until that point, and fed into a steam-water heat exchanger. The steam is condensed for using also the condensing energy therein and further collected in the central condensate tank.

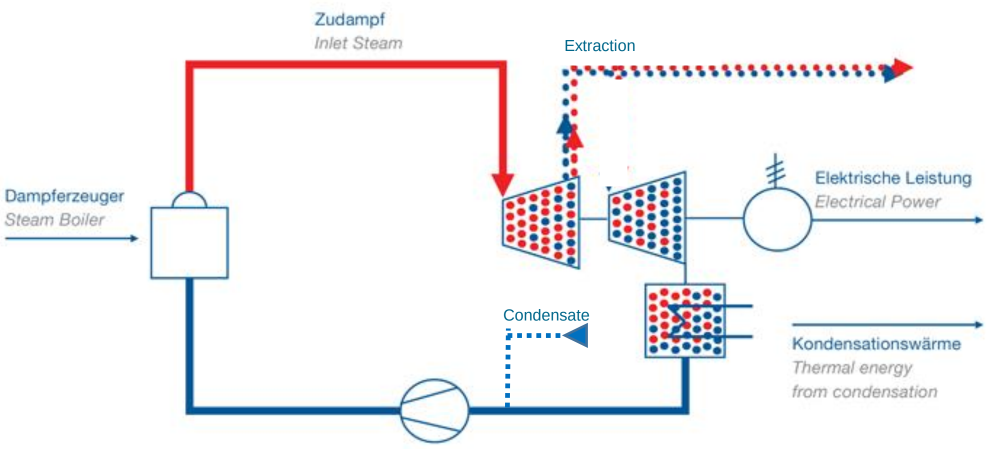


Figure 20: Scheme of Extraction condensing turbine process **(Source: M+M Turbinentechnik)**

A district heating pump circulates the heat from the heat exchanger through the district heating pipes to the different heat consumer.

The pipe system used, is a pre-insulated steel pipe consisting of the medium pipe made of steel, the PU-foam insulation with leakage detection system and a PE-coat at the end. This system is rather stiff and the steel pipes need to be welded together. At the connection points, collars are mounted. The remaining area is further filled with PU-foam on site and the heat insulation secured. Before that, the leakage detection of the pipes are connected.

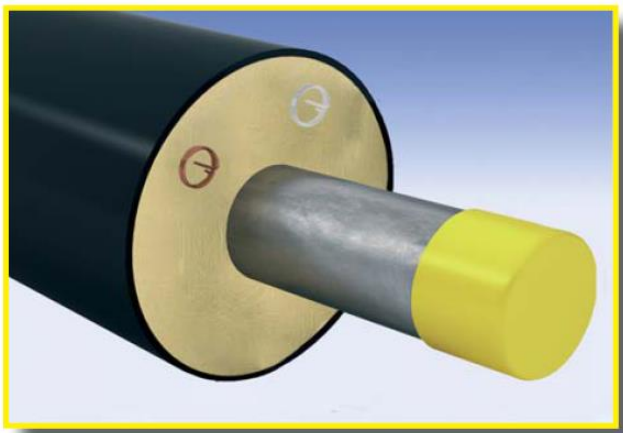


Figure 21: district heating pipe system (source: Isoplus)

4.2.1.2 Evaluation of necessary frame conditions for implementation

As described above, this heat concept must ensure a heat off-take of 40,000 MWh/a. To calculate roughly how many heat consumers that means, taking usual 1.600 full load hours into account, this means 25 MW_{th} heat consumers. Estimating further and average of 10 kW/household would this result in 2,500 households.

The village Jasenovac, where the project will be implemented, has in total 1.997 inhabitants (2011) [15]. With an average of 3 persons per household assumed, in Jasenovac 665 households are available to be connected to the district heating system. No further industry is located there, which could be acquired as heat consumer. The next bigger town in that area is Novska. With its 13,518 inhabitants, a potential of 4,506 households is provided. This means for this solution the thermal connection of the two cities is necessary. The distance between Jasenovac and Novska is 10.5 km which would mean low heat connection on this path.

The max. dimension of the district heating can be calculated like follows:

$$P = \dot{m} \; x \; cp \; x \; \Delta t$$

$$\dot{m} = \frac{P}{cp \; x \; \Delta t} = \frac{26{,}700 \; kJ.kg.K}{4.2 \; kJ.s \; x \; 30K} = 211.9 \frac{kg}{s}$$

$$\dot{V} = \frac{\dot{m}}{\sigma} = \frac{211.9 \frac{kg}{s}}{1{,}000 \frac{kg}{m3}} = 0.2119 \frac{m3}{s} = 762.84 \frac{m3}{h}$$

$$\dot{V} = A \; x \; v$$

$$A = \frac{\dot{V}}{v} = \frac{0.2119 \frac{m3}{s}}{1.5 \frac{m}{s}} = 0.1412 \; m2$$

$$A = \frac{d^2 x \; \pi}{4}$$

$$d = \sqrt{\frac{4 \; x \; A}{\pi}} = \sqrt{\frac{4x0.1412m2}{\pi}} = 0.424m \rightarrow \boldsymbol{DN\ 450}$$

dt = 30 K which reflects the optimum temperature difference in district heating systems

[15] Source: de.wikipedia.org/wiki/Jasenovac, viewed 19.09.2015

Density of water = 1,000 kg/m3

V=1.5 m/s is the design velocity for dimensioning of district heating systems[16]

The exact dimensioning of the district heating system will request a detailed investigation of each household, visiting each building and filling out a questionnaire about the existing heating system, annually demand of primary energy carrier (oil, wood, etc.) estimation of square meters heated, actual quality of windows and insulation of the house. Following to this information, the data are collected in a data base. The annual demand given, is multiplied with the heat value of the respective prime energy carrier. This leads to the heat demand of the house. To prevent mistakes in data collection or accuracy of information, this demand will be compared with the result of multiplying the heated space of the house with benchmarks of specific heat demand. In this area and with not realized heat insulation yet, the expected specific heat demand is from 360 to 440 kWh/m2.a. In case of a deviation between the energy demands, a further clarification will be conducted. The demands will be, in a next step, fed into a calculation program working in parallel with a design application for district heating piping.
Following this procedure for this project, it would exceed the master thesis.

To get data for further calculation, I decided to work with average data gained through maps and calculations, which are documented in the following section. The district heating network was design on the basis of a satellite map and placed in line with the main roads or roads with high density of heat consumers. Along the pipe system the residential buildings are counted and multiplied with 10 kW/house. This benchmark represents for a house with 100 m2 a specific heat demand of 160 kWh/m2.a, which is a category E to F of energy certificate and a realistic assumption.

All the connection points have been numbered and put in a table. According to the power connected, the pipe system has been designed. The following design criteria have been applied:

[16] Kelit company broschure (source: http://www.kekelit.com/uploads/media/Fernwaerme-Rohrsystem-3_Projektierung.pdf)

Power per household	10 kW
Synchrony	1.0
Density	1,000 kg/m^3
Heat capacity of water	4.2 kJ/kg.K
Temperature difference	30 K (between primary and return flow)
Design velocity	1.5 m/s

The power and the temperature difference defining the water volume, necessary to transport the power.

$$P = \dot{m}\ x\ \dot{cp}\ x\ \Delta t \ \text{->}\ \dot{m} = \frac{\dot{P}}{cp\ x\ \Delta t}$$

With the density and the design velocity the required inner diameter of the pipe is calculated. The official available norm conform pipe data are defining further the necessary pipe type in DN.

$$\dot{V} = A\ x\ v\ \text{->}\ d = \sqrt{\frac{4\ x\ A}{\pi}}$$

Figure 22: District heating system of part Jasenovac (source: Google maps, own design)

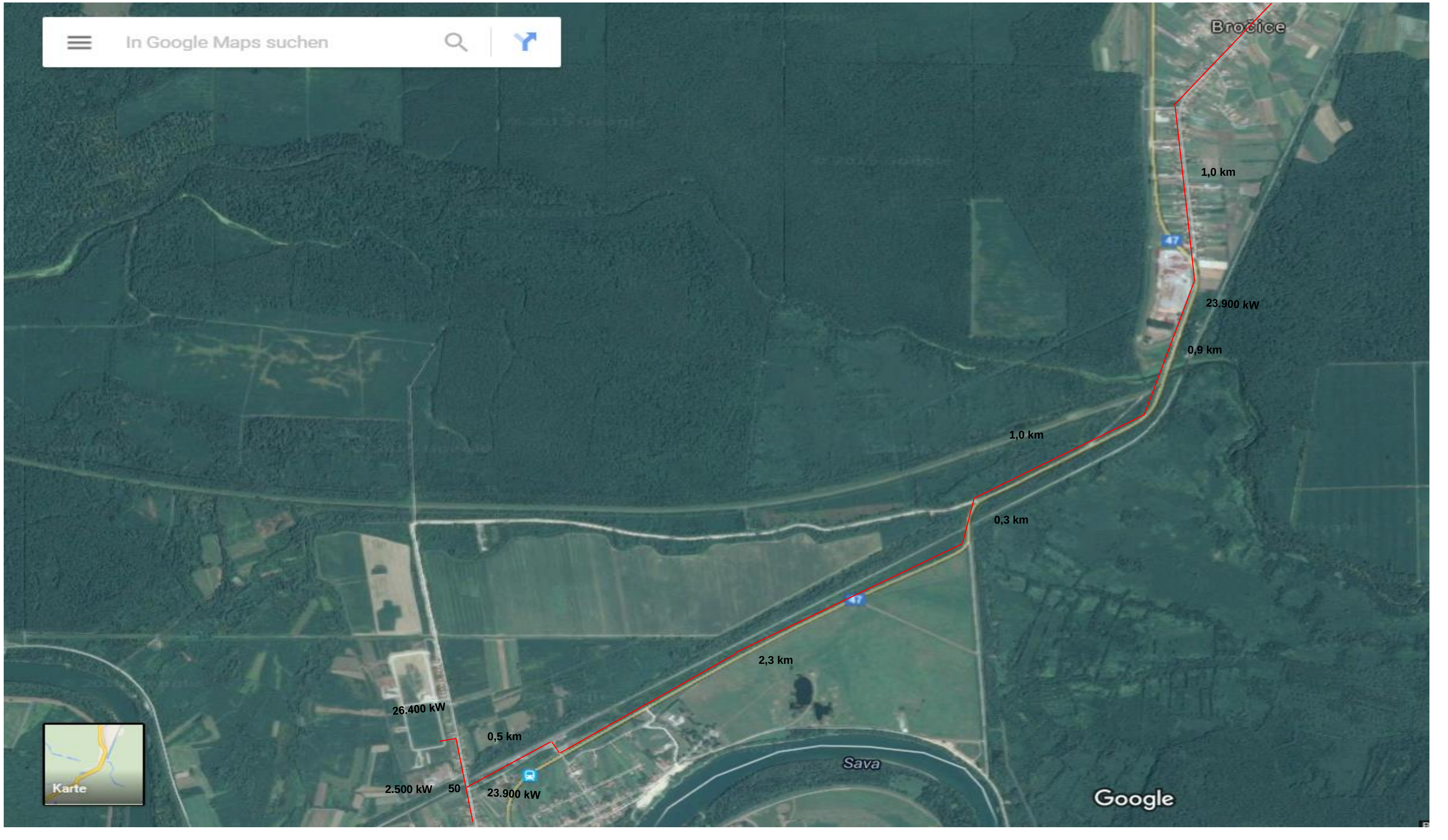


Figure 23: Connection pipe Jasenovac to Novska part 1 (source: Google maps, own design)

Figure 24: Connection pipe Jasenovac to Novska part 2 (source: Google maps, own design)

Figure 25: District heating part of Novska (western part)

Figure 26: District heating part of Novska (eastern part) (source: Google maps, own design)

Section	Power	Length	Volume		required	Selected
Start-End	connected				Dimension	Dimension
Novska						
1-2	270	0.4	2.14	7.71	42,58	50
3-6	160	0.5	1.27	4.57	32.78	50
5-6	400	0.5	3.17	11.43	51.83	50
7-8	450	0.6	3.57	12.86	54.97	65
6-8	560	0.1	4.44	16.00	61.32	65
9-10	640	0.7	5.08	18.29	65.56	65
8-10	1010	0.1	8.02	28.86	82,36	100
11-12	850	1	6.75	24.29	75.55	80
10-12	1650	0.5	13.10	47.14	105,26	125
12-2	2500	0.2	19.84	71.43	129.57	125
12a-13	460	0.6	3.65	13.14	55,58	65
13a-13	380	0.45	3.02	10.86	50.52	50
13-14	380	0.1	3.02	10.86	50.52	50
15-14	260	0.35	2.06	7.43	41.79	50
14-13	640	0.1	5.08	18.29	65.56	65
13-17	1100	0.15	8.73	31.43	85.95	100
18-17	500	0.55	3.97	14.29	57.95	65
16-17	180	0.4	1.43	5.14	34.77	50
17-21	2420	0.7	19.21	69.14	127.48	125
21a-21	240	0.3	1.90	6.86	40.15	50
21-22	2500	0.3	19.84	71.43	129.57	125
19-20	700	0.6	5.56	20.00	68.56	65
2-20	2770	0.5	21.98	79.14	136,39	150
20-22	3470	0.5	27.54	99.14	152.65	150
22-26	6240	0.5	49.52	178.29	204.71	200
23-24	1500	1.6	11.90	42.86	100,37	100
25-24	550	0.9	4.37	15,71	60.77	65
24-26	2050	0.1	16.27	58.57	117.33	125
26a	8290	0.1	65.79	236.86	235.95	250

27-27a	1100	1.4	8.73	31.43	85.95	100
27a-26a	5030	0.75	39.92	143.71	183.79	200
28-29	120	0.25	0.95	3.43	28.39	50
30-31	220	0.2	1.75	6.29	38.44	50
29-31	120	0.2	0.95	3.43	28.39	50
32-33	280	0.25	2.22	8.00	43.36	50
31-33	410	0.2	3.25	11.71	52.47	50
34-35	340	0.25	2.70	9.71	47.78	50
33-35	740	0.2	5.87	21.14	70.49	80
34-35	340	0.3	2.70	9.71	47.78	50
35-37	1130	0.1	8.97	32.29	87.11	80
36-37	300	0.25	2.38	8.57	44.88	50
37-39	1480	0.2	11.75	42.29	99.69	100
38-39	370	0.4	2.94	10.57	49.85	50
39-41	2050	0.2	16.27	58.57	117.33	125
40-41	400	0.4	3.17	11.43	51.83	65
41-42	2860	0.2	22.70	81.71	138.59	150
45-46	200	0.25	1.59	5.71	36.65	50
47-46	1410	0.45	11.19	40.29	97.31	100
48-48	1740	1.25	13.81	49.71	108.10	100
43-44	250	0.3	1.98	7.14	40,97	50
26a-48	13320	0.1	105.71	380.57	299,08	250
48-44	15060	0.1	119.52	430.29	318,02	350
44-42	15600	0.4	123.81	445.71	323,67	350
42-49	17980	1	142.70	513.71	347.48	350
49a-49	3200	1.35	25.40	91.43	146.59	150
49-50	23900	8.76	189.68	682.86	400.62	350
Jasenovac						
54-53	670	1.1	5.32	19.14	67.08	65
56-55	200	0.3	1.59	5.71	36.65	50
55a-55	200	0.25	1.59	5.71	36.65	50
55-53	950	0.9	7.54	27.14	79.87	80
53-51	2300	0.4	18.25	65.71	124.28	150

52-51	350	1	2.78	10.00	48.48	50
51-50	2500	0.2	19.84	71.43	129.57	150
50-CHP	26400	0.7	209.52	754.29	421.06	350
		37.96				

Table 13: District heating calculations (source: own calculation)

Heat losses (KeKelit, Project brochure):

The pipe system used is pre-insulated pipe with PU foam. Heat losses are depending on depth of pipes, distance between the pipes, temperatures of the medium and heat insulation characteristics of surrounding earth, foam material und PE coat. The U-value is valid for one pipe and the heat exchange between the pipes is considered. In the project brochure, the U-value is calculated by the pipe producer Kelit and is taken from this table. The Series 2 is chosen which reflects the laying method of thermal pre-stressed.

Calculation basics:

tp = 90°C Primary flow temperature

tr = 60°C Return flow temperature

tE = 8°C Earth temperature

Section	Power	Length	U value	Heat loss
Start-End	connected			
Novska				
1-2	270	0.4	0.187	10.02
3-6	160	0.5	0.187	12.53
5-6	400	0.5	0.187	12.53
7-8	450	0.6	0.187	15.03
6-8	560	0.1	0.237	3.18
9-10	640	0.7	0.237	22.23
8-10	1010	0.1	0.26	3.48
11-12	850	1	0.249	33.37
10-12	1650	0.5	0.3	20.10
12-2	2500	0.2	0.3	8.04
12a-13	460	0.6	0.237	19.05
13a-13	380	0.45	0.187	11.28
13-14	380	0.1	0.187	2.51

15-14	260	0.35	0.187	8.77
14-13	640	0.1	0.187	2.51
13-17	1100	0.15	0.26	5.23
18-17	500	0.55	0.187	13.78
16-17	180	0.4	0.187	10.02
17-21	2420	0.7	0.3	28.14
21a-21	240	0.3	0.187	7.52
21-22	2500	0.3	0.3	12.06
19-20	700	0.6	0.187	15.03
2-20	2770	0.5	0.341	22.85
20-22	3470	0.5	0.341	22.85
22-26	6240	0.5	0.363	24.32
23-24	1500	1.6	0.26	55.74
25-24	550	0.9	0.187	22.55
24-26	2050	0.1	0.3	4.02
26a	8290	0.1	0.354	4.74
27-27a	1100	1.4	0.26	48.78
27a-26a	5030	0.75	0.363	36.48
28-29	120	0.25	0.187	6.26
30-31	220	0.2	0.187	5.01
29-31	120	0.2	0.187	5.01
32-33	280	0.25	0.187	6.26
31-33	410	0.2	0.187	5.01
34-35	340	0.25	0.187	6.26
33-35	740	0.2	0.249	6.67
34-35	340	0.3	0.187	7.52
35-37	1130	0.1	0.249	3.34
36-37	300	0.25	0.187	6.26
37-39	1480	0.2	0.26	6.97
38-39	370	0.4	0.187	10.02
39-41	2050	0.2	0.3	8.04
40-41	400	0.4	0.187	10.02
41-42	2860	0.2	0.341	9.14
45-46	200	0.25	0.187	6.26
47-46	1410	0.45	0.26	15.68
48-48	1740	1.25	0.26	43.55
43-44	250	0.3	0.187	7.52
26a-48	13320	0.1	0.354	4.74
48-44	15060	0.1	0.392	5.25
44-42	15600	0.4	0.392	21.01
42-49	17980	1	0.392	52.53
49a-49	3200	1.35	0.341	61.69
49-50	23900	8.76	0.392	460.15
				1298.93
Jasenovac				
54-53	670	1.1	0.187	27.56

56-55	200	0.3	0.187	7.52
55a-55	200	0.25	0.187	6.26
55-53	950	0.9	0.249	30.03
53-51	2300	0.4	0.341	18.28
52-51	350	1	0.187	25.06
51-50	2500	0.2	0.341	9.14
				0.00
50-CHP	26400	0.7	0.392	36.77
		37.96	165.615121	160.62
				1459.55

Table 14: Calculation heat losses of district heating (source: own calculation)

The so calculated heat losses are **1,460 kW** for the whole district heating network.

With all of these results, the heat load curve can be calculated according to Sochinsky method. The area beyond the curve reflects the heat energy demand.

According to Table 13: District heating calculations, the total power demand is 26.4 MW. With the base of 1.600 h/a the heat demand amounts to **42,240 MWh/a**. Another factor, the heat losses calculated in Table 14, represent with 1,460 kW the basis for further calculation.

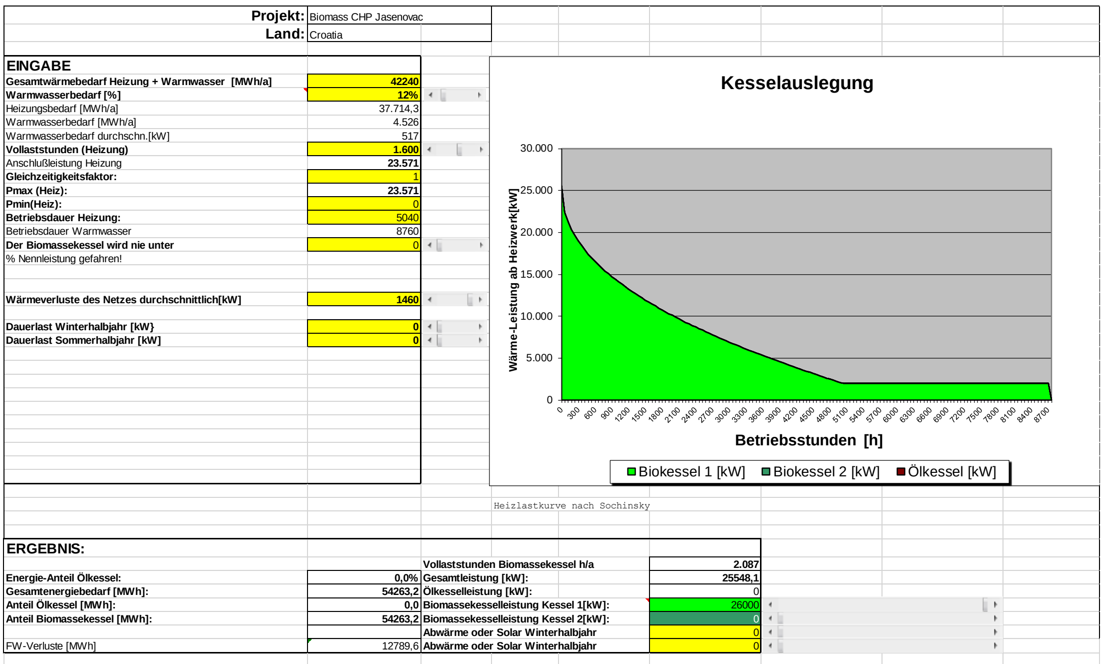


Figure 27: Heat load curve district heating network (own sources)

Putting all information into the calculation form of the Sochisky heat load curve, Figure 27 presents the heat load curve. The whole heat demand including

- Heat demand
- Demand for hot water preparation, assumption are 12% of heat demand
- Heat losses

sums up to **54,263 MWh/a**.

This solution grants the project following efficiency:

$$\eta = \frac{Q_{el} + Q_{th}}{Q_{fuel}} \geq 50\%$$

$$\eta = \frac{44{,}000\ MWh + (10{,}000\ MWh + 54{,}263\ MWh)}{188{,}000\ MWh} = \mathbf{57.59}\%$$

4.2.1.3 Economic calculation

The investment costs of the district heating system are calculated as follows:
A route length of 38,000m means double pipe length (primary flow and return flow) and results in 76,000 m.

To get to valid **investment costs**, a design would need to be conducted. During design phase the whole district heating network is inspected and the other utilities investigated. Based on this design a tender for the implementation of the network will be published and offers collected. For this master thesis a tender procedure would have exceed the content of the work. However, to work further with accurate data, I decided to take a tender result from a recent conducted tender procedure. The middle price of the different bids was 2.2 Mio. EUR. The length of the main route including connection pipes to the houses was 9.23 km and finally lead to unit price of 238 EUR/m. Average dimension of the pipe system was DN 125. In the network for Jasenovac the average diameter was calculated in Table 13: District heating calculations with 165 mm. The next dimension is DN 200. Further, the calculation base was selected with **260 EUR/m** which leads for the whole district heating network to **investment costs of 19,900.000 EUR** including network pumps (3 x 50%) and the control system as well as hydraulic installation in the CHP plant. Necessary heat exchanger will be paid by the heat consumer and are therefore investment neutral.

Maintenance costs are defined with **0.5% of investment costs per year**. Due to the quality of the pipe system installed, no major overhauls are necessary.

Additional operation costs are not necessary because the whole administration will be covered by the existing management of the CHP project.

For calculating the income part we need to look into the heat structure of Croatia. Fire wood and gas are main prime energy carrier for individual houses.

The gas price was 0.363 Kuna/kWh or **0.0477 EUR/kWh** in 2014 according to Eurostat information[17] and include the basic price of the electricity/gas, transmission and distribution charges, meter rental, and other services. Service charge per year for maintenance of gas boiler is calculated with 250 EUR/a and the costs for chimney sweeper of 100 EUR/a. An individual house with 10 kW and 16,000 kWh/a purchased, the costs can be allocated to 0.022 EUR/kWh which finally sums up to 0.0477 + 0.022 EUR/kWh = 0.0697 EUR/kWh or **69.7 EUR/MWh**.

The second energy source, the fire wood, can be bought on forest road for 216 kn/t 28.4 EUR/t related to a water content of w35 at average[18] from Hrvatske sume, Croatia's national forest company. Biomass having a water content of 35% included, can provide heat energy for 2,99 MWh/t.

c	30,87%
h	3,78%
o	26,78%
n	1,58%
s	0,00%
w	**35,00%**
a	**2,00%**
Summe	1,0000
Heizwert [MWh/t]	2,9896
MJ/kg	10,7624

Table 15: Calculation of Heat value (own source)

Transportation costs can be calculated with 1 EUR/t according to information of a transport company. To get fire wood to the households cutting and splitting additional 4 EUR/t (estimation by the author) need to be added which finally sums up to 33.4 EUR/t or **11.17 EUR/MWh**. Also here the service charge per year for

[17] Source: Eurostat homepage http://ec.europa.eu/eurostat/statistics-explained/images/e/e6/Natural_gas_prices_2014s2.png, viewed 29.09.15
[18] Source: Current HS tender procedure.

maintenance of fire wood boiler calculated with 250 EUR/a and the costs for chimney sweeper of 100 EUR/a, allocate to an individual house with 10 kW and 16,000 kWh/a purchased to 0.022 EUR/kWh which finally sums up to 11.17 EUR/MWh + 22.0 EUR/kWh = **33.17 EUR/MWh.**

Electricity costs for the district heating pumps does not need to be considered. The CHP plant bears theses costs and they are already included in the heat price.

The whole amount of sold heat is according to Table 13: District heating calculations **42,240 MWh/a.**

Economic calculation:
The aim of this master thesis is to compare different heat concept solutions. To get comparable results, the NPV calculation method according to Module 1 of the MSc Program presented by Lukas Weissensteiner, is taken.

Following frame parameter have been considered:

Investment horizon	12 years
Cost of capital:	6.5%
Price escalation of heat price:	2%/year
Fuel costs:	15 EUR/MWh

If we consider the district heating system as separate company or extra profit centre, the fuel costs need to be understood as the heat costs which needs to be paid from district heating profit centre to CHP company.

Dynamic Investment Calculation for a District Heating system

Financial parameters							
Investment Horizont	12	[years]					
Discount rated / cost of capital	6,5	[%/year]					
Rated Capacity elctrical	0	[MW]					
Sold heat	42.200	[MWh]					
Full load Hours	8.000	[hours/year]					
Investment Costs	19.900.000	[€/MW]					
Repair Works	0	[€/MW]	Variation of O&M Costs				
O&M (incl. All variable costs)	0,50	[%/EUR Invests	0%			8,5	[€/MWh]
Feed-In-Tariff for 15 years (flat)	0	[€/MWh]					
Heat price	**68,50**	**[€/MWh]**					
Escaltaiton of heat price	**2,00**	**[%/a]**					
Real escalation of O&M Costs	2,5	[%/year]					
Fuel costs	15	[EUR/MWh]					

Year	Discounted CF	Nominal CF	O&M	Investment/	Fuel	Heat sale			Electricity sale	
				Replacement			heat price			
[-]	[€]	[€]	[€]	[€]	[€]	[€]	[€/MWh]		[€]	
Esc. %			2,5							
0	-19.900.000	-19.900.000,00	0	-19.900.000	0				0	
1	2.026.479	2.158.200,00	-99.500,00	0	-633.000	2.890.700	68,50		0	
2	1.953.769	2.216.014,00	-99.500,00	0	-633.000	2.948.514	69,87		0	
3	1.883.344	2.274.984,28	-99.500,00	0	-633.000	3.007.484	71,27		0	
4	1.815.154	2.335.133,97	-99.500,00	0	-633.000	3.067.634	72,69		0	
5	1.749.150	2.396.486,64	-99.500,00	0	-633.000	3.128.987	74,15		0	
6	1.685.282	2.459.066,38	-99.500,00	0	-633.000	3.191.566	75,63		0	
7	1.623.500	2.522.897,71	-99.500,00	0	-633.000	3.255.398	77,14		0	
8	1.563.754	2.588.005,66	-99.500,00	0	-633.000	3.320.506	78,68		0	
9	1.505.991	2.654.415,77	-99.500,00	0	-633.000	3.386.916	80,26		0	
10	1.450.162	2.722.154,09	-99.500,00	0	-633.000	3.454.654	81,86		0	
11	1.396.216	2.791.247,17	-99.500,00	0	-633.000	3.523.747	83,50		0	
12	1.344.102	2.861.722,11	-99.500,00	0	-633.000	3.594.222	85,17		0	
NPV	96.903									NPV of Costs
Annuity	11.877									Annuitiy of Costs

Table 16: NPV calculation of district heating solution – 12 years horizon (own calculation)

The result shows that this solution will turn into a positive result after **12 years** with a heat price of **68.5 EUR/MWh**. 12 years would reflect the loan payback period.

Compared to the heat price 69.7 EUR/MWh for gas fired heating system and 33.17 EUR/MWh for a wood fired heating system of an individual house, the gas consumer will probably switch to the district heating system. But the price difference is too low for the heat consumer to totally switch dependent heat energy source where he depends on. For the fire wood user, it is seems very hard to convince this kind of consumer to connect to the more expensive district heating system. This would lead to a very intense acquisition of heat consumer and a long lasting process and bears the risk of disconnection of heat consumers without heat off-taking but the investment of the network has already been taken.

By extending the investment horizon to 20 years, the necessary heat price to guarantee a positive result, would be reduced to **52 EUR/MWh**. This heat price is still much higher than fire wood consumer can achieve.

Dynamic Investment Calculation for a District Heating system

Financial parameters							
Investment Horizont	20	[years]					
Discount rated / cost of capital	6,5	[%/year]					
Rated Capacity elctrical	0	[MW]					
Sold heat	42.200	[MWh]					
Full load Hours	8.000	[hours/year]					
Investment Costs	19.900.000	[€/MW]					
Repair Works	0	[€/MW]	Variation of O&M Costs				
O&M (incl. All variable costs)	0,50	[%/EUR Invests	0%			8,5	[€/MWh]
Feed-In-Tariff for 15 years (flat)	0	[€/MWh]					
Heat price	**52**	**[€/MWh]**					
Escaltaiton of heat price	**2,00**	**[%/a]**					
Real escalation of O&M Costs	2,5	[%/year]					
Fuel costs	15	[EUR/MWh]					

Year	Discounted CF	Nominal CF	O&M	Investment/ Replacement	Fuel	Heat sale			Electricity sale	
							heat price			
[-]	[€]	[€]	[€]	[€]	[€]		[€/MWh]		[€]	
Esc. %			2,5							
0	-19.900.000	-19.900.000,00	0	-19.900.000	0				0	
1	1.372.676	1.461.900,00	-99.500,00	0	-633.000	2.194.400	52,00		0	
2	1.327.592	1.505.788,00	-99.500,00	0	-633.000	2.238.288	53,04		0	
3	1.283.625	1.550.553,76	-99.500,00	0	-633.000	2.283.054	54,10		0	
4	1.240.775	1.596.214,84	-99.500,00	0	-633.000	2.328.715	55,18		0	
5	1.199.040	1.642.789,13	-99.500,00	0	-633.000	2.375.289	56,29		0	
6	1.158.417	1.690.294,91	-99.500,00	0	-633.000	2.422.795	57,41		0	
7	1.118.897	1.738.750,81	-99.500,00	0	-633.000	2.471.251	58,56		0	
8	1.080.472	1.788.175,83	-99.500,00	0	-633.000	2.520.676	59,73		0	
9	1.043.130	1.838.589,35	-99.500,00	0	-633.000	2.571.089	60,93		0	
10	1.006.858	1.890.011,13	-99.500,00	0	-633.000	2.622.511	62,14		0	
11	971.643	1.942.461,36	-99.500,00	0	-633.000	2.674.961	63,39		0	
12	937.468	1.995.960,58	-99.500,00	0	-633.000	2.728.461	64,66		0	
13	904.318	2.050.529,79	-99.500,00	0	-633.000	2.783.030	65,95		0	
14	872.174	2.106.190,39	-99.500,00	0	-633.000	2.838.690	67,27		0	
15	841.018	2.162.964,20	-99.500,00	0	-633.000	2.895.464	68,61		0	
16	810.831	2.220.873,48	-99.500,00	0	-633.000	2.953.373	69,99		0	
17	781.592	2.279.940,95	-99.500,00	0	-633.000	3.012.441	71,38		0	
18	753.283	2.340.189,77	-99.500,00	0	-633.000	3.072.690	72,81		0	
19	725.882	2.401.643,57	-99.500,00	0	-633.000	3.134.144	74,27		0	
20	699.369	2.464.326,44	-99.500,00	0	-633.000	3.196.826	75,75		0	
NPV	229.058									NPV of Costs
Annuity	20.788									Annuitiy of Costs

Table 17: NPV calculation of district heating solution – 20 years horizon (own calculation)

4.2.2 Heat Concept: Installation of a pellets production plant

4.2.2.1 Technical solution of pellets production system

General regarding pellets and market perspective

Pellets, an energy carrier invented in the late 1970th by Jerry Witfield, an aeronautic engineer from Seattle with the goal to fully-automatically and comfortable combust renewable energy in a furnace by burning until that time unused saw dust. This was during the time of the oil crisis. In his private garage, Witfield construed the first pellets oven for individual houses and presented the model in 1983. Pellets was at that time just in industrial use. Few years after, more than one docent companies offered pellet oven on the USA market. In Europe, Denmark and Sweden had the pioneer role in the pellet market with its boom in the 90tieth. Reason for the fast development in Sweden was the established tax on CO_2 emissions, which boosted the technology. Also Austria need to be mentioned in this row. In 1994, first pellets from Sweden were imported and after positive prove of usage, the first production facility was implemented. In 2000 approximately 45,000 t of annual production was reached. From Austria the pellets wave swapped into the German market. In America, in parallel the pellet market reached stagnation due to reduced oil and gas prices. Witflield prognoses an increase of pellets demand in USA in the next years going along with rising energy prices. In Europe in contrary, the interest in the use of pellets grows year by year. [19]

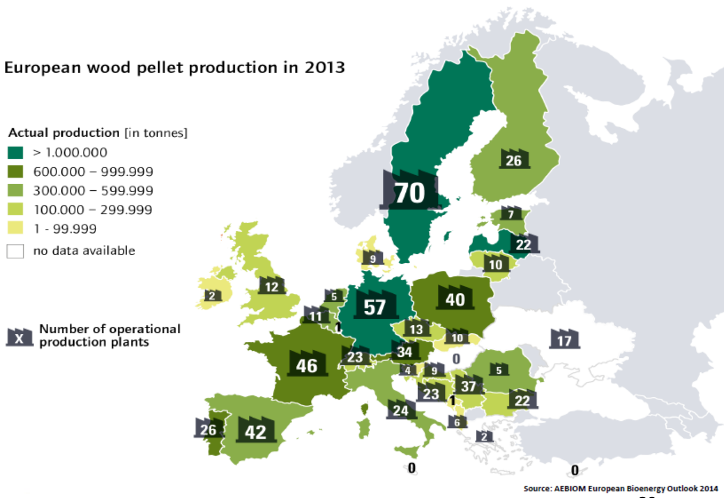


Figure 28: European wood pellet production in 2013[20]

[19] Janzuing B., article „Der Holzofen aus der Werkstatt eines Flugingenieurs", brochure pellets Markt und technik 01-04, 2004

[20] Source: Aebiom European Energy Outlook 2014

The figure above shows the actual production situation in Europe. High production countries are Sweden, Germany and Latvia.

When we compare to the production now the consumption, a trend of high consumption exceeding 1,000,000 t of pellets per year are visible in the western EU countries of Sweden, Denmark, England, Germany the Benelux countries and Italy.

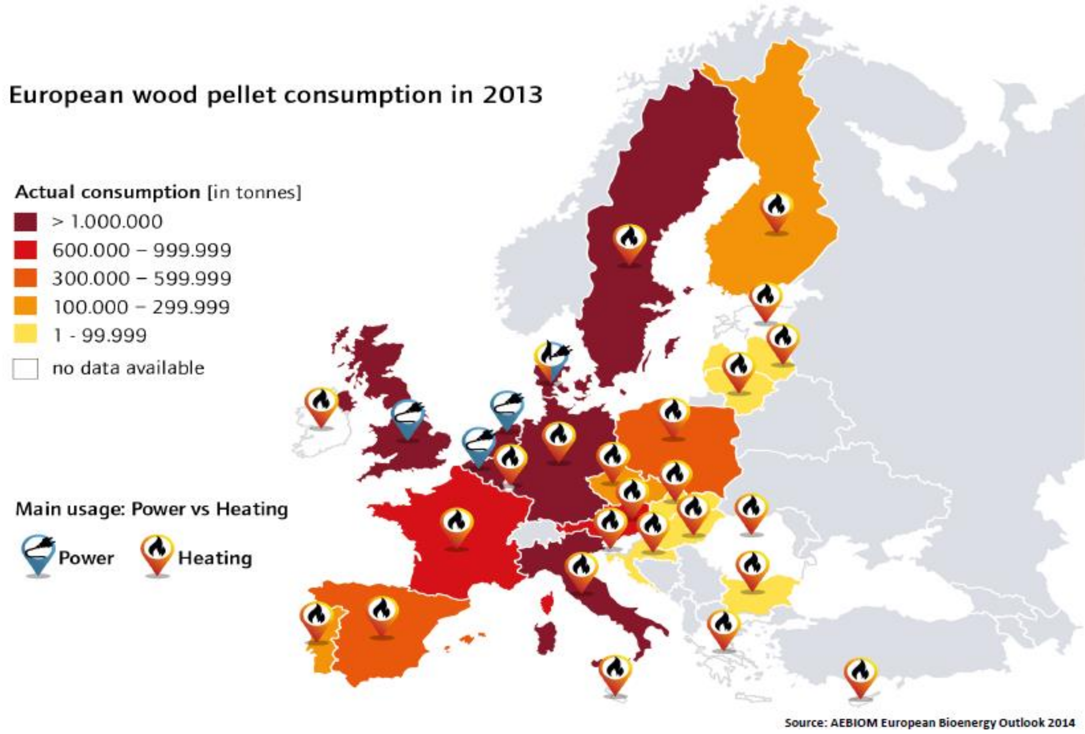


Figure 29: European wood pellet consumption in 2013[21]

Main use of pellets is for heating purpose. Just England Benelux and partially in Denmark, pellet are primarily used for electrical power production.

In Eastern Europe pellet is not intensively used. Croatia consumes approximately up to 99.999 t/years which means considering a heat value of 4.8 kWh/kg 480,000 MWh or 300 MW heat power installed (1,600 fullloadhours/a).

[21] Source: Aebiom European Energy Outlook 2014

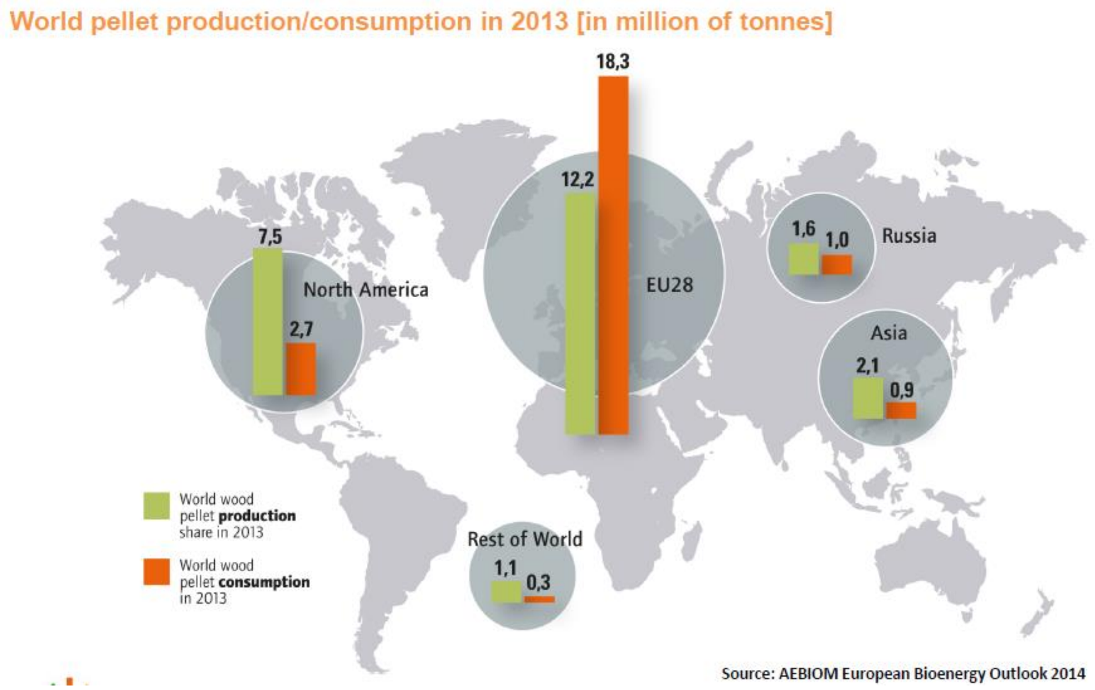


Figure 30: World pellet production/consumption in 2013 (source: Aebiom)

Looking into the worlds pellet production and compare it to the consumption, it is clear visible that Europe is an importer of wood pellets. So still a lack of production capacity of 6.1 Mill. to of pellets on the European market exists. Investment of a pellet production in Europe still is feasible, a demand guaranteed and an investment can be done with future perspective.

This is the basis for an investor to look deeper in the feasibility of this business.

Pellets is another form of stored energy. On the one hand it consist of biomass, which is in itself a carbon product of stored sun energy – photosynthesis under the influence of sunlight and absorption of CO_2 from the atmosphere - enable the growth of wood biomass. Heat is necessary to dry the natural grown biomass to an extent to make further processing to pellets possible. This ensures a long storage stability without losing heat value.

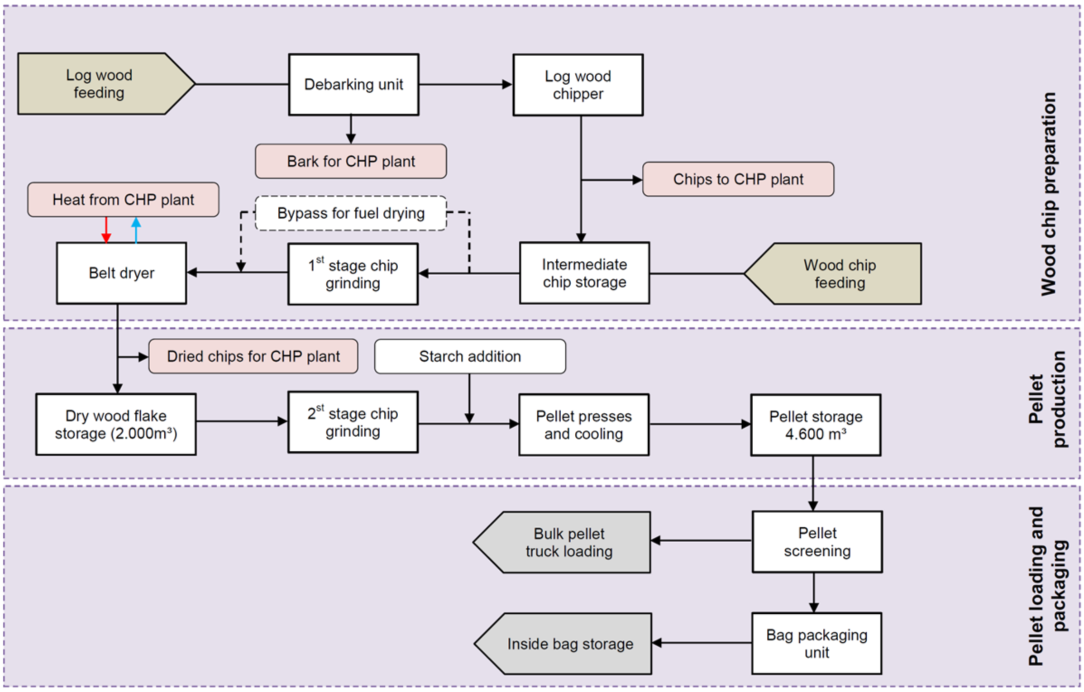


Figure 31: Flow diagram of a pellet production (own source)

Raw material of a wood pellets production is in general natural grown wood. This material can be delivered as logs, wood chips or sawdust. If the production is based on log wood, first stage of processing is a debarking unit to get rid of the woods bark to ensure the high quality EN Plus[22], a quality label of pellets for A1 certified pellets according to the norm EN ISO 17225-2 from 2014. The bark can be transferred to the CHP plant, to be burned. The debarked logs will now be chipped to short pieces and further grinded to get small pieces and a high surface to enable an easy drying of this saw dust. Main instrument of the drying process is the belt dryer.

[22] Source Propellets Austria

Figure 32: Picture of wood chipper and belt dryer (own source)

The belt dryer is continuously fed by an automatic feeding system with the grinded saw dust. A screw on the beginning of the intake spreads the material along the whole belt to create an approx. 10 cm layer of wood on the belt, which is a perforated, synthetic belt. The belt itself runs on the bottom of the drying box. On top of this drying box heat exchanger are located to heat up ambient air to dry the material, Big ventilator systems are placed along and beneath the whole belt, sucking ambient air through this heat exchanger and the saw dust layer which finally dries up the material more and until it reaches the end of the belt. At the end, the final water content of the biomass should be around 6-8%.

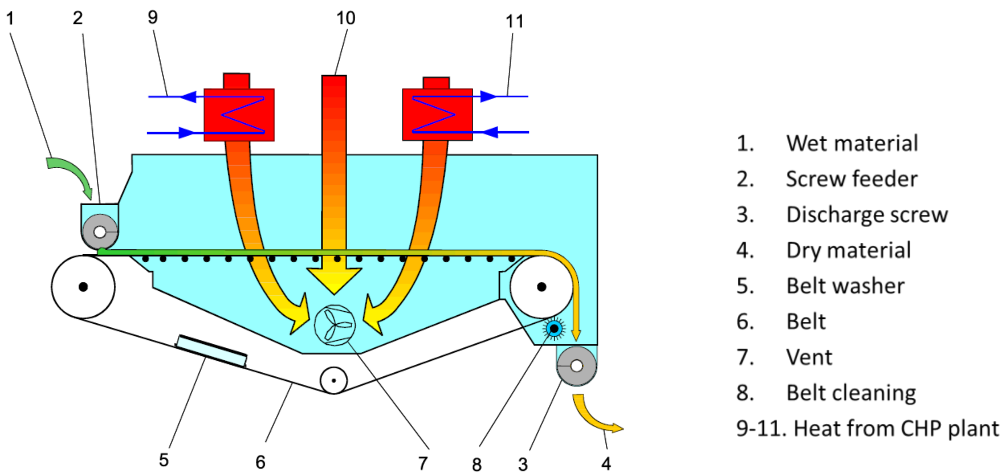


Figure 33: Scheme of a belt dryer (Source: company Swisscombi)

Figure 34: Heat exchanger of belt dryer (own resources)

The dried material will now be stored because also her, the water content is reduced to an extend to ensure stable storage conditions of the material.

For the pelleting process, material is now taken out of this storage and further transported to the next stage of grinding. Following that process, to reach a material which can be pressed a bit of water need to be added to reach around 11%. The biomass is also mixed with natural maize starch to better the compaction and to ensure a smooth going in the following pellet pressing process. At the end of the process, the norm pellets will be cooled and finally stored for packaging in 15 kg bags, big bags or for filling them loose into trucks, to get to the distributors or end consumer.

In the industrial cone of Jasenovac, a plot suitable for the implementation of a pellets production plant is available. The space is approximately 25,000 m2 and the plot requires a 550 m long heat connection between CHP plant and belt dryer.

Log wood is purchased by the pellets production plant and delivered by truck to the factory. Entering the area, the weight of the material on a weight bridge is defined and the water content tested. The logistic personal allocates the material the specific place for storage where the truck can unload. The eastern part of the plot is dedicated to storage purposes. A big wheel loader takes the logs, if needed, from this storage and fills up the production line, feeding the de-baring unit. After chipping two wet chip storages are foreseen. Following the belt dryer, two additional dry material storages are planned. The pellets production line consisting of two parallel presses, the treatment before and after pressing, the control room and auxiliary facilities are placed in a compact build. The ready made pellets are stored in a steel silo which feeds the following packaging unit to fill up 15kg plastic bags. This bags are stored in a big warehouse, were also uploading to trucks for long distance transport takes place.

This project idea was drawn into a layout under the usage of project component information from a pellet factory producer Urbas.

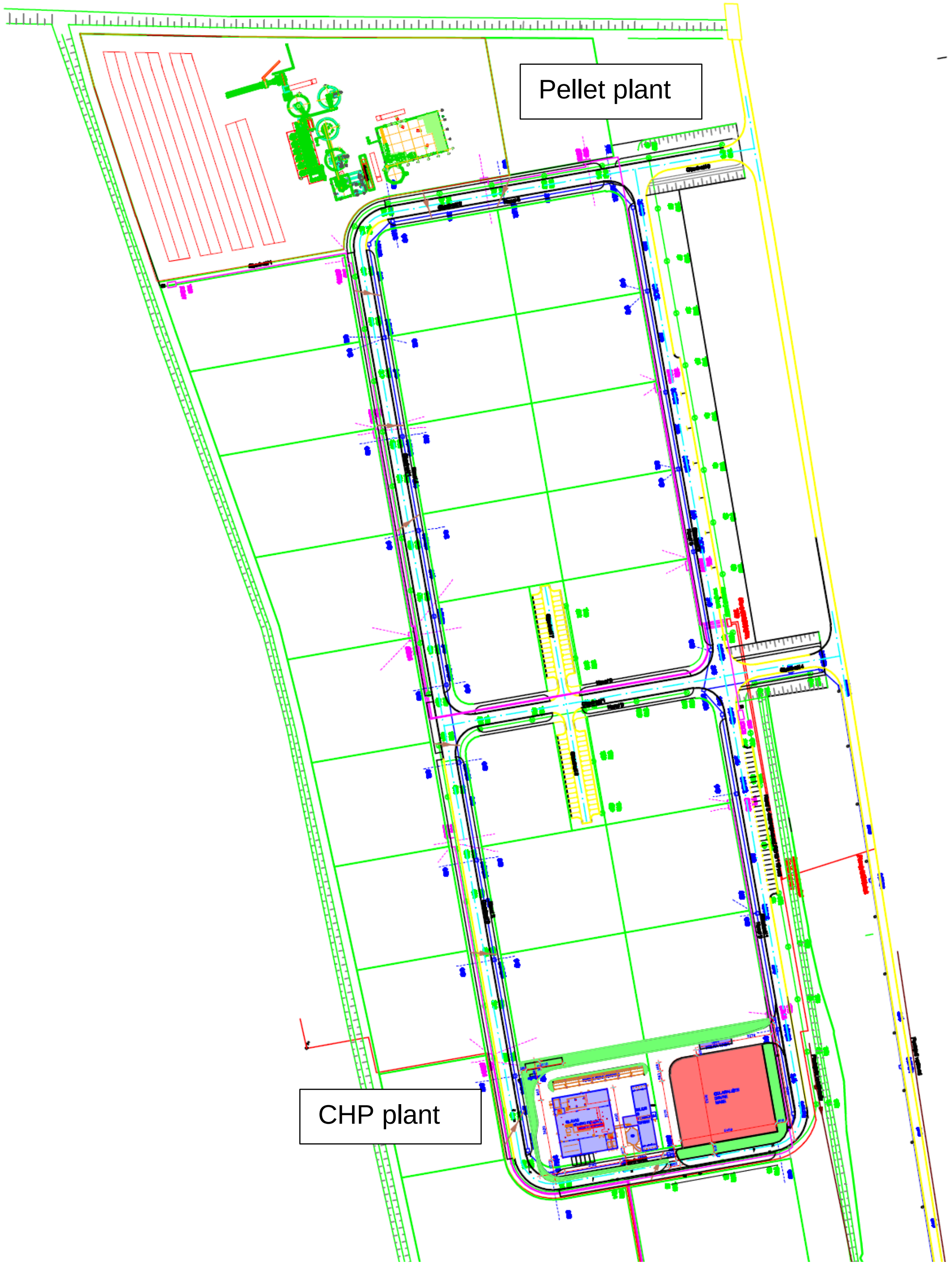


Figure 35: Layout pellets production facility (own design)

4.2.2.2 Evaluation of necessary frame conditions for implementation

The most energy consuming production process is beside electrical energy, the thermal energy for the drying process.

However, practise differs here from theory. To get profound calculation data a meeting with Austira's biggest pellets producer RZ Pellets, Mr. Riegler, was held on 14th of April 2015. The information gained was that for

1 t of pellets, 1.0 to 1.1 MWh_{heat}/t.a

is needed.

For the project in Jasenovac a production facility of 50,000 t pellets per year is needed. This further leads to an energy demand of **50,000 MWh/a for the pellets** production. Adding hereto the energy demand of the existing heat consumer (see above) with 18,000 MWh/a the total demand sums up to 68,000 MWh/a.

CAPEX prices:
The project as described, was tendered and budget prices were asked for the following components:

- Debarking with drum chipper
- Beltdryer
- Bagging unit

Company Knoblinger, a well known Austrian company for delivering and the installation of pellets production facilities offered for these **equipment 6,400,000 EUR** net.

In addition to the equipment, the investment costs for
- Pellets production building
- Concrete silos for wet chips and dry saw dust
- Ware house for pellets
- Asphalt plate for storage area and surrounding
- Weight bridge
- Drainage system

have to be considered.

These investment costs are calculated and estimated as follows:

Unit	Price	Source
Pellets production building	150,000	estimation
Concrete silos for wet chips and dry saw dust	250,000	250,000 EUR x 4 silos estimation
Ware house for pellets	100,000	
Asphalt plate for storage area and surrounding	400,000	20 EUR/m2, 20,000 m2
Weight bridge	50,000	estimation
Drainage system	120,000	estimation
Auxiliaries	300,000	
Sum	**1,370,000**	

Table 18: Estimation of building and construction costs – Pellets (own source)

The equipment costs which will be contracted to a General contractor are:

Equipment 6,400,000 EUR + Buildings 1,370,000 EUR = **7,700,000 EUR**

Besides the construction costs itself, a project consumes also costs in the stage of project development and land acquisition.

These costs are:

Unit	Price	Source
Engiennering, Permission phase, Set in operation	1,210,000	experience
Spare parts	200,000	estimation
Land costs	500,000	offer
Electrical connection	100,000	estimation
Sum project development costs	**2,010,000**	

Table 19: Estimation for project development costs – Pellets (own source)

The total **CAPEX** are in total **9,710,000 EUR**.

OPEX prices:

The operational expenditures consisting of the following components:

- Biomass
- Heat consumption
- Electricity consumption
- Maintenance costs
- Management and personnel expenditures, as well as administration
- Consumables like maze starch, water etc.
- Insurance

Biomass:

The raw material of biomass is transported in logs from forest with a water content of w35 to the pellets production plant. Bark takes around 11-12%[23] which corresponds with own date of 10%. This value will be further calculation base. To produce 50,000 t of pellets per year, to amount of input material can be calculated through the equation that the water content w represents the water content of the wood biomass related to the dry masse of the wood:

In the belt dryer water will be dried down to 8%. So the start water content of 35% minus 8 % means 27% loss of water until final product:

$$w = \frac{Mass\ wet - Mass\ dry}{Mass\ wet}$$

$$Mass\ wet = \ (w * Mass\ dry) + Mass\ dry$$

$$Mass\ et = (0.27 * 50{,}000\ t) + 50{,}000\ t = \mathbf{63{,}500\ t\ fresh\ wood\ with\ w\ 35}$$

This fresh wood includes bark with an amount of 10% which also needs to be purchased

63,500 t + 10% = **70.000 t/a**

The needed biomass comes from the fire wood regime and can be bought on forest road for 216 kn/t = 28.4 EUR/t related to a water content of w35 at average[24] from Hrvatske sume, Croatia's national forest company. The transportation costs can be calculated in this case with 7 EUR/t according to information of a transport company through heavy transport to pellet location and longer distances out of the forest compared to the transportation above. The raw material costs are therefore **35.4 EUR/t**.

Heat consumption:

As described above the heat consumption is **50,000 MWh/a. The heat price agreed with the CHP plant is 15 EUR/MWh**

[23] United Nations, Forest product conversion factors for the UNECE Region, 2010

[24] Source: Current HS tender procedure.

Electricity consumption:

Summing up all electrical producer in the pellet production cycle, the electrical connection is 1,600 kW (from offer pellets production unit), taking a simultaneousness of 80% into account and full load hours of the whole plant from 7,500 h/a it results in 9,600 MWh/a. The electricity price of 80 EUR/MWh for industrial consumer results in electricity price of **768.000 EUR/a**. Broken down to the pellets produced, 1 t of pellet consumes 15.36 EUR/t of electricity costs. This is slightly higher than the value according experience, which have been told to me with 11 EUR/t.

Maintenance costs:

A pellets production company named the value with 3.0%/a of the investment. 9.710 Mio EUR x 3,0% = **291,300 EUR/a**.

Management and personnel expenditures as well as administration:

1 person fuel logistic (wheel loader driver)		18,000 EUR/a
1 person chipper		18,000 EUR/a
1 pellet plant operator		21,000 EUR/a
1 mechanical expert		21,000 EUR/a
1 electrical expert		21,000 EUR/a
1 shift		99,000 EUR/a
3 shifts = 9 persons		297,000 EUR/a
Management, laboratory, etc.	total	**440,000 EUR/a**

Consumables like maze starch, water etc.:

Maize starch will be needed to an extent of 1 % and the costs are 2-3 EUR/t.

50,000 t x 1 % x 2.5 EUR/t = 1,250 EUR

Water costs approx. 50,000 EUR/a

Costs for diesel of wheel loader

Lubricants 0.5 EUR/t = 50,000 t x 0.5 EUR = 25,000 EUR/a

Unforeseeable

The total costs for consumables are estimated with **250,000 EUR/a.**

Insurance:

According to an offer from an insurance company the annual premium is 0.9% of the total investment and so **87,400 EUR/a**.

Income:

From the income side, a pellet price of 130 EUR/t is considered. This is a valuable price in loose form and is lower than the current price in Austria which is according to information approx. 165 EUR/t.

4.2.2.3 Economic calculation

Economic calculation:

The aim of this master thesis is to compare different heat concept solutions. To get comparable results, the NPV calculation method according to Module 1 of the MSc Program presented by Lukas Weissensteiner, is taken.

Following frame parameters have been considered:

Investment horizon	12 years
Cost of capital:	6.5%
Heating costs:	15 EUR/MWh

The pellets project is seen as separate company or extra profit centre.

Dynamic Investment Calculation for Pellets production

Financial parameters					
Investment Horizont	12	[years]			
Discount rated / cost of capital	6,5	[%/year]			
Pellets produced and sold	50.000	[t/a]			
Full load Hours	7.500	[hours/year]			
Investment Costs	9.710.000	[€]			
Biomass demand	70.000	[t/a]			
Biomass price	35	[EUR/t]			
Electrical costs	768.000	[EUR/a]			
O&M (incl. All variable costs)	3,00	[%/EUR Invests	0%	8,5	[€/MWh]
Consumeables	250.000	[EUR/a]			
Personel costs	440.000	[EUR/a]			
Insurance	0,9%	[% of invest]			
Heat demand	50.000	[MWh/a]			
Heat price	**15**	**[€/MWh]**			
Real escalation of O&M Costs	0	[%/year]			
Pellets sales price (Ex Works)	130	[EUR/t]			

Year	Discounted CF	Nominal CF	O&M	Insurance	Consumables	Investment/ Replacement	Personal	Electricity	Biomass	Heat demand	Pellets sale
[-]	[€]	[€]	[€]			[€]			[€]	[€]	[€]
Esc. %			0								
0	-9.710.000	-9.710.000,00	0			-9.710.000			0		0
1	1.347.709	1.435.310,00	-291.300,00	-87.390,00	-250.000,00	0	-440.000	-768.000	-2.478.000	-750.000	6.500.000
2	1.265.454	1.435.310,00	-291.300,00	-87.390,00	-250.000,00	0	-440.000	-768.000	-2.478.000	-750.000	6.500.000
3	1.188.220	1.435.310,00	-291.300,00	-87.390,00	-250.000,00	0	-440.000	-768.000	-2.478.000	-750.000	6.500.000
4	1.115.700	1.435.310,00	-291.300,00	-87.390,00	-250.000,00	0	-440.000	-768.000	-2.478.000	-750.000	6.500.000
5	1.047.605	1.435.310,00	-291.300,00	-87.390,00	-250.000,00	0	-440.000	-768.000	-2.478.000	-750.000	6.500.000
6	983.667	1.435.310,00	-291.300,00	-87.390,00	-250.000,00	0	-440.000	-768.000	-2.478.000	-750.000	6.500.000
7	923.631	1.435.310,00	-291.300,00	-87.390,00	-250.000,00	0	-440.000	-768.000	-2.478.000	-750.000	6.500.000
8	867.259	1.435.310,00	-291.300,00	-87.390,00	-250.000,00	0	-440.000	-768.000	-2.478.000	-750.000	6.500.000
9	814.328	1.435.310,00	-291.300,00	-87.390,00	-250.000,00	0	-440.000	-768.000	-2.478.000	-750.000	6.500.000
10	764.627	1.435.310,00	-291.300,00	-87.390,00	-250.000,00	0	-440.000	-768.000	-2.478.000	-750.000	6.500.000
11	717.960	1.435.310,00	-291.300,00	-87.390,00	-250.000,00	0	-440.000	-768.000	-2.478.000	-750.000	6.500.000
12	674.140	1.435.310,00	-291.300,00	-87.390,00	-250.000,00	0	-440.000	-768.000	-2.478.000	-750.000	6.500.000
NPV	2.000.300										
Annuity	245.173										

Table 20: NPV calculation of Pellets production solution – 12 years horizon (own calculation)

4.2.3 Heat Concept: Installation of a cooling network (Tri-Generation)

4.2.3.1 Technical solution of Cooling network

A service becoming more of importance in the last decade is cooling as an energy service. In southern European countries, where temperature is by trend higher, split cooling installations based on electrical driven compressor chiller are commonly used. Increased warmer periods with higher temperatures and not cooling down during the night, created higher demand of space cooling. The growing wealth on the other hand side allows investments in cooling facilities and the compensation of operation costs. In parallel to this development, dwelling sizes are increasing so the space used by on person is higher than some years ago. The enlarged electrical energy demand already is already felt during summer period and can be blamed to the cooling energy demand.

In general, this trend of increased cooling energy demand is contradicting the EU's effort to reduce the CO_2 emission.

Therefore, new technologies or applications need to be considered, to combine cooling energy production and renewable energy as prime energy carrier.

When we are talking about electrical driven compressor cooling chiller, the technology used in general is a heat pump principle. However, this electrical driven cooling process does not want to be stressed in this master thesis.

Should the driver for generating cooling service be the electricity, it can also be said, that PV as a renewable energy carrier would be able to run the electric driven compressor chiller. This is true, but due to electricity being the highest quality of energy service, the engineers target should be to look for other solutions. Staying at the same level of energy service, heat would be a choice. So, the focus is on an application driven by heat. If "waste heat" is available, the whole process gets more of energetic and economic importance and can play off its advantages. In particular two main types of process are available, the absorption and the adsorption process. Driver of the process is in both cases heat energy, while the adsorption using a fluid to absorb the refrigerant, the adsorption process includes a solid material adsorbing the refrigerant.

In general producing cooling energy and using heat, seams to be a paradox but the further short process description will bring the idea to light.

The absorption cooling cycle, like the mechanical vapour compression refrigeration cycle, utilizes the latent heat of evaporation of a refrigerant to remove heat from the entering chilled water. Vapour compression refrigeration systems use a chlorine-based refrigerant and a compressor to transport the refrigerant vapour to be condensed in the condenser. The absorption cycle, however, uses water as the refrigerant and an absorbent lithium bromide solution to absorb the vaporized refrigerant. Heat is then applied to the solution to release the refrigerant vapour from the absorbent. The refrigerant vapour is then condensed in the condenser. The basic single-effect absorption cycle (see Figure 36) includes generator, condenser, evaporator and absorber with refrigerant (liquid) and lithium bromide as the working solutions. The generator utilizes a driving heat source to vaporize the diluted lithium bromide solution. The water vapour that is released, travels to the condenser where it is condensed back into a liquid, transferring the heat to the cooling tower water. Once condensed, the liquid refrigerant is distributed over the evaporator tubes, removing the heat from the chilled water and vaporizing the liquid refrigerant. The concentrated lithium bromide solution from the generator passes into the absorber, absorbs the refrigerant vapour solution from the evaporator and dilutes itself. The diluted lithium bromide solution is then pumped back to the generator where the cycle is started again.[25]

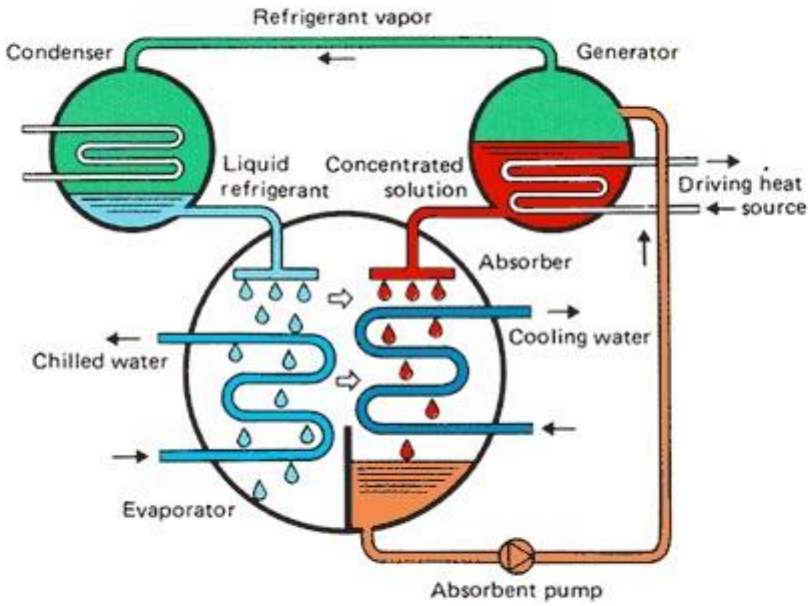


Figure 36: Working principal of an absorption chiller[25]

[25] Source: Carrier product description Super Absorber 16 Lj 11-53, 2006

4.2.3.2 Evaluation of necessary frame conditions for implementation

As described already in chapter 4.2, a heat demand from biomass CHP of **40,000 MWh/a** needs to be guaranteed.

According to the EU commission report "Heat and cooling demand and market Perspective" with reference to Natural Resources CANada (NRCAN), 2011, the cooling demand can be treated like the heat demand and is very influenced by climate conditions. The basis of cooling demand uses the concepts of design cooling temperature and cooling degree-days. The procedure for calculating the cooling duration curve is equal to the heating load curve. Peak cooling is demanded on the hottest period of the year and during the year just a part of the peak cooling demand is requested. Base cooling demand represents constant cooling loads throughout the year and is independent of the weather. For construing the cooling load curve, the base cooling load represents the hot water demand and the cooling degree days replace the heating-degree days. (EU commission report, 2012)

The peak cooling demands depends on the cooling design temperature, which more or less implies the climate conditions and building characteristics with its insulation efficiency. The following figure Figure 37 can be used as an estimation tool to calculate peak cooling demand. Peak load cooling demand is given in a period of the year when the cooling system works on maximum capacity same as the heat demand.

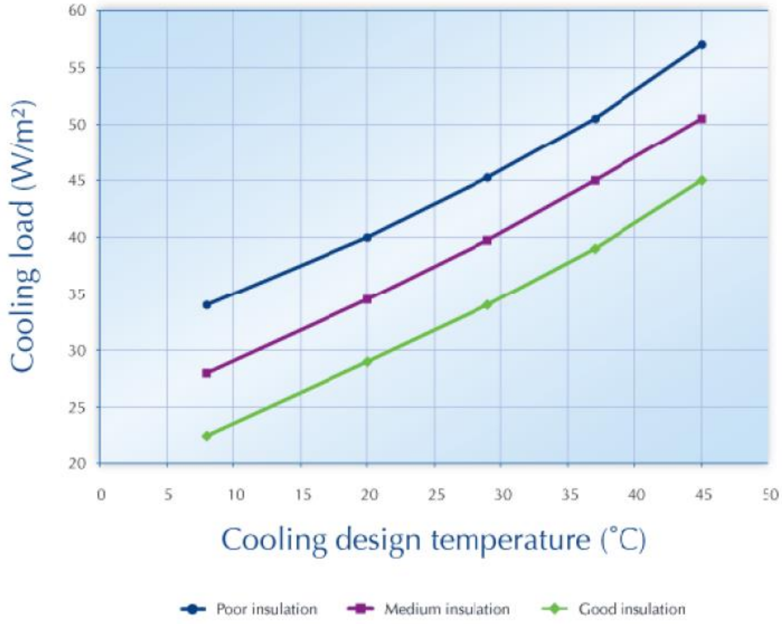


Figure 37: Cooling load (EU commission report, 2012)

In this case a calculation backwards was done to finally result in the space which would need to be cooled.

In the study from EU commission from 2012, Croatia was not a EU member yet, so for reasons of comparison Romania is taken because being on the same line of latitude. The total cooling demand is the following:

Object type	Energy demand [PJ]
Hospital	0.4
Hotel & Restaurant	1.3
Sport & Recreation	0.4
Shop Large	0.8
Shop Small	0.0
Offices	1.8
Total	3.0

Table 21: Breakdown of useful space cooling energy demand of Romania (source: EU commission report 2012)

Referring to chapter 4.2 the concept requires a heat demand of **40,000 MWh/a** which is turned into cooling energy.

The absorption chiller on the other hand side requests also hat media demand of 95°C and returns with 80°C.

Spezifikation:

Item		Medel	SAB-HW								
			040G1	046G1	052G1	058G1	064G1	072G1	080G1	090G1	100G1
Kälteleistung		USRT	400	460	520	580	640	720	800	900	1000
		kW	1,407	1,617	1,828	2,039	2,250	2,532	2,813	3,165	3,516
		kcal/h	1,209,600	1,391,040	1,572,480	1,753,920	1,935,360	2,177,280	2,419,200	2,721,600	3,024,000
Kalt-wasser	Temp.	℃	Eintritt 13 Austritt 8								
	Durchfluß	㎥/h	241.9	278.2	314.5	350.8	387.1	435.5	483.8	544.3	604.8
	Druck-verlust	kPa	105	107	116	108	59	56	72	94	97
	Rohran-schluß	A	200				250				300
	Pass	-	ODD				EVEN				
Kühl-Wasser	Temp.	℃	Eintritt 31 Austritt 36.5								
	Durchfluß	㎥/h	521.3	599.5	677.7	755.8	834	938.3	1,042.5	1,172.9	1,303.2
	Druck-verlust	kPa	82	92	85	91	142	154	45	59	59
	Rohran-schluß	A	250	300				350		400	
	Pass	-	ODD						EVEN		
Heiß-wasser	Temp.	℃	Eintritt 95 Austritt 80								
	Durchfluß	㎥/h	114.1	131.2	148.3	165.5	182.6	205.4	228.2	256.7	285.3
	Druck-verlust	kPa	21	24	30	32	50	54	60	79	84
	Rohran-schluß	A	150			200					
	Pass	-	EVEN								
Leistungsaufnahme		kVA	16.4		16.4		19.5		22.1	26.6	
Pumpen (50Hz)	Lösung	kW	5.5+3.7				5.5+5.5			7.5+5.5	
	Kältemittel	kW	2.0		2.0		2.0		3.7		
	Vakuum	kW	0.4								
Maße	Länge	mm	5,843		6,689		7,445		7,816	8,387	
	Breite	mm	1,916		2,039		2,035		2,047	2,158	
	Höhe	mm	3,250		3,353		3,358		3,358	3,489	
Tube Space		mm	4,900		5,600		6,300		6,600	7,000	
Betriebsgewicht		Ton	14.9	15.1	21.3	21.7	25.4	25.8	27.5	29.2	31.1
Transportgewicht		Ton	13.3	13.5	16.3	16.6	22.1	22.5	23.9	25.4	26.3
Isolierung	Heiß	㎡	16.6		19.7		21.6		22.7	24.5	
	Kalt	㎡	18.2		22		24.6		25.9	27.5	

Notes.

1. 1 USRT entspricht 3,516 kW (3,024 kcal/h)
2. Der fouling factor für Kalt-, Kühl- und Heißwasser beträgt 0.000086 ㎡ K/W)
3. Maximaler Arbeitsdruck für Kalt-, Kühl- und Heißwasser beträgt 780 kPa

Figure 38: Technical data of Absorption chiller – Shinsung Engineering and Hitachi

Considering the biggest engine with **3,516 kW cooling power**, the heat energy demand is 285.3 m3/h with 90°C in and 80°C out.

$$P = \dot{m}\,.\,cp\,.\,dt = \frac{285.3\ m3\,.\,1{,}000\ kg.h}{h\,.\,m3\,.\,3600s}\,.\,4.2\ \frac{kJ}{kg.K}\,.\,(95-80)K = \mathbf{4{,}992.8\ kW}$$

Density of water is considered with 1,000 kg/m3

Heating power in relation to cooling power is 3,516 kW / 4,993 kW = **1 / 1.42**.

The energy which needs to be extracted from the process is 1,303.2 m3/h with cooling water temperatures of 31.0°C to 36.5 °C:

$$P = \dot{m}\,.\,cp\,.\,dt = \frac{1{,}303.2\ m3\ .\ 1{,}000\ kg.h}{h\ .\ m3\ .\ 3600s}\ .\ 4.2\ \frac{kJ}{kg.K}\ .\ (36.5 - 31)K = \mathbf{8{,}362.2\ kW}$$

Research regarding full load hours resulted in an information, which I could take from a calculation tool in excel which, made available on the TU Graz public download area[26]. This document provides for London 280 h/a for areas dedicated for working and 220 h/a for residential areas and for Madrid with 600 h/a and 480 h/a for resident. London is climatically located on the latitude of 51.1°, Madrid on 40.4°, Jasenovac is on 45°. It can be said that the climatic location which is investigated is between the both locations, hence the average of both fullloadhours are taken. The result is:

Jasenovac:

Fulloadhours for working areas	440 h/a
Fullloadhours for residential areas	350 h/a

Viewing other sources for fullload hours the numbers provided are much different. In other documents, numbers of 1,800 h/a are found. This means to me that for a the next step calculation, more focus on this topic must be given and investigated for which purpose the heat energy is needed. For buildings dedicated for working and for living the numbers above seem to be realistic. Cooling for industrial purposes which probably demands cooling energy the whole year, reflect another fullloadhours and will come to 1,800 h/a. The rest of the year the cooling can be provided by free-cooling which means the surrounding air conditions provides the cooling of the industrial building.

Another reliable document provides also feasible information. Austrian Energy provided a study of district cooling plants in operation and referred hereto fullloadhours of 1,100 h/a for business and office use. (Simader, Rakos, 2005)

[26] Source: TU Graz Homepage; ftp.tugraz.at/pub/igeabgabe/Kuehlbedarf_entwurfNEU.xls

Taking a weighted mixture from both figures as the further basis for calculation, **fulloadhours** of **1,000 h/a** are taken under consideration.

4,992.8 kW heat energy driving the absorption process runs on 1,000 h/a and demands 4,992.8 MWh/a. The heat demand of the cooling section must be 40.000 MWh/a, hence **8** of these cooling units need to be installed which produces around 3,516 kW each, so total **28,128 kW peak cooling energy**. Going through the area of Jasenovac, barely insulated houses are visible if they even have a façade or plastering. Figure 37 provides hereto with cooling design ambient temperature of 40°C, 53 W/m2 as peak cooling demand. With our peak cooling energy of the 8 absorption chiller, we can supply cooling energy for **530,717 m2** of working or residential areas.

If we consider the average area in a single family house for Jasenovac, for which a cooling facility is installed, the living room, the bedroom and two rooms for kids, I estimate the total area of the residential house for these rooms with 80 m2 (4.24 kW cooling demand). However, the connection of **6,634 houses** would cause the cooling demand and finally the 40,000 MWh/a of heat energy demand.

The village Jasenovac has, according to Wikipedia (www.wikipedia.at), 1,997 inhabitants resulted from last census in March 2011. This number corresponds with another source found in the internet. Therefore, this specific necessary heating load for absorption cooling can't be reached in Jasenovac.

Until now, the view was just on the usage of heat out of CHP being the driver energy of the absorption cooling process. Due to the fact of the necessity regarding 28 MW of cooling energy demand is provided to finally create the heat demand which is necessary to successfully operate the CHP plant, different locations of absorption cooling chiller need to be installed. To connect all these cooling productions a heating network need to be installed to supply all the units with the heat driver. On the secondary side of this absorption chiller, the district cooling network need to be installed, to supply the buildings itself with the cooling energy.

Hence, having already a district heating network to supply absorption chiller on different locations, it makes sense to also connect the objects to the heat supply and sell also the heat to the heat consumer.

With reference to item 4.2.1.2 of this document, the village of Jasenovac requires a heat demand of 2,500 kW or 4,000 MWh/an (á 1,600 h/a). Following the approach of cooling demand supply would need to amount from 40,000 MWh/a down to 36,000 MWh/a or 36 MW thermal power to run absorption chillers. The corresponding number of units is 7 with a total cooling power of 25.3 MW and with a demand of approx. 6,000 family houses to be cooled. Also this number can't be achieved in Jasenovac itself. Here we would need to build a wider district heating network and this would include the project which was investigated in chapter 4.2.1.

According to these results, it can be said that just a supply with cooling energy without heat energy in wintertime is not doable and a solution realized just in Jasenovac can't find a feasible ground.

Now the investigation of this solution could be stopped, because a cooling installation does not result in a positive feasibility result in Jasenovac.

Nevertheless, I would like to look further into this technical solution, but changing the location of the plant into an area where heating and cooling is demanded anyhow.

All these comparisons show up, that the development of a district cooling of this size is a big challenge and will lead to a development of a wide network for district cooling. Also some industrial cooling energy consumer need to be acquired to be connected and consume cooling service with higher fullload hours as working and residential areas can.

As the previous calculation gave an impression already about the demand of cooling energy consumers and huge numbers of different clients, a feasibility of this kind of project can realistically be realized just in a bigger city (compare 530,717 m2 of cooled area or 6,634 cooled houses needed) where cooling demand in a narrow space can be found. Hence, city of Zagreb servers here favourable conditions.

Here, company Colliers International, a real estate and advisory company in Zagreb, published a market trend report on its web page [27] that mid of 2014 the number of

[27] Source: http://www.colliers.hr/wp-content/uploads/2015/06/Market-Trends-Office-space-in-Zagreb.pdf, viewed 11.11.15

office units has reached 1,253.000 m2 in total. That means with the cooling capacity we have, we can supply half of these available offices space in Zagreb.

Comparing the district cooling system of Vienna, with status 2014, City of Vienna had installed a capacity of 56.9 MW of cooling energy and the target for 2020 is the installation of totally 200 MW[28].

For further investigation, I selected the area left and right of the road "Uliza Grada Vukovara" where the main universities, different ministries and a lot of new big office building from banks and insurance companies, as well as hotels are located. The length of this area is 3.8 km and the width 1.0 km, so 3.8 km2. The location of the biomass CHP for the further calculation is now selected to be at the outer limit of this area.

It need to be mentioned that in Zagreb a district heating network already exists and a feed- in of the heat into the existing network is not considered in the following calculations.

[28] Source: Magistrat der Stadt Wien, „Fernkälte in Wien – Umweltfreundliche Gebäudeklimatisierung im Gewerbebereich, 2013

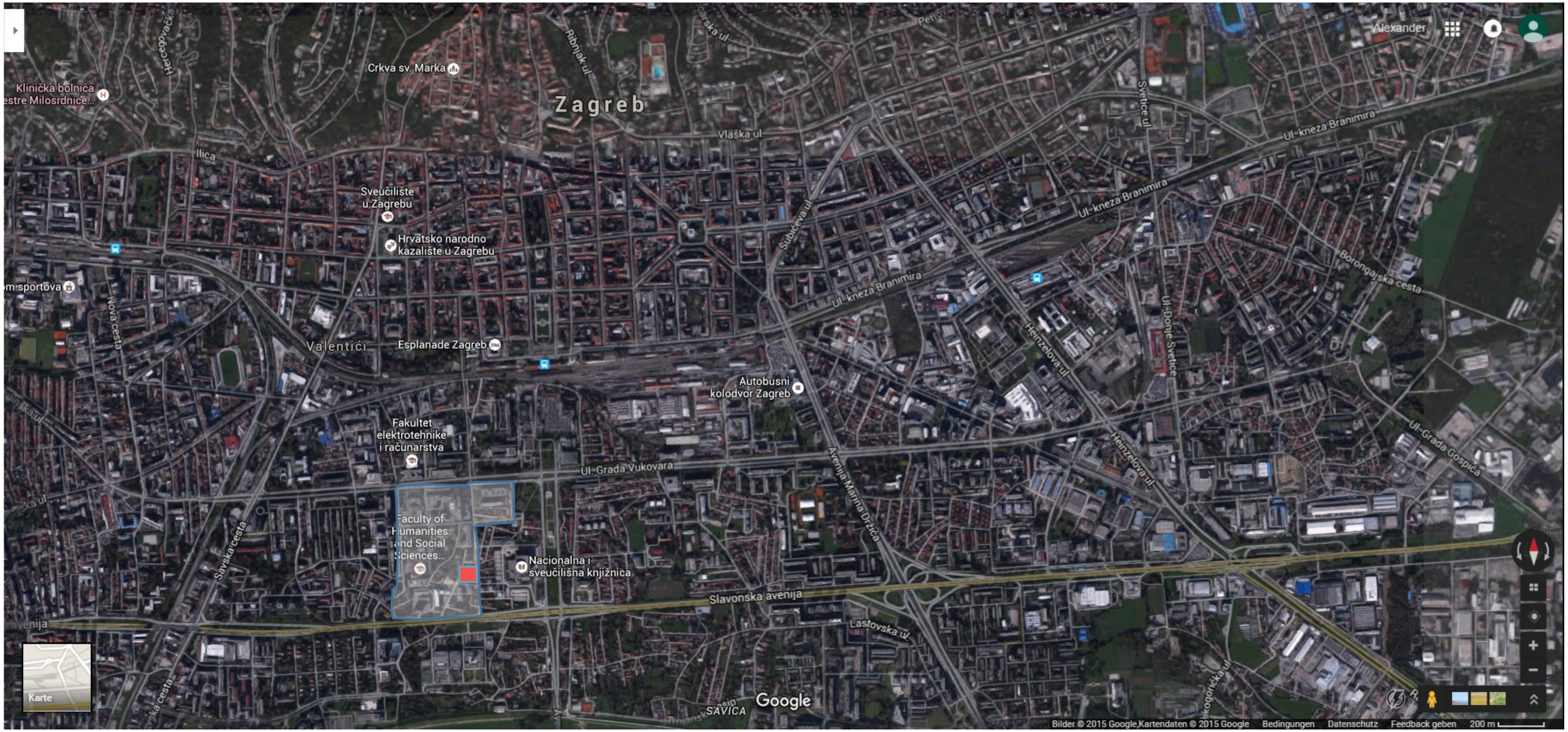


Figure 39: Zagreb map with district heating and cooling area A (source: Google maps)

To estimate the cooling and heating demand the following parameters have been used:

According to Entranze project report, different building types for different locations have been investigated. Regarding location, I selected Bucharest out of this report as the location having similar climatic conditions and building structures as Zagreb do. The following results have been presented out of the report (Entranze report):

	Net floor area	Heating demand [kWh/m2]	Domestic hot water [kWh/m2]	Sum [kWh/m2]	Colling demand [kWh/m2]
Single house	140 m2	189.1	15.9	**205**	**31**
Apartment	900 m2	118.9	24.3	**143,2**	**20.6**
Office	2,400 m2	118,6	9.3	**127.9**	**37,4**
School	3,500 m2	142.1	11.9	**154**	**21,0**

Table 22: Heating and cooling demand from Entranze report (source: Entranze report)

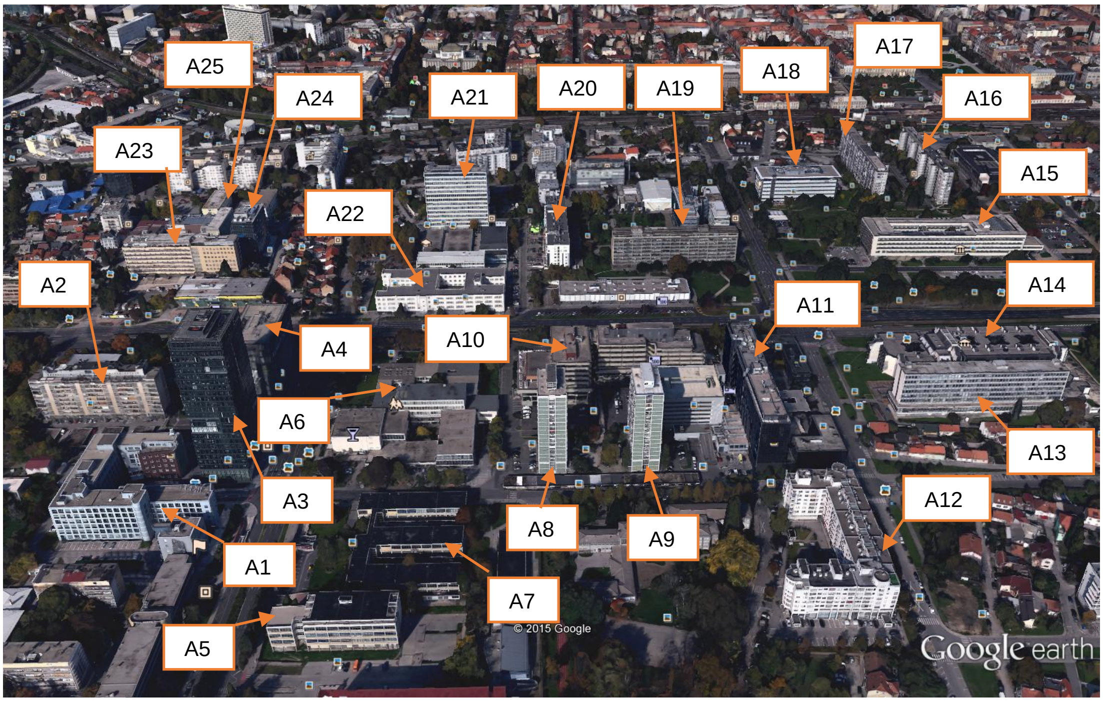


Figure 40: Zagreb district heating and cooling area A with object numbering (source: google maps, own design)

According to Figure 40, I prepared a calculation of the object's net heated and cooled areas. Hereto, I took from Google Earth the dimensions of the building and with the function of 3D-objects I could also take out of this picture the number of floors. Here I received the gross floor area. Considering, that one floor consists of rooms and in addition other secondary areas like walkways, stairs, elevators, bathrooms which are not heated or cooled, I considered for office houses a factor 0.75 and for apartment a factor 0.90 gross to net area. The net heated area was further multiplied with the results, the unit heat and cooling demands from Entranze report in Table 22 taken, leads to the heat and cooling demand. The cooling demand itself was further converted into the necessary heating demand for the driver heat of the absorption chiller and calculated with the factor 1 / 1.42 (see above) into the heat demand.

Obj.	Typ	lengh	width	no of floors	gross floor area	gros/net	net area	Heating demand	Cooling demand
[-]	[-]	[m]	[m]	[pc.]	[m2]	[-]	[m2]	[kWh/a]	[kWh/a]
A1	O	190	10	6	11,400	0.75	8,550	1,093,545	319.770
A2	A	80	10	9	7,200	0.90	6,480	927,936	133.488
A3	O	30	30	25	22,500	0.75	16,875	2,158,313	631.125
A4	O	50	30	11	16,500	0.75	12,375	1,582,763	462.825
A5	O	60	20	4	4,800	0.75	3,600	460,440	134.640
A6	O	210	150	4	126,000	0.75	94,500	12,086,550	3.534.300
A7	A	225	38	3	25,650	0.90	23,085	3,305,772	475.551
A8	A	16	26	18	7,488	0.90	6,739	965,053	138.828
A9	O	16	26	18	7,488	0.75	5,616	718,286	210.038
A10	A	113	39	9	39,663	0.90	35,697	5,111,767	735.352
A11	O	225	88	28	32,992	0.75	24,744	3,164,758	925.426
		120	18	12	25,920		0		
		50	10	4	2,000		0		
		22	22	4	1,936		0		
		14	28	4	1,568		0		
		19	10	4	1,568		0		
A12	O	117	48	8	760	0.75	570	72,903	21.318
A13	O	100	15	7	10,500	0.75	7,875	1,007,213	294.525
A14	A	110	35	5	19,250	0.90	17,325	2,480,940	356.895
A15	A	120	40	4	19,200	0.90	17,280	2,474,496	355.968
A16	A	130	10	11	14,300	0.90	12,870	1,842,984	265.122
A17	A	130	10	9	11,700	0.90	10,530	1,507,896	216.918
A18	O	75	30	7	15,750	0.90	14,175	1,812,983	530.145
A19	A	100	15	8	12,000	0.90	10,800	1,546,560	222.480
A20	O	95	16	8	12,160	0.75	9,120	1,166,448	341.088
A21	O	55	16	15	13,200	0.75	9,900	1,266,210	370.260
A22	O	68	72	3	14,688	1.75	25,704	3,287,542	961.330

A23	O	88	15	8	10,560	2.75	29,040	3,714,216	1.086.096
A24	O	40	16	14	8,960	3.75	33,600	4,297,440	1.256.640
A25	O	80	30	5	12,000	4.75	57,000	7,290,300	2.131.800
							348,706	65,343,312	16.111.927
								65,343,312	22.878.937
								88,222,249	
Legend									
S	Single House								
A	Apartment house								
O	Office								
S	School								

Table 23: Zagreb Area A Heating and Colling demand (own calculation)

The first run of this calculation considered all objects from A1 to A25 lead to a heat demand of 88,222 MWh/a. This result would satisfy an investor due to high income from selling the heat, but for this work it would lead to a wrong result if we want to compare the different results. In practice all these objects would be connected to the heat supply. Hence in a next step, objects were deleted out of the list and therefore considered as not to be connected to the district heating supply. The decision for deleted objects were made with the view of centralized cool energy production and short secondary distribution lines to the consumers. The following objects remained connected to finally result in approx. 53,000 MWh/a heating demand, to see if the additional income from running the absorption chiller with heat in combination with the additional investment pays off.

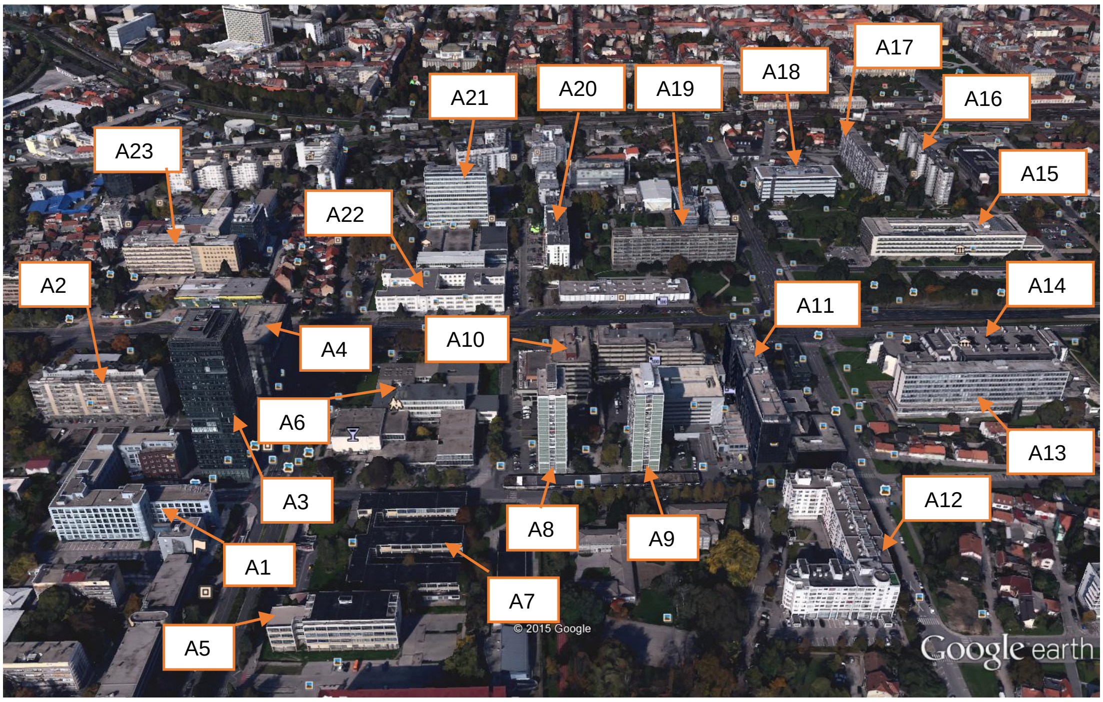


Figure 41: Zagreb district heating and cooling area A connected (source: google maps, own design)

Obj.	Typ	lengh	width	no of floors	gross floor area	gros/net	net area	Heating demand	Cooling demand
[-]	[-]	[m]	[m]	[pc.]	[m2]	[-]	[m2]	[kWh/a]	[kWh/a]
A1	O	190	10	6	11,400	0.75	8,550	1,093,545	319.770
A2	A	80	10	9	7,200	0.90	6,480	927,936	133.488
A3	O	30	30	25	22,500	0.75	16,875	2,158,313	631.125
A4	O	50	30	11	16,500	0.75	12,375	1,582,763	462.825
A5	O	60	20	4	4,800	0.75	3,600	460,440	134.640
A6	O	210	150	4	126,000	0.75	94,500	12,086,550	3.534.300
A7	A	225	38	3	25,650	0.90	23,085	3,305,772	475.551
A8	A	16	26	18	7,488	0.90	6,739	965,053	138.828
A9	O	16	26	18	7,488	0.75	5,616	718,286	210.038
A10	A	113	39	9	39,663	0.90	35,697	5,111,767	735.352
A11	O	225	88	28	32,992	0.75	24,744	3,164,758	925.426
		120	18	12	25,920		0		
		50	10	4	2,000		0		
		22	22	4	1,936		0		
		14	28	4	1,568		0		
		19	10	4	1,568		0		
A12	O	117	48	8	760	0.75	570	72,903	21.318
A13	O	100	15	7	10,500	0.75	7,875	1,007,213	294.525
A14	A	110	35	5	19,250	0.90	17,325	2,480,940	356.895
A15	A	120	40	4	19,200	0.90	17,280	2,474,496	355.968
A16	A	130	10	11	14,300	0.90	12,870	1,842,984	265.122
A17	A	130	10	9	11,700	0.90	10,530	1,507,896	216.918
A18	O	75	30	7	15,750	0.90	14,175	1,812,983	530.145
A19	A	100	15	8	12,000	0.90	10,800	1,546,560	222.480
A20	O	95	16	8	12,160	0.75	9,120	1,166,448	341.088
A21	O	55	16	15	13,200	0.75	9,900	1,266,210	370.260
A22	O	68	72	3	14,688	1.75	25,704	3,287,542	961.330
A23	O	88	15	8	10,560	2.75	29,040	3,714,216	1.086.096
							348,706	53,755,572	12.723.487
								53,755,572	18.067.352
								71,822,924	
Legend									
S	Single House								
A	Apartment house								
O	Office								
S	School								

Table 24: Zagreb area A – heating and cooling demand (own calculation)

This solution provides now a heat supply of approx. 53,755 MWh/a and a cooling demand of 12,723 MWh/a cooling energy or 18,067 MWh/a driving heat energy. If we make now a crosscheck and take 42 W/m2 of peak cooling power for medium insulation 40°C ambient design temperature according to Figure 37 into consideration to cool the 348,706 m2, 14,.645 kW cooling energy is necessary. This number multiplied with 1.000 fullloadhours per year would lead to an cooling energy demand of 14,645 MWh/a which fits perfect to the calculation above of 12,723 MWh/a. The difference is a small variation in fullload hours or insulation quality and can be, for this calculation case, be neglected.

The 14,645 kW of peak cooling power demands 4 units each 3,516 kW.

Location of the absorption chiller and the corresponding district heating and cooling network is as follows:

Figure 42: Zagreb district heating and cooling area A with object numbering (source: google maps, own design)

Legend

- Heating Plant
- Absorption chiller
- District heating network
- District cooling network

For further investment calculation, the boundary of investigation were drawn until heat connection to main supply. It is considered that all buildings does have existing heat and cooling distribution and heating and cooling units in the rooms already. Necessary heat exchanger will be paid by the heat consumer and are therefore investment neutral.

COP values (Coefficient of performance) are taken as follows:

Chiller	Site COP	Source -to-Site Factor	Resource COP
Electric	2.0 - 6.1	0.27	0.54 - 1.65
Absorption	0.65 - 1.2	0.91	0.59 - 1.1

Figure 43: COP's of chillers from New buildings institute (source: Benndorf & Hildebrand)

The selected values are:

Absorption chiller: 0.7

Electric compressor chiller 2.9

CAPEX prices:

For calculation of the total CAPEX the district heating network trench is measured out of the Google Earth drawing with 2.5 km and the secondary net of district cooling trench 1,8 km. For the district heating network the average price of different dimensions is according to 4.2.1.3 calculated with 260 EUR/m (single line) and for cooling network due to smaller dimensions with 180 EUR/m. Piping costs therefore **1,300,000 EUR** for **district heating network** and **648,000 EUR** for the secondary **district cooling network**.

Compared hereto the village shape of a district heating solution which requires for approximately the same heat supply, trench length of 38 km and invest of 19.9 Mio EUR.

For the absorption chiller company Benndorf & Hildebrand (Germany) was contacted and they provided a price indication for each of the 3,500 kW absorption chiller unit with 420,000 EUR to 500,000 EUR related to the frame conditions and the cooling unit for the remaining heat with 300,000 EUR each.

Attachment 4: Information from company Benndorf & Hildebrand

The cooling towers are wet towers, hence additional water is needed which needs to be treated accordingly. This water treatment plant is estimated with 50,000 EUR per unit.

The investment costs are as follows:

District heating network	1,300,000 EUR
District cooling network	648,000 EUR
Absorption chiller 4 x 460,000 EUR	1,840,000 EUR
Colling tower 4 x 300,000 EUR	1,200,000 EUR
Water treatment 4 x 50,000 EUR	200,000 EUR
Building and construction	500,000 EUR
Electrical, Regulation and Control	300,000 EUR
Intermediate sum	5,538,000 EUR
Engineering	350,000 EUR
CAPEX	**5,888,000 EUR**

Maintenance costs:

According to low maintenance costs of the pipe system but maintenance effort for absorption chiller the value is calculated with 1.0% of the investment.

Operation management costs:

Additional operations cost are not appropriate because the services are covered by the operations team of the CHP plant.

OPEX operational expenditures:

The **heat** is bought from CHP plant for 15 EUR/MWh.

Electricity costs are according to Eurostat homepage for industrial tariff 0.092 EUR/kWh.[29] The electricity demand is according to information form the producer Benndorf&Hildebrand 17 kW plus 4x15 kW for the cooling towers for one 3,516 kW cooling, so in total 77 kW. 4 units require 308 kWel with 1.000 fullloadhours 308,000 kWhel and therefore 28,336 EUR/a. The unit electrical demand is 77 kW/3,516 kW= 0.0219 kWel/kWc. The pumping costs for district

[29] Source: http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Half-yearly_electricity_and_gas_prices,_second_half_of_year,_2012%E2%80%9314_(EUR_per_kWh)_YB15-de.png, viewed 14.11.15

heating pumps are covered by the CHP plant and included in heat price to be paid to CHP plant.

Water demand:

The cooling tower is designed as open cooler to save space which is important for the location in Zagreb. A part of the cooling water evaporates during operation and need to be replaced. Data are available out of Austrian Energy Agency report with 26 m3/h for 5,000 kW. Considering different climate conditions the same value will be taken into account for our 3,516 kW unit. The unit demand amounts to **0.0074 m3/kWh**. Water costs will come up with 2 EUR/m3 and with 1,000 h/a the plant demand 4 x 26 m3/h=104 m3/h x 1,000 h/a=104,000 m3/a and 208,000 EUR/a. In this case a solution of using ground water can be further investigated and to reduce the costs and do not waste good quality tap water.

Income structure:

In Croatia, HERA the regulatory agency, defines the prices for heat. Following table has been taken out of HERA annual report 2013 which have been the latest data available at webpage officially published. [30]

Energy entity		Households	Industrial and commercial consumers	Households	Industrial and commercial consumers
		Tariff element - Energy		Tariff element - Power	
		HRK/kWh		HRK/kW	
HEP-Toplinarstvo d.o.o.	Zagreb	0.17	0.34	11.41	15.49

Figure 44: HERA price table for heat in Zagreb (source HERA)

Tariff element - energy:		
Households	0.17 HRK/kWh	0.02225 EUR/kWh
Industry and commercial consumer	0.34 HRK/kWh	0.04450 EUR/kWh

Tariff element - power:		
Households	11.41 HRK/kW	1.49325 EUR/kW
Industry and commercial consumer	15.49 HRK/kW	2.02721 EUR/kW

(exchange rate 1 HRK = 0,13087 EUR; Oanda currency converter from 15.11.15)

For our project the industrial tariffs apply. If we calculate for 1,000 kW and take the 1,600 fullload hours into account we get a mixed tariff of:

[30] Source: HERA webpage, http://www.hera.hr/en/html/annual_reports.html, viewed 15.11.2015

1,000 kW x 1,600 h/a = 1,600,000 kWh/a x 0.0445 EUR7kWh = 71,200 EUR/a

1.000 kW x 2,02721 EUR/kW = 2,027.21 EUR/a

Sum 73,227 EUR/a / 1,600,000 kWh/a = **0.0458 EUR/kWh**

Getting a result for cooling energy I decided to take the factor 1 / 1,42 from above as benchmark which considers from my point of view already the electrical demand of the absorption chiller 0.0458 EUR/kWh x 1.42 = **0.065 EUR/kWh**

Summarized:

Income from Heat energy supply:	0.0458 EUR/kWh
Income from Cooling energy supply:	0.065 EUR/kWh

4.2.3.3 Economic calculation

The aim of this master thesis is to compare different heat concept solutions. To get comparable results, the NPV calculation method according to Module 1 of the MSc Program presented by Lukas Weissensteiner, is taken.

Following frame parameter have been considered:

Investment horizon	12 years
Cost of capital:	6.5%
Fuel costs:	15 EUR/MWh

If we consider the district heating and cooling system as separate company or extra profit centre, the fuel costs need to be understood as the heat costs which needs to be paid from district heating profit centre to CHP company.

Dynamic Investment Calculation for a District Heating system

Financial parameters							
Investment Horizont	12	[years]					
Discount rated / cost of capital	6,5	[%/year]					
Rated Capacity elctrical	0	[MW]					
Sold heating energy	53.755	[MWh/a]					
Sold cooling energy	12.723	[MWh/a]					
Primary heat demand	71.822	[MWh/a]					
Full load Hours	1.000	[hours/year]					
Investment Costs	5.888.000	[€]					
Repair Works	0	[€/MW]	Variation of O&M Costs				
O&M (incl. All variable costs)	1,00	[%/EUR Inve]	0%			8,5	[€/MWh]
Feed-In-Tariff for 15 years (flat)	0	[€/MWh]					
Electricity demand absorption ch.	0,02190	[kWhel/kWhc]					
Water demand	0,00740	[m3/kWh]					
Heat energy consumer price	**45,80**	**[€/MWh]**					
Colling energy consumer price	**65,00**	**[€/MWh]**					
Escaltaiton of heat prices	**2,00**	**[%/a]**					
Real escalation of O&M Costs	2,5	[%/year]					
Primary heat energy costs	15	[EUR/MWh]					
Electricity costs	92	[EUR/MWh]					
Water costs	2	[EUR/m3]					

Year	Discounted CF	Nominal CF	O&M	Investment/ Replacement	Water	Electricity	Primary heat	Cooling Energy sale		Heat sale	
									colling pr.		heat price
[-]	[€]	[€]	[€]	[€]	[€]	[€]	[€]		[€/MWh]	[€]	[€/MWh]
Esc. %			2,5								
0	-5.888.000	-5.888.000,00	0	-5.888.000			0				
1	1.820.502	1.938.834,40	-58.880,00	0	-188.300	-25.634	-1.077.325	826.995	65,00	2.461.979	45,80
2	1.767.386	2.004.613,88	-58.880,00	0	-188.300	-25.634	-1.077.325	843.535	66,30	2.511.219	46,72
3	1.715.062	2.071.708,95	-58.880,00	0	-188.300	-25.634	-1.077.325	860.406	67,63	2.561.443	47,65
4	1.663.585	2.140.145,92	-58.880,00	0	-188.300	-25.634	-1.077.325	877.614	68,98	2.612.672	48,60
5	1.613.001	2.209.951,63	-58.880,00	0	-188.300	-25.634	-1.077.325	895.166	70,36	2.664.925	49,58
6	1.563.352	2.281.153,46	-58.880,00	0	-188.300	-25.634	-1.077.325	913.069	71,77	2.718.224	50,57
7	1.514.672	2.353.779,32	-58.880,00	0	-188.300	-25.634	-1.077.325	931.331	73,20	2.772.588	51,58
8	1.466.987	2.427.857,69	-58.880,00	0	-188.300	-25.634	-1.077.325	949.957	74,66	2.828.040	52,61
9	1.420.322	2.503.417,64	-58.880,00	0	-188.300	-25.634	-1.077.325	968.956	76,16	2.884.601	53,66
10	1.374.694	2.580.488,79	-58.880,00	0	-188.300	-25.634	-1.077.325	988.336	77,68	2.942.293	54,74
11	1.330.115	2.659.101,35	-58.880,00	0	-188.300	-25.634	-1.077.325	1.008.102	79,23	3.001.139	55,83
12	1.286.596	2.739.286,17	-58.880,00	0	-188.300	-25.634	-1.077.325	1.028.264	80,82	3.061.161	56,95
NPV	12.648.274										
Annuity	1.550.276										

Figure 45: NPV calculation of Heating and Cooling supply – 12 years horizon (own calculation)

It is obvious that this solution is a highly feasible one. Due to the narrow area within high amount of heat consumer can be found and in addition also heat consumer are existing, the investment part is little, because just a short district heating and cooling net must be installed.

4.2.3.4 Comparison with an electric driven compressor chiller

The comparison is based on the same conditions as the absorption solution.

For this solution also company Benndorf&Hildebrand was contracted and provided the necessary data.

Sold cooling energy: 12,723 MWh/a

CAPEX:

District cooling network	648,000 EUR
Compressor chiller	1,480,000 EUR

Turbocorekompressor chiller with higher efficiency 4 x 370,000 EUR
According to an offer from company Benndorf&Hildebrand

Building and construction	200,000 EUR
Electrical, Regulation and Control	500,000 EUR
Intermediate sum	2,828,000 EUR
Engineering	150,000 EUR
CAPEX	**2,978,000 EUR**

OPEX:

Regarding the electrical energy demand, company Benndorf&Hildebrand provided the data for the EER (Energy Efficiency Ratio) and the ESEER (European Seasonal Energy Efficiency Ratio) value.

The EER is comparable to the COP value and defines the electrical energy demand in relation to the cooling energy demand

$$EER = \frac{Cooling\ Energy\ supply}{Electrical\ energy\ demand}$$

EER represents the correlation of 100% load. To take also part load behaviour into consideration the ESEER value is used. Here during a cooling season the chiller operates in 100%, 75%, 50% and 25% load and this operation time is weighted as follows:

	ESEER parameters		
Part load ratio	Air temperature (°C)	Water temperature (°C)	Weighting coefficient
100%	35	30	**3%**
75%	30	26	**33%**
50%	25	22	**41%**
25%	20	18	**23%**

Table 25: ESEER calculation of weighted EER coefficient (source: Benndorf&Hildebrand)

The turbocorecompressor chiller from company Benndorf&Hildebrand has the following efficiencies:

EER= 5.8

ESEER= 8.5

Electricity costs: 0.092 EUR/kWh (see above)

The economic calculation provides the following result:

Dynamic Investment Calculation for a District Heating system

Financial parameters							
Investment Horizont	12	[years]					
Discount rated / cost of capital	6,5	[%/year]					
Rated Capacity elctrical	0	[MW]					
Sold heating energy	0	[MWh/a]					
Sold cooling energy	12.723	[MWh/a]					
Primary heat demand	0	[MWh/a]					
Full load Hours	1.000	[hours/year]					
Investment Costs	2.978.000	[€]					
Repair Works	0	[€/MW]	Variation of O&M Costs				
O&M (incl. All variable costs)	1,00	[%/EUR Inve]	0%			8,5	[€/MWh]
Feed-In-Tariff for 15 years (flat)	0	[€/MWh]					
Electricity demand absorption ch.	0,34483	[kWhel/kWhc]					
COP	2,9						
Water demand	0,00000	[m3/kWh]					
Heat energy consumer price	**0,00**	**[€/MWh]**					
Colling energy consumer price	**65,00**	**[€/MWh]**					
Escalation of heat prices	**2,00**	**[%/a]**					
Real escalation of O&M Costs	0	[%/year]					
Primary heat energy costs	0	[EUR/MWh]					
Electricity costs	92	[EUR/MWh]					
Water costs	0	[EUR/m3]					

Year	Discounted CF	Nominal CF	O&M	Investment/ Replacement	Water	Electricity	Primary heat	Cooling Energy sale		Heat sale	
									cooling pr.		heat price
[-]	[€]	[€]	[€]	[€]	[€]	[€]	[€]		[€/MWh]	[€]	[€/MWh]
Esc. %			0								
0	-2.978.000	-2.978.000,00	0	-2.978.000			0				
1	369.567	393.588,79	-29.780,00	0	0	-403.626	0	826.995	65,00	0	0,00
2	361.594	410.128,69	-29.780,00	0	0	-403.626	0	843.535	66,30	0	0,00
3	353.491	426.999,39	-29.780,00	0	0	-403.626	0	860.406	67,63	0	0,00
4	345.293	444.207,50	-29.780,00	0	0	-403.626	0	877.614	68,98	0	0,00
5	337.030	461.759,78	-29.780,00	0	0	-403.626	0	895.166	70,36	0	0,00
6	328.729	479.663,10	-29.780,00	0	0	-403.626	0	913.069	71,77	0	0,00
7	320.417	497.924,48	-29.780,00	0	0	-403.626	0	931.331	73,20	0	0,00
8	312.116	516.551,10	-29.780,00	0	0	-403.626	0	949.957	74,66	0	0,00
9	303.846	535.550,24	-29.780,00	0	0	-403.626	0	968.956	76,16	0	0,00
10	295.625	554.929,37	-29.780,00	0	0	-403.626	0	988.336	77,68	0	0,00
11	287.470	574.696,08	-29.780,00	0	0	-403.626	0	1.008.102	79,23	0	0,00
12	279.395	594.858,13	-29.780,00	0	0	-403.626	0	1.028.264	80,82	0	0,00
NPV	916.574										
Annuity	112.343										

Figure 46: NPV calculation of absorption chiller – 12 years horizon (own calculation)

For answering the question raised regarding the direct comparison of a compressor chiller with an absorption chiller, the district cooling solution need to be calculated without the income of additional heat to heat consumer. This solution implies the necessary investment in a district heating network only to supply the absorption chiller, the chiller and the district cooling network.

Dynamic Investment Calculation for a District Heating system

Financial parameters							
Investment Horizont	12	[years]					
Discount rated / cost of capital	6,5	[%/year]					
Rated Capacity elctrical	0	[MW]					
Sold heating energy		[MWh/a]					
Sold cooling energy	12.723	[MWh/a]					
Primary heat demand	18.067	[MWh/a]					
Full load Hours	1.000	[hours/year]					
Investment Costs	5.888.000	[€]					
Repair Works	0	[€/MW]	Variation of O&M Costs				
O&M (incl. All variable costs)	1,00	[%/EUR Inve]	0%			8,5	[€/MWh]
Feed-In-Tariff for 15 years (flat)	0	[€/MWh]					
Electricity demand absorption ch.	0,02190	[kWhel/kWhc]					
Water demand	0,00740	[m3/kWh]					
Heat energy consumer price	**45,80**	**[€/MWh]**					
Colling energy consumer price	**65,00**	**[€/MWh]**					
Escaltaiton of heat prices	**2,00**	**[%/a]**					
Real escalation of O&M Costs	2,5	[%/year]					
Primary heat energy costs	15	[EUR/MWh]					
Electricity costs	92	[EUR/MWh]					
Water costs	2	[EUR/m3]					

Year	Discounted CF	Nominal CF	O&M	Investment/ Replacement	Water	Electricity	Primary heat	Cooling Energy sale		Heat sale	
									colling pr.		heat price
[-]	[€]	[€]	[€]	[€]	[€]	[€]	[€]		[€/MWh]	[€]	[€/MWh]
Esc. %			2,5								
0	-5.888.000	-5.888.000,00	0	-5.888.000			0				
1	265.897	283.180,40	-58.880,00	0	-188.300	-25.634	-271.000	826.995	65,00	0	45,80
2	264.251	299.720,30	-58.880,00	0	-188.300	-25.634	-271.000	843.535	66,30	0	46,72
3	262.090	316.591,00	-58.880,00	0	-188.300	-25.634	-271.000	860.406	67,63	0	47,65
4	259.470	333.799,11	-58.880,00	0	-188.300	-25.634	-271.000	877.614	68,98	0	48,60
5	256.445	351.351,38	-58.880,00	0	-188.300	-25.634	-271.000	895.166	70,36	0	49,58
6	253.063	369.254,70	-58.880,00	0	-188.300	-25.634	-271.000	913.069	71,77	0	50,57
7	249.369	387.516,09	-58.880,00	0	-188.300	-25.634	-271.000	931.331	73,20	0	51,58
8	245.404	406.142,70	-58.880,00	0	-188.300	-25.634	-271.000	949.957	74,66	0	52,61
9	241.206	425.141,85	-58.880,00	0	-188.300	-25.634	-271.000	968.956	76,16	0	53,66
10	236.808	444.520,98	-58.880,00	0	-188.300	-25.634	-271.000	988.336	77,68	0	54,74
11	232.242	464.287,69	-58.880,00	0	-188.300	-25.634	-271.000	1.008.102	79,23	0	55,83
12	227.538	484.449,74	-58.880,00	0	-188.300	-25.634	-271.000	1.028.264	80,82	0	56,95
NPV	-2.894.218										
Annuity	-354.739										

Figure 47: Economic calculation just cooling with district cooling (comparison) (own calculation)

The calculation provides a negative result.

Through iteration the electricity price was increased until the economic calculation provided the same result as the absorption solution without income of heat. The electric price must be double the price to reach equal economic conditions.

Dynamic Investment Calculation for a District Heating system

Financial parameters							
Investment Horizont	12	[years]					
Discount rated / cost of capital	6,5	[%/year]					
Rated Capacity elctrical	0	[MW]					
Sold heating energy	0	[MWh/a]					
Sold cooling energy	12.723	[MWh/a]					
Primary heat demand	0	[MWh/a]					
Full load Hours	1.000	[hours/year]					
Investment Costs	2.978.000	[€]					
Repair Works	0	[€/MW]	Variation of O&M Costs				
O&M (incl. All variable costs)	1,00	[%/EUR Inve]	0%			8,5	[€/MWh]
Feed-In-Tariff for 15 years (flat)	0	[€/MWh]					
Electricity demand absorption ch.	0,34483	[kWhel/kWhc]					
COP	2,9						
Water demand	0,00000	[m3/kWh]					
Heat energy consumer price	**0,00**	**[€/MWh]**					
Colling energy consumer price	**65,00**	**[€/MWh]**					
Escalation of heat prices	**2,00**	**[%/a]**					
Real escalation of O&M Costs	0	[%/year]					
Primary heat energy costs	0	[EUR/MWh]					
Electricity costs	200	[EUR/MWh]					
Water costs	0	[EUR/m3]					

Year	Discounted CF	Nominal CF	O&M	Investment/	Water	Electricity	Primary heat	Cooling Energy sale		Heat sale	
				Replacement					cooling pr.		heat price
[-]	[€]	[€]	[€]	[€]	[€]	[€]	[€]		[€/MWh]	[€]	[€/MWh]
Esc. %			0								
0	-2.978.000	-2.978.000,00	0	-2.978.000			0				
1	-75.336	-80.233,28	-29.780,00	0	0	-877.448	0	826.995	65,00	0	0,00
2	-56.156	-63.693,38	-29.780,00	0	0	-877.448	0	843.535	66,30	0	0,00
3	-38.762	-46.822,68	-29.780,00	0	0	-877.448	0	860.406	67,63	0	0,00
4	-23.020	-29.614,57	-29.780,00	0	0	-877.448	0	877.614	68,98	0	0,00
5	-8.804	-12.062,29	-29.780,00	0	0	-877.448	0	895.166	70,36	0	0,00
6	4.003	5.841,03	-29.780,00	0	0	-877.448	0	913.069	71,77	0	0,00
7	15.510	24.102,41	-29.780,00	0	0	-877.448	0	931.331	73,20	0	0,00
8	25.818	42.729,03	-29.780,00	0	0	-877.448	0	949.957	74,66	0	0,00
9	35.022	61.728,17	-29.780,00	0	0	-877.448	0	968.956	76,16	0	0,00
10	43.208	81.107,30	-29.780,00	0	0	-877.448	0	988.336	77,68	0	0,00
11	50.458	100.874,01	-29.780,00	0	0	-877.448	0	1.008.102	79,23	0	0,00
12	56.849	121.036,06	-29.780,00	0	0	-877.448	0	1.028.264	80,82	0	0,00
NPV	-2.949.211										
Annuity	-361.479										

Figure 48: Economic calculation electric chiller (comparison) (own calculation)

5 Description of results

With this master thesis, a specific biomass CHP project in Jasenovac were taken as reference and possible heat concepts analysed, with the view through the eyes of an investor. Environmental issues are in general very important, but have not been considered during this work. Using biomass as a prime energy source and producing green electricity and heat out of this renewable energy source is environmental friendly per se.

The heat concepts out of various possible one's, which are being partly very fancy, have been pre-selected according to discussions with the investor. The selection was also done from the perspective which solution does fit in the portfolio of the investor and he can stand behind. The following heat concepts have been selected to be further investigated:

Heat concepts
1. Building up an own district heating system
2. Installation of pellets production plant and use the heat for biomass drying
3. Heat use for cooling networks (Tri-Generation)

Table 26: Possible heat concepts (own source)

This master thesis looked into the heat concept from the demand of the biomass CHP plant side. To be able to get the feed-in tariff in Croatia, a minimum efficiency of the CHP plant is required. This demand is, considering the already fixed heat consumer, minimum 40,000 MWh/a. The investor's perspective to just fulfil this minimum criterion and find out what is the most feasible solution from technical and economic point of view. Probably with the heat concept executed, more available heat will used in practice, but for this work the minimum heat needs to be considered.

Repeating once again the questions:

a. **What is the most promising heat concept from an investor's perspective for a biomass CHP plant in Croatia, considering its technical and economic feasibility?**

b. **Would the implementation of a district cooling network be feasible in Zagreb? What would be the lowest national electricity price for compressor chiller as alternative solution, to still create a breakeven of heat absorber solution?**

5.1 Building up an own district heating system

Jasenovac is a small village in Slavonia at the border to Bosnia with roughly 2,000 inhabitants. The shape of the village is wide and the centre small with not really big heat consumer. Individual houses are primarily found. Starting from necessary heat demand to be sold to heat consumer, to get a rough idea about the area to be supplied with heat, the number of necessary heat consumer were calculated. Here it turned out, that 2,500 households need to be found, whereby Jasenovac out if its inhabitants can provide just around 660. Hence, the investigation and design area needed to be extended to next bigger city Novska, providing approximately 4,500 additional households to the project area.

Following the analyse of the heat demand of each house, a district heating network was designed which finally sums up to 38 km of district heating network trench to supply Jasenovac and Novska. The total heat demand of the heat consumer is 42,240 MWh/a and the connected power 26.4 MW. The resulting investment costs are 19.9 Mio EUR. Yearly incomes for selling heat are 1.65 Mio EUR.

Calculating the benchmarks

$$\frac{Sold\ heat\ energy}{network\ lengh} = \frac{42{,}240\ MWh/a}{38{,}000\ m} = 1.11\frac{MWh}{m}$$

$$\frac{Heat\ consumer\ power}{network\ lengh} = \frac{26{,}400\ kW}{38{,}000\ m} = 0.69\ \frac{kW}{m}$$

The Austrian Kommunalkredit Public Consulting defined in the previous related benchmarks, the request to achieve 0.9 MWh/m as their minimum criteria to subsidize this kind of district heating supplies. This criteria result from minimum quality standards, such a biomass fired district heating network should have, to finally achieve economic efficiency. The request of this minimum criterion is fulfilled, although the connection between the village Jasenovac and the village Brocice, which is located south of Novska, requires a 5 km main pipe district heating connection and does not provide any heat consumer. This pipe need to have a big dimension and creates also heat losses.

The heat losses are calculated with 1,460 kW in total to the connected 26,400 kW. This is a factor of 6% and is very blow the requested 20% from Kommunalkredit.

For the existing houses fired with gas, their current heat price is calculated with 69.7 EUR/MWh including maintenance and chimney sweeper. Houses using fire wood as energy source, would have current energy costs of 33.2 EUR/MWh.

The calculation performed, provides a positive result with a 12 years investment horizon of:

	Heat price [EUR/MWh]		
	69,7	68,5	68
NPV 12 years	551,907 EUR	96,903 EUR	- 92,682 EUR
annuity	67,646 EUR	11,877 EUR	- 11,360 EUR

Table 27: Economic result District heating (own calculation)

A positive result of this solution is provided with a heat price of around 68.5 EUR/MWh. This price is very close to the heating costs of a household with existing gas fired heat supply. Moreover, this heat price is double the price, a household using fire wood needs to pay. Both heat consumer are hard to convince to connect to district heating also in front of the background of additional investment costs he need to take, to cover the heat connection and the price for the heat exchanger. This solution bears several risks in acquisition of heat consumer once the investment in district heating is taken, to go get all heat consumers convinced and connected.

Just if we expand our investment horizon to 20 years this concepts turns into a more positive light. A heat price of 52 EUR/MWh will turn after 20 years into a positive result. This need to be discussed with the investor if this expanded investment horizon is excepted by him and also financing structure provides the necessary frame conditions to enable this calculation.

If we would run the calculation with the heat prices set by HERA for district heating systems in Croatia according to following table, we can see, that even the highest heat tariff which is now for 0.4 HRK/kWh in Split (52 EUR/MWh) for household, is not the price necessary to achieve economic feasibility within 12 years.

Energy entity		Households	Industrial and commercial consumers	Households	Industrial and commercial consumers
		Tariff element - Energy		Tariff element - Power	
		HRK/kWh		HRK/kW	
HEP-Toplinarstvo d.o.o.	Zagreb	0.17	0.34	11.41	15.49
	Osijek	0.16	0.31	11.41	15.49
	Sisak	0.18	0.34	13.09	16.96
	Samobor, Zaprešić and Velika Gorica	0.30	0.34	16.96	16.96
Gradska toplana d.o.o.,	until 31/05/2013	0.38	0.50	24.70	37.10
Karlovac	from 01/06/2013	0.38	0.50	18.00	24.00
Energo d.o.o., Rijeka		0.37	0.37	19.30	20.00
Brod-plin d.o.o., Slavonski Brod		0.34	0.49	22.00	22.00
Tehnostan d.o.o., Vukovar		0.39	0.50	19.00	19.00
Grijanje Varaždin d.o.o.,	until 31/01/2013	0.34	0.34	18.70	18.70
Varaždin	from 01/02/2013	0.44	0.44	20.00	20.00
GTG Vinkovci d.o.o., Vinkovci	until 28/02/2013	0.37	0.42	18.07	18.07
	from 01/03/2013	0.43	0.49	21.28	21.28
Plin VTC d.o.o., Virovitica	until 31/08/2013	0.22	0.23	18.00	18.00
	from 01/09/2013	0.43	0.48	22.00	22.00
Tekija d.o.o., Požega		0.39	-	19.00	-
Hvidra d.o.o., Split		0.40	0.46	11.42	14.85
SKG d.o.o., Ogulin	until 31/10/2013	5.74 HRK/m²	12.18 HRK/m²		
	from 01/11/2013	0.41	0.51	22.00	22.00
Top-terme d.o.o., Topusko	until 31/01/2013	5.10 HRK/m²	6.80 HRK/m²	-	-
	until 31/01/2013	0.05	0.07	12.60	19.89

Table 28: HERA prices of district heating in Croatia (source: HERA)

5.2 Installation of pellets production plant and use the heat for biomass drying

The second selected heat concept is the implementation of a pellet production plant.

After investigated the market situation, it turned out, that Europe is an importer of pellets and has a lack of 6 Mio t/a. This provides the space for covering part of this demand with an additional pellet production plant. This solution is also in line with the investor's portfolio and energy production out of renewable energy.

The pellet solution is a project in the vicinity of the biomass CHP plant. Hence, also synergy effects can be used. The business case itself is a stable project with a product, required in whole Europe and you can easily transport and store it.

As plant size a pellet production of 50,000 t pellet per year was selected, which recieves from the CHP plant the necessary heat demand.

Talks to famous Austrian pellet producer, gained actual operation data. With a general design of the production facility, the investment costs could have been collected from Austrian production companies. The total CAPEX for this project amounts to 9.71 Mio EUR and the annual income from selling pellets are 6.5 Mio EUR.

NPV 12 years	2,000,300 EUR
annuity	245,173 EUR

Table 29: Economic result Pellet production (own calculation)

For the income side, a reasonable pellet price, lower then gained in Austria for the same quality of product is considered. Therefore, the risk to be not able to sell the product due to its origin, is reduced.

5.3 Heat use for cooling networks (Tri-Generation)

A service, which became more important, is cooling energy service. On the one hand side changed climate conditions with warmer summer increased the demand to cool down our offices and flats or houses which we know already from regions more south. On the other hand side, growing wealth enable us to afford compensating the additional investment costs and operation costs of cooling devices.

Commonly used cooling energy production are electrical driven compressor chiller. This higher electrical energy demand is visible in the electrical grids all over in summertime. A sustainable solution to produce cooling is the usage of heat energy in the technology of an absorption chiller.

First step again was getting an overview about the necessary space, which creates the required cooling demand, reflected in the driver heat demand of the absorption chiller. Using different sources of information a difference in achieved fullloadhours of cooling system was visible. Hence, for further and deeper analysis, a deeper investigation into the topic of fullloadhours need to be performed. Out of a producer's brochure, the cooling/heating ratio was calculated with 1 / 1.42.

To use the whole 40,000 MWh/a in a cooling facility with 1,000 h/a, 4 cooling units with 3,516 kW cooling energy each are necessary to be installed. Taking a peak load cooling demand into consideration, cooled space of 531,000 m2 are necessary. Due to the fact, this space is by far not available in Jasenovac, this solution is not realistically be installed there. This brief calculation showed, that just a district cooling system is not realistically doable.

A possible technical solution would be the combination of heat concept with the district heating network and a district cooling network. Looking again into the structure of the buildings, this area has a lack of huge buildings (offices, etc.) which has a high cooling demand. Small cooling demands, need a wide cooling network which will lead into a second expensive district cooling network.

Never the less this technical solution was worth to be further analysed and so I decided to analyse this solution, if it would be installed on a different location. The

City of Zagreb and here the area around "Ulica Grada Vukovara" was selected. This area is rich in high office and administration buildings as well as in big block of flats.

The floor space of the heated and cooled objects was analysed and with the use of unit heating and cooling demands, the respective energy calculated. Requesting the necessary CAPEX and OPEX data by a supplier of this kind of equipmen,t brought the necessary basics for the economic calculation. Investment costs of 5.89 Mio EUR

NPV 12 years	12,648,274 EUR
annuity	1,550,276 EUR

Table 30: Economic result Tri-Generation (own calculation)

5.4 Comparison with el. compressor chiller

Competitor to the absorption chiller and widely used in the cooling sector, are electrical driven compressor chiller. Lot of supplier are available on the market. Due to high demand of these units, a development and innovation proceeded. Hence, the efficiencies increased.

The economic result, if instead an absorption chiller, a compressor chiller electrical driven would be installed, is in comparison with the absorption solution:

	El compressor	Tri generation
CAPEX	2.6 Mio EUR	5.53 Mio EUR
Income	0.82 Mio EUR	3,29 Mio EUR
Heat price with CHP	0 EUR/MWh	15 EUR/MWh
OPEX	0.16 Mio EUR	1.33 Mio EUR
NPV 12 years	3,486,316 EUR	12,648,274 EUR
annuity	427,311 EUR	1,550,276 EUR
Return on Invest	32%	60%

Table 31: Economic results compressor vs. absorption chiller (own calculation)

Here the absorption solution provided a higher result than the electrical compressor does. Reason for this is the additional heat sale, which contributes to the repayment of the investment costs. Double the investment creates 4 times more income.

5.5 Summary of results

As heat concepts out of the 3 pre-selected, just the district heating system and the pellet production facility is realistically feasible to be implemented for the biomass CHP plant in Jasenovac. The Tri-generation with production of cooling energy and running a district cooling grid does not work out there, due to the building structure.

For the district heating concept also here, the wide area of heat consumers, connected to the district heating network, demands high investment costs in district heating pipes and bears a high risk of a project default, if the heat consumer can't be acquired accordingly. The heat price collected from the heat consumer need to be higher than the actual costs of gas or fire wood. Also, the necessary heat price can't compete with the heat price defined by HERA, the Croatian regulatory agency, for the most expensive district heating network. The economic calculation results in low returns per year compared to the high previous investment.

The pellet project on the other hand has reasonable investment costs and creates a good return on invest. In the economics is enough room to have reduced income. The risk of costs is relatively low because heat is charged from same organisation and electricity bought from public grid. The biomass price has to follow fixed pricing rules.

Producing through tri-generation also cooling would be the most feasible solution due to lower investment costs and a high return on invest, but this solution would win a comparison in an area with big cooling energy consumer in a narrow area, which is not valid and applicable for the CHP plant location in Jasenovac.

	District heating	Pellet production	Tri generation
CAPEX	19.9 Mio EUR	9.71 Mio EUR	4.72 Mio EUR
Income	2.9 Mio EUR	6.5 Mio EUR	3.29 Mio EUR
Heat price with CHP	15 EUR/MWh	15 EUR/MWh	15 EUR/MWh
OPEX	0.732 Mio EUR	5.064 Mio EUR	1.33 Mio EUR
NPV 12 years	551,907 EUR	2,000,300 EUR	12,648,274 EUR
annuity	67,646 EUR	245,173 EUR	1,550,276 EUR
Return on Invest	14.6%	67%	70%

Table 32: Summary of economic results of the heat concepts (own calculation)

Summing up all investigations and the out coming results to the question

a.) What is the most promising heat concept from an investor's perspective for a biomass CHP plant in Croatia considering its technical and economic feasibility?

Answer a.)
This work documents, that a **Pellet Production plant** is from an investor's perspective the most promising heat concept for the CHP plant in Jasenovac.

For answering question

b.) Would the implementation of a district cooling network be feasible in Zagreb? What would be the lowest national electricity price for compressor chiller as alternative solution, to still create a breakeven of heat absorber solution?

a comparison of the economic calculation of the district cooling project with the no income from heat were made.

Answer b.)
This work documents, that for the selected area in Zagreb, a **district cooling network is feasible**.

Comparing to a just cooling solution with absorption chiller, the solution of compressor chiller to reach the same feasibility as the absorption solution, the price for electricity needs to be 2 times higher for this specific location.

6 Conclusions

Unfortunately heat concepts, or more the missing heat concepts of biomass CHP projects, which are wood biomass driven or also applicable for biogas projects, influencing the energetic and economic feasibility of such a project.

At the beginning of the development of biomass project the focus seated on enabling and the quick installation of such projects. The feed-in tariffs of various countries where also Austria and Croatia have been a part of, just compensated electrical energy production. Unimportant which efficiency this projects had, the high feed-in tariff at that time, compensated the prime energy demand. Most of the project did not have any heat concept and so these projects just used, depending on its technology, 25-41% of the fuel energy demand. In some projects, a sole electrical production showed a better economic result than a cogeneration operation. What followed were the installation of various projects all over with just electrical production and releasing the useable heat into the atmosphere. Austria has here huge experience in that field. A logic result out of the big numbers of plants, was a big demand of biomass. The price of that good, which did not enjoy that importance before, increased dramatically. This price increase was not included in any the business cases and so lot of the projects went in financial trouble. The better plants could compensate this higher operation costs, but will face their problems when they ran out of the regulated feed-in tariff after the 12 years. The last plants started operation in 2007 hence, within the next 4 years, when the feed-in tariff is over, I expect lots of problems in this sector.

The countries learned earlier already, adopted its feed-in tariff systems and required a minimum efficiency of 50 to 60%. With just an electrical production, this result is not achievable, hence a heat concept is necessary.

View days before the author finished this master thesis, the author attended to a convention in Vienna for district heating. What was mentioned during a discussion, was the affordable energy price for the population. From my point of view, this is a very important factor to have always in mind when structuring a project concept. If something overshoots the affordable price for the end consumer, at the long run politics is obliged to interfere and probably retrospectively changes laws or invents new ones to reduce the incentive. For example, this happens with renewable energy projects in Romania and Bulgaria.

In Eastern Europe where probably the conditions for the implementation of biomass CHP projects are already better than in Central and Western Europe, a heat concept is one of the biggest challenges of the project. Just in view countries, existing district heating systems are available where the heat energy of a biomass CHP can be sold to. For these cases, the solution is easy. Nevertheless, for greenfield projects the developer of a project needs to carefully investigate the right solution. In addition, there are different perspectives how you can look at such a project.

The learning effect out of this master thesis is that especially for Eastern European countries the heat concept in the form of a district heating system is difficult the realize. On the one hand side the village structure with small heat consumer requires high investments in district heating systems, this on the other hand would require higher heating costs which are exceeding the above mentioned affordable costs.

From the author’s point of view, what is also reflected in the results of this master thesis, a separate project using the heat completely for a process and producing a good where a demand is available in Central and Western Europe is the best solution. This is represented by the Pellet production facility. The project, beside the economic effect, creates additional labour and produces a transportable and storable energy carrier. Croatia having currently not the pellet demand, but will become an off taker of this renewable energy source soon, since Croatia mentioned this kind of REN to support the use to enable its 2020 targets.

A district cooling network is feasible in compact areas like bigger cities where heat and cooling demand is provided in a narrow area. Hence, district cooling requires a certain building structure to be feasible and can hardly be realized in village shaped area like Jasenovac.

When a comparison of absorption and electrical driven compressor chiller is drawn, the advantages of the absorber solution are coming up if in that project also the heat energy is used. Otherwise, through higher investment costs of the absorber and very low electrical tariffs, as well as low fullload hours of a conventional space cooling installation, the electric chiller has an advantage.

Since cooling as energy service gets of more importance and unfortunately due to the expected average temperature increase, we all need to concern about energy production and energy efficiency. The energetic efficient use of energy should be our mayor goal.

More development and research in high efficient cooling units should be invested. The people who are in charge of development of energy project should more forced or better have a simple self-conception to include highest efficient solutions into our energy concepts to prevent this world from a collapse.

We have already many efficient technologies available and some will be further developed in the future. We need to use them!

And always have the following in mind:

Making developments sustainable means, the current generation satisfies its needs, without endangering the ability of future generations,
to satisfy their needs."

Brundtland-report – Our common future (1987)

REFERENCES:

Aebiom European Energy Outlook 2014

BP British Petrol (2011): "*Energy Outlook 2030, London Januar 2011*", BP, 2011

Croatian Ministry of Economy, National Action Plan for reneable energy sources to 2020, 2013

European Commission Joint Research Centre, N. Pardo, K. Vatopoulos, A. Krook-Riekkola, J.A. Moya, A. Perez, "Heat and cooling demand and market perspective", 2012

Fischer A., Lecture: "Sustainable Energy Concepts", FH Campus Wien, 2015

HERA, Croatian Energy Regulator Agency, Annual Report 2013, 2014

Hrvatske Sume, company presentation, 2013

International Energy Agency (2013): "*Key World Energy Statistics*", International Energy Agency, 2013

Janzuing B., article „Der Holzofen aus der Werkstatt eines Flugingenieurs", brochure pellets Markt und technik 01-04, 2004

Kost, Mayer, Thomsen, Harmann, Senkpiel, Philpps, Nold, Lude, Schlegl, Studie, „Stromgestehungskosten Erneuerbare Energien", Frauenhoferinstitut für Solarenergie ISE, 2013,

Magistrat der Stadt Wien, „Fernkälte in Wien – Umweltfreundliche Gebäudeklimatisierung im Gewerbebereich, 2013

Neubarth J., Kaltschmitt M., „Erneuerbare Energien in Österreich", Springer Verlag, 2000

New Bulidngs Institute, Absorption Chiller, Souther California Gas Company, New Buildings Institute, Advanced Design Guideline Series, 1998

Obernberger I., Band 1: „Nutzung fester Biomasse in Verbrennungsanlagen“, dbv-Verlag, 1998

Obernberger I. Hammerschmid A., Band 4: „Dezentrale Biomasse-Kraft-Wärme-Kopplungstechnologien“, dbv-Verlag, 1999,

Obernberger I., “Final publishable report, Biomass fired CHP plant based on an ORC cycle- Project: ORC-STIA Admont”, 2001

Ortner M., Lecture: “Project Development, Planning, Construction and Implementation of Biomas Heating and CHP plants”, 2014

Resch G.: REN-Lecture, „Potentials/Economics of electricity generation from renewable energy sources“, 2013

Simader R., Rakos C., Klimatisierung, Kühlung und Klimaschutz: Technologien, Wirtschaftlichkeit und CO2-Reduktionspotenziale, Austrian Energy Agency, 2005

Sommer Werner; „Biomsse - Kraftwerk in Güssing“, article on TU-Wien homepage

United Nations, Forest product conversion factors for the UNECE Region, 2010

Zangheri P., Armani R., Pietrobon M., Pagliano L., (eERG) end-use Efficiency Research Group Politecnico di Milano Maria Fernandez Boneta (CENER) National Renewable Energy Centre Andreas Müller (EEG) Vienna University of Technology, Entranze, Heating and cooling energy demand and loads for building types in different countries of the EU, 2014

Attachment 1:
Average price calculation for Jun 2015
provided by HROTE

HROTE HRVATSKI OPERATOR TRŽIŠTA ENERGIJE d.o.o. CROATIAN ENERGY MARKET OPERATOR Ltd.

Referentne cijene električne energije uravnoteženja

kn/MWh

Datum	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20	H21	H22	H23	H24	Average
2015.06.01	140,32	119,77	109,92	104,99	112,04	144,68	336,39	341,13	344,58	341,24	316,45	312,47	338,44	308,49	293,07	293,94	319,26	361,75	373,73	410,64	363,27	471,37	436,39	310,69	291,88
2015.06.02	208,51	186,14	171,85	161,32	162,23	166,96	329,49	350,91	361,41	344,32	320,51	320,41	317,67	293,04	275,74	277,68	279,27	318,27	314,45	285,87	289,28	280,37	235,34	167,78	267,45
2015.06.03	157,00	241,18	74,03	66,58	85,06	272,87	345,00	377,14	422,03	409,32	393,87	381,16	374,64	376,68	388,28	405,87	404,01	390,03	362,21	379,22	390,29	403,82	295,72	271,69	319,49
2015.06.04	236,06	211,69	200,55	190,16	192,36	199,79	212,71	290,38	284,96	281,20	284,92	378,96	369,78	330,14	339,39	318,54	289,20	274,46	255,77	307,55	310,01	301,56	276,62	237,84	273,94
2015.06.05	216,88	200,96	187,47	171,10	181,48	185,73	230,22	289,96	290,91	288,71	301,29	282,49	326,20	257,02	265,70	243,91	227,27	259,90	288,10	292,54	299,59	311,30	285,03	235,08	254,95
2015.06.06	197,86	185,23	174,58	164,58	164,16	155,02	160,41	159,19	188,23	191,41	182,20	177,77	157,30	151,99	134,78	132,28	144,87	174,73	201,02	236,02	292,61	340,86	275,56	226,17	190,37
2015.06.07	187,47	167,53	152,75	137,82	122,35	118,26	122,81	133,76	142,52	170,94	205,66	208,32	194,06	157,56	145,55	129,25	141,46	206,35	259,22	294,89	341,24	420,84	333,32	286,55	199,19
2015.06.08	166,85	165,86	144,49	135,09	140,24	171,85	252,51	322,52	329,23	325,51	300,57	362,89	375,02	354,59	359,47	369,41	369,82	297,54	359,10	324,15	401,77	412,12	353,18	256,61	293,77
2015.06.09	185,75	164,73	143,12	130,54	138,04	160,94	222,04	308,91	345,56	324,38	318,54	320,74	317,89	315,13	311,34	303,61	269,38	273,43	280,22	298,68	297,31	315,24	275,63	207,71	259,54
2015.06.10	198,35	178,07	161,47	153,09	165,64	186,86	283,10	319,41	360,46	381,57	389,23	394,76	385,82	385,82	393,89	399,31	397,26	387,14	385,59	364,33	368,00	352,69	267,37	241,44	312,53
2015.06.11	221,54	208,47	192,81	181,37	188,04	195,20	238,75	309,14	314,98	345,91	338,10	347,19	336,24	297,73	319,30	343,56	335,97	341,40	311,07	326,73	329,11	320,81	280,48	228,25	285,51
2015.06.12	231,70	216,88	210,59	198,39	201,04	210,78	260,77	310,81	335,33	331,09	340,67	374,90	384,15	369,75	403,78	417,47	348,75	342,27	322,82	326,50	313,23	326,61	293,90	249,71	305,08
2015.06.13	200,89	181,18	166,43	157,26	153,89	149,00	152,60	176,93	208,85	221,96	216,31	212,56	206,31	195,16	177,43	166,36	174,36	179,66	210,67	218,21	227,65	248,95	222,87	183,68	192,05
2015.06.14	124,82	98,93	100,29	85,36	69,33	51,21	49,77	68,19	90,97	123,87	121,75	158,78	147,46	134,71	123,72	116,51	108,14	129,40	180,34	216,81	214,15	236,36	253,95	194,22	133,29
2015.06.15	166,40	148,77	126,20	115,38	115,68	132,66	236,02	323,09	343,71	339,16	344,24	367,43	389,30	397,98	431,26	411,44	347,08	330,55	304,55	324,91	351,33	431,42	353,49	316,72	297,87
2015.06.16	206,54	202,74	177,01	192,09	191,22	192,51	262,33	376,46	380,70	398,14	408,60	412,31	396,47	393,93	388,32	380,70	345,37	338,06	304,29	303,61	334,12	345,64	277,83	232,80	310,07
2015.06.17	218,85	193,08	185,39	177,24	177,46	194,29	251,83	324,83	324,60	297,77	299,55	316,19	324,64	288,79	284,12	233,29	226,24	238,71	272,52	287,61	284,96	252,44	249,40	194,03	254,08
2015.06.18	181,94	161,32	147,10	132,21	140,20	166,24	214,00	286,55	318,69	320,02	315,92	320,02	306,26	285,64	271,65	265,40	262,63	245,73	254,98	271,84	307,70	325,25	283,78	250,01	251,46
2015.06.19	242,28	231,82	222,49	215,25	218,21	233,26	292,52	304,78	317,74	354,05	296,78	292,65	321,15	294,93	288,10	319,60	325,59	260,66	288,37	297,96	317,48	326,99	281,70	287,42	284,66
2015.06.20	252,78	207,52	192,28	182,09	180,12	178,83	186,75	270,36	292,01	266,16	255,70	266,31	260,55	265,78	260,55	252,13	250,43	251,26	224,01	240,69	248,61	243,49	247,43	214,76	237,11
2015.06.21	180,00	139,75	137,85	136,45	117,77	100,71	107,04	121,29	141,49	159,12	164,50	190,76	166,32	173,10	151,08	140,43	136,53	161,16	216,50	234,70	248,30	250,54	245,08	213,21	168,07
2015.06.22	197,17	182,31	173,03	165,07	159,35	179,51	267,60	343,93	365,12	358,07	351,33	350,83	322,52	316,91	323,43	290,72	310,88	306,83	324,91	334,19	311,26	291,82	287,46	260,81	282,29
2015.06.23	230,57	217,49	206,88	180,72	180,57	188,23	262,71	331,69	343,90	338,86	319,30	367,97	364,25	359,89	376,23	385,97	375,02	345,60	343,78	284,20	285,11	275,14	284,65	243,07	295,49
2015.06.24	190,81	173,56	155,40	143,26	147,60	172,35	298,45	317,33	328,36	318,20	314,37	327,45	328,36	318,58	269,15	312,74	261,08	248,91	323,81	324,45	318,08	311,41	296,21	261,15	269,21
2015.06.25	220,29	212,45	193,76	181,86	197,10	200,89	246,37	311,57	316,34	311,19	298,73	298,87	262,63	255,77	251,34	254,41	253,65	294,93	307,93	314,60	317,48	294,85	325,17	271,99	266,42
2015.06.26	242,20	222,04	205,36	196,04	200,05	216,12	257,08	317,63	329,87	310,69	302,43	284,27	274,84	277,11	263,81	267,98	269,11	277,83	289,20	284,96	277,83	268,73	270,86	233,18	264,13
2015.06.27	266,88	217,72	196,04	192,28	200,70	189,33	204,30	238,94	259,18	265,32	260,96	246,90	241,94	195,39	197,10	187,55	169,47	202,02	242,32	251,64	261,00	261,00	259,64	231,51	226,63
2015.06.28	181,94	165,07	141,08	127,13	116,74	92,37	96,88	124,25	150,74	150,10	161,09	155,40	130,77	110,30	96,50	97,71	110,68	181,18	245,31	260,77	271,39	276,92	293,07	263,05	166,69
2015.06.29	215,14	201,87	200,89	179,43	188,49	202,40	280,07	330,14	343,56	331,50	326,46	322,56	329,07	330,48	294,51	296,97	300,19	311,15	332,37	351,78	344,09	317,55	318,99	284,39	288,92
2015.06.30	244,25	228,18	213,77	208,16	209,98	228,78	276,28	337,07	341,40	321,53	315,09	322,59	353,07	339,31	330,18	324,00	288,60	326,16	317,44	328,32	325,97	312,70	306,37	276,58	294,82
																									257,90

Attachment 2:

Biomass fuel analysis

Prüfbericht Nr.: BEA 2014129

Brennstoffanalyse „Scheinindigo/ Amorpha fruticosa“

Antragsteller:	iC projecte Project Development and Trading GmbH z.Hd.: Hrn. Fischer Dreyhausenstraße 18/2 1140 Wien
Gegenstand:	1 Muster Brennstoff „Scheinindigo/ Amorpha fruticosa“
Inhalt:	Brennstoffanalyse
Antrag:	vom 23.07.2014 durch Hrn. Fischer
Datum der Probenahme / Befundaufnahme:	-
Ort der Probenahme / Befundaufnahme:	-
Zeichen:	Woj
Datum:	17.08.2014

1 AUFGABENSTELLUNG / SACHVERHALT

An dem Muster „Scheinindigo/ Amorpha fruticosa“ sollte eine Brennstoffanalyse chemischer und physikalischer Parameter nach EN 14961-1 „Feste Biobrennstoffe — Brennstoffspezifikationen und –klassen, Teil 1: Allgemeine Anforderungen“ durchgeführt werden.

2 GELTUNGSBEREICH

Die Prüfergebnisse beziehen sich ausschließlich auf die untersuchten Prüfgegenstände. Sie stellen in der Regel nicht das einzige Kriterium zur Bewertung des Produktes und seiner Eignung für den spezifischen Anwendungsbereich dar. Die Verantwortung für eine richtige und repräsentative Probenahme wird nur übernommen, wenn diese im Auftrag enthalten ist und durch BEA durchgeführt wird.

3 PROBEMATERIAL

1 Muster Biobrennstoff (2 Stück Holz je ca. 30cm), Bezeichnung „Scheinindigo/ Amorpha fruticosa“, durch Herrn Fischer am 24.07.2014 überbracht, interne Probennummer: BEA2014129.

Abbildung 1: Brennstoffmuster „Scheinindigo/ Amorpha fruticosa“ im Anlieferzustand

4 PRÜFERGEBNISSE

Tabelle 1: Analysenergebnisse des Brennstoffmusters Bezeichnung „Scheinindigo/ Amorpha fruticosa“

Probe 2014129	**Standard**	**Einheit**	**Brennstoff Scheinindigo**
Wassergehalt	EN 14774-2	[%]	41,4
Aschegehalt 550° (wf)	EN 14775	[%]	1,47
Heizwert (roh)	EN 14918	[MJ/kg]	9,3
Heizwert (wf)	EN 14918	[MJ/kg]	17,6
Schwefelgehalt (wf)	EN 15289	[%]	0,015
Chlorgehalt (wf)	EN 15289	[%]	<0,01
Kohlenstoffgehalt (wf)	EN 15104	[%]	48,0
Wasserstoffgehalt (wf)	EN 15104	[%]	6,2
Stickstoffgehalt (wf)	EN 15104	[%]	0,45
Ascheschmelzverhalten			
Schrumpfungstemp. SST	CEN/TS 15370-1	[°C]	740
Erweichungstemperatur DT	CEN/TS 15370-1	[°C]	1260
Halbkugeltemperatur HT	CEN/TS 15370-1	[°C]	1520
Fließtemperatur FT	CEN/TS 15370-1	[°C]	1540

Anmerkungen: wf: Probe wasserfrei
Die Probe wurde für die Bestimmung des Ascheschmelzverhaltens bei 550°C verascht.

Institut
für
Bioenergie

Das vorliegende Prüfbericht Nr. **BEA 2014129**

umfasst 4 Blätter mit 1 Tabelle(n), 1 Abbildung(en), 0 Beilag(en).

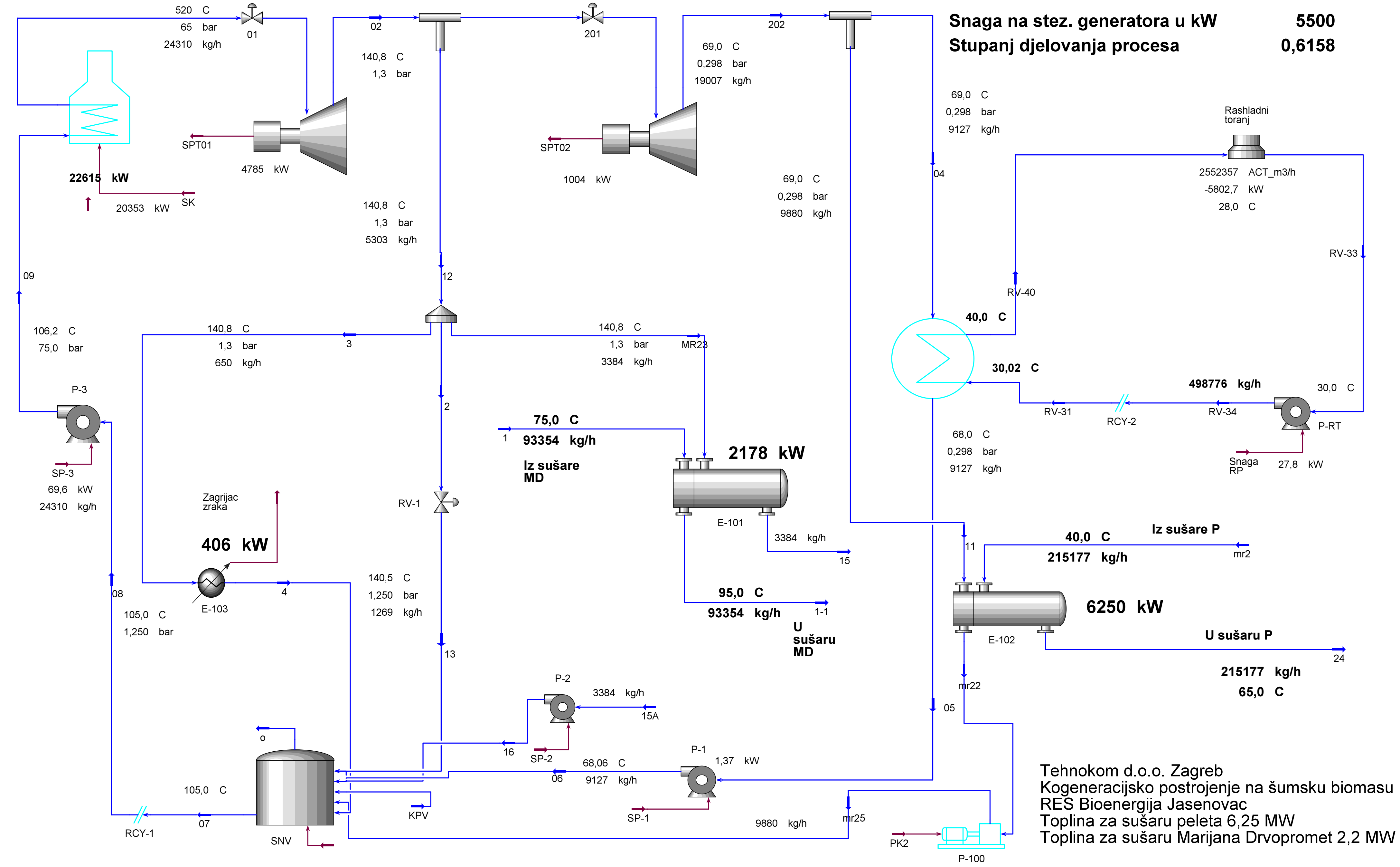
Verantwortlicher Prüfleiter

....

DI (FH) Magdalena Wojcik

Attachment 3:

Balance of heat


Snaga na stez. generatora u kW 5500
Stupanj djelovanja procesa 0,6158
520 C
65 bar
24310 kg/h
01
02
140,8 C
1,3 bar
201
202
69,0 C
0,298 bar
19007 kg/h
SPT01
4785 kW
SPT02
1004 kW
22615 kW
20353 kW
SK
140,8 C
1,3 bar
5303 kg/h
69,0 C
0,298 bar
9127 kg/h
04
69,0 C
0,298 bar
9880 kg/h
Rashladni toranj
2552357 ACT_m3/h
-5802,7 kW
28,0 C
RV-33
RV-40
09
12
106,2 C
75,0 bar
140,8 C
1,3 bar
650 kg/h
3
140,8 C
1,3 bar
3384 kg/h
MR23
40,0 C
30,02 C
498776 kg/h
30,0 C
P-3
2
RV-31
RCY-2
RV-34
P-RT
75,0 C
93354 kg/h
1
Iz sušare MD
2178 kW
68,0 C
0,298 bar
9127 kg/h
Snaga RP
27,8 kW
SP-3
69,6 kW
24310 kg/h
Zagrijac zraka
RV-1
E-101
3384 kg/h
15
Iz sušare P
40,0 C
215177 kg/h
mr2
11
406 kW
E-103
4
08
105,0 C
1,250 bar
140,5 C
1,250 bar
1269 kg/h
95,0 C
93354 kg/h
1-1
U sušaru MD
6250 kW
E-102
U sušaru P
24
215177 kg/h
65,0 C
13
P-2
3384 kg/h
15A
mr22
05
o
16
SP-2
68,06 C
9127 kg/h
06
P-1
1,37 kW
105,0 C
07
RCY-1
SNV
KPV
SP-1
9880 kg/h
mr25
PK2
P-100
Tehnokom d.o.o. Zagreb
Kogeneracijsko postrojenje na šumsku biomasu
RES Bioenergija Jasenovac
Toplina za sušaru peleta 6,25 MW
Toplina za sušaru Marijana Drvopromet 2,2 MW

Attachment 4:

Information from company Benndorf & Hildebrand

Gmail by Google

Fischer, Alexander <a.fischer@ic-projecte.org>

Vorabinformationen Maschinenrichtpreise BV KWKK Kroatien - IC-PROJECTE

3 Nachrichten

Klose, Sven <ske@benndorf-hildebrand.eu> 13. November 2015 um 14:25
An: "a.fischer@ic-projecte.org" <a.fischer@ic-projecte.org>

Sehr geehrter Herr Fischer,

wie telefonisch besprochen, vorab ein paar Maschinenrichtpreise für Ihre Kalkulationen.

Die Preise sind grob vorkalkuliert und kalkulieren einen möglichen Anlagebauer (Wiederverkäufer) bereits ein.

1 Stk. Turbokompressormaschine 3500kW ca. €245.000,-

1 Stk. Turbocorkompressormaschine 3500kW ca. €370.000,-

1 Stk. Absorptionskältemaschine 3500kW ca. €420.000,- - €500.000,- (stark von den Randbedingungen abhängig)

1 Stk. offener Axialkühlturm (4 Zellen á 1 Ventilator) ca. €300.000,- (Wasserbehandlung ist nicht enthalten)

Die Absorbervarianten sind bereits in der Berechnung/Auslegung. Wir bieten Ihnen sobald wie möglich mit entsprechendem Detaillierungsgrad an.

Sollten Sie Fragen haben, so bin ich (begrenzt auch am Wochenende) per Mail oder mobil unter +49/173/6089652 erreichbar.

Ihnen ein schönes Wochenende und beste Grüße nach Wien!

Sven Klose

Planer- und Projektberatung

BENNDORF HILDEBRAND KÄLTESYSTEME

Benndorf und Hildebrand GmbH

tel +49 (0) 30 49 97 92 - 21

fax +49 (0) 30 49 97 92 - 821

mail ske@benndorf-hildebrand.eu

web www.benndorf-hildebrand.eu

Sitz: Bürgerstraße 17, 13409 Berlin

Handelsregister: Berlin Charlottenburg

HRB-Nr.: 64443, USt.ID-Nr.: DE190494241

Geschäftsführer: Ralf Benndorf, Ralf Jaroni

Sven Klose, Frank Hartmann

Klose, Sven <ske@benndorf-hildebrand.eu> 16. November 2015 um 15:23
An: "a.fischer@ic-projecte.org" <a.fischer@ic-projecte.org>

Sehr geehrter Herr Fischer,

wie besprochen, kann man bei Kompressormaschinen als Grundlage für eine grobe Wirtschaftlichkeitsberechnung den sog. ESEER-Wert (European Seasonal Energy Efficiency Ratio) heranziehen.

Dieser Wert errechnet sich auf Grundlage der Teillastwerte bei 100, 75, 50 und 25% und wichtet diese nach Häufigkeit pro Jahr.

	ESEER parameters		
Part load ratio	Air temperature (°C)	Water Temperatures (°C)	Weighting coefficients
100	35	30	3%
75	30	26	33%
50	25	22	41%
25	20	18	23%

Für die als erste Näherung betrachteten Maschinentypen bedeutet das:

(Der EER ist der Effizienzwert bei Vollast)

Turbokompressormaschine 3500kW EER ca. 6,3; ESEER ca. 7,0

Turbocorkompressormaschine 3500kW EER ca. 5,8; ESEER ca. 8,5

Absorptionskältemaschine 3500kW elektr. Leistungsaufnahme konstant, da nur die internen

	Umwälzpumpen Strom aufnehmen (Regelung vernachlässigt). Die el. Leistungsaufnahme einer Maschine dieser Größenordnung beträgt ca. 17kW
offener Axialkühlturm (4 Zellen á 1 Ventilator)	Leistungsaufnahme ca. 60kW (4x 15kW) bei Vollast

Mit freundlichen Grüßen

Sven Klose

Planer- und Projektberatung

BENNDORF HILDEBRAND KÄLTESYSTEME

Benndorf und Hildebrand GmbH

tel +49 (0) 30 49 97 92 - 21

fax +49 (0) 30 49 97 92 - 821

mail ske@benndorf-hildebrand.eu

web www.benndorf-hildebrand.eu

Sitz: Bürgerstraße 17, 13409 Berlin

Handelsregister: Berlin Charlottenburg

HRB-Nr.: 64443, USt.ID-Nr.: DE190494241

Geschäftsführer: Ralf Benndorf, Ralf Jaroni

Sven Klose, Frank Hartmann

Von: Klose, Sven
Gesendet: Freitag, 13. November 2015 14:26
An: 'a.fischer@ic-projecte.org'
Betreff: Vorabinformationen Maschinenrichtpreise BV KWKK Kroatien - IC-PROJECTE

[Zitierter Text ausgeblendet]

Fischer, Alexander <a.fischer@ic-projecte.org> 17. November 2015 um 08:53
Entwurf

---------- Weitergeleitete Nachricht ----------
Von: **Klose, Sven** <ske@benndorf-hildebrand.eu>
Datum: 16. November 2015 um 15:23
Betreff: AW: Vorabinformationen Maschinenrichtpreise BV KWKK Kroatien - IC-PROJECTE
An: "a.fischer@ic-projecte.org" <a.fischer@ic-projecte.org>
[Zitierter Text ausgeblendet]

--

Mit freundlichen Grüßen | Best regards

EUR Ing. Alexander Fischer

Partner, Authorized officer

iC projecte Project Development and Trading GmbH

Dreyhausenstraße 18/2

1140 Wien

phone: +43 (1) 985 9855-20

mobile: +43 664 161 0 689

a.fischer@ic-projecte.org

www.ic-group.org