4th SEMESTER PROJECT, AALBORG UNIVERSITY
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IMPLEMENTATION OF SUSTAINABLE PRODUCTION UNITS IN THE HEATING SECTOR

AALBORG UNIVERSITY
STUDENT REPORT

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Title:

Implementation of Sustainable Production Units in the Heating Sector

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Participants:

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Synopsis:

This project seeks to compare how implementation of sustainable production units can reduce the CO_2 emissions for the district heating sector, to achieve the goal of being CO_2 free, in the most feasible way. The production units that will be implemented are a heat pump, biomass boiler and a biomass turbine. Therefore the scenario with the implementation of these production units will be compared to a Reference model, from an economical and technical perspective. To simulate the scenarios is the simulation tool called EnergyPRO used. The investment of a heat pump, biomass boiler and the biomass turbine, is favorable seen from from a economical and technical perspective, it will give an positive Net present value for the company, as well as removing the CO_2 emissions from the production.

Report pages: 34
Appendix pages: 0
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Preface

This Semester Project is written by a 4^th semester student on the master's program of Sustainable Energy Planning and magagement at Aalborg University.

A special thanks to my supervisor Peter Sorknæs for guidance as well as inputs, feedback throughout the project, and being available quick responding.

Readers guide The figures and tables in this report will be numerated. e.g a table referred to as Table 4.6 is the 6 th. figure in Chaper 4. The figures and tables in the report will have a caption with an explanation.

Just before the Table of Contents a Nomenclature is placed, at page vii, the Nomenclature have all the acronyms used in the report. Furhthermore will the acronym be in brackets after first time the word is used in the report.

In the report Sources will be noted in brackets by the name or website and the year of publish, i.e if the auther is called Jens Jensen and its published in 2019 it will be noted as [Jens Jensen, 2019]. A source list can be found on Page 31.

Nomenclature

Acronyms

AAU	*Aalborg University*
bb	*Biomass boiler*
CHP	*Combined Heat and Power*
CO_2	*Carbondioxid*
COP	*Coefficient of Performance*
DH	*District Heating*
dkk	*Danish krone*
DPT	*Dynamic Payback Time*
GJ	*Giga Joule*
HOP	*Heat only production*
HP	*Heat Pump*
MW	*Mega Watt*
MWh	*Mega Watt hour*
NG	*Natural gas*
Nm^3	*normal cubic meters*
NO_X	*Nitric oxide*
NPV	*Net Present Value*
O&M	*Operation and maintenance*
RE	*Renewable Energy*

Contents

1 Introduction

The amount of carbon dioxide (CO_2) was in June 2018 at 410.79 parts per million (ppm) this is the largest amount of CO_2 in the atmosphere in the last 800.000 years. This number is steadily increasing each year, which can be seen on 1.1. [National Oceanic and Atmospheric Administration, 2018]

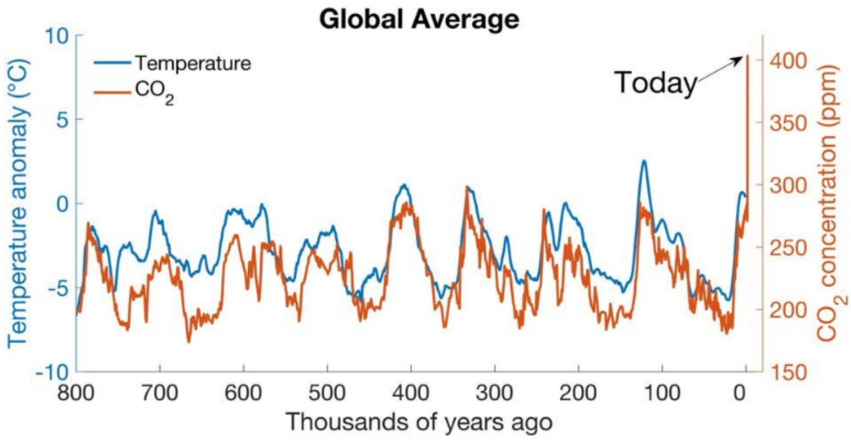

Figure 1.1: Illustration of the increase in CO_2 and temperature for the last 800,000 years [World Economic Forum, 2016]

Furthermore it can be seen that the temperature has been following the amount of CO_2 in the atmosphere, this increase in temperature can result in huge changes, which has already started to happen, each year the amount of ice at the poles are reducing[The IMBIE team, 2018], which results in raising water level [National Ocean Service, 2018]. For example an increase in temperature causes a higher higher chance for wild fires, but by reducing the temperature the wild fires we decrease as well [Qiaohong Sun et al, 2019].

To avoid the increasing amount of CO_2 in the atmosphere, and the changes that follows, the EU commission has set up goals to reduce the amount of CO_2 emissions, the goals that have been established are: [European Commission, 2019]

- At least 40% cuts in greenhouse gas emissions (from 1990 levels)
- At least 32% share for renewable energy
- At least 32.5% improvement in energy efficiency

To reach these goals guidelines has been made, that a reduction of 1,5 % of the annually CO_2 emission from 2020 to 2030, and between 3,3 and 4,6 % annually reduction from 2030 to 2050 is required .

The government in Denmark has made specific goals for Denmark, that by the year 2030 the District heating sector has to be 100 % independent of fossil fuels. Furthermore, the entire energy sector has to be 100 % independent of fossil fuels by the year 2050 [Klima-, Energi- og Forsyningsministeriet, 2018]. In 2018 the total danish energy demand was at 749 PJ, whereas 138.9 PJ is in the district heating sector. For the total danish energy demand 474 PJ of the energy is produced by fossil fuels and non-biodegradable waste. For the district heating sector 53.29 PJ of the heat is based on fossil fuels and non-biodegradable waste[Energistyrelsen, 2017]. Therefore, by removing the CO_2 from the district heating sector, the total amount of energy produced by fossil fuels and non-biodegradable waste, will be reduced by 11.45 %.

In Denmark 64.4 % of the households are heated by district heating [Energistyrelsen, 2017]. District heating consist of heat production units that produces hot water, the hot water is used for space heating and domestic water supply for the consumers. The consumers pay a yearly subscription, which is equal to the cost of producing the hot water, and maintaining the heat production units and the district heating grid[Sven Werner, 2019]. The sizes of the district heating grids variate depending on the heat demand that has to be covered. Therefore, the district heating companies are not operated the same way, and they can be using different technologies and sizing to produce the heat.

The production share for the district heating can be divided into two groups, one where it is combined heat and power (CHP) and one where it is district heating (DH) only. The production share can be seen on Figure 1.2.

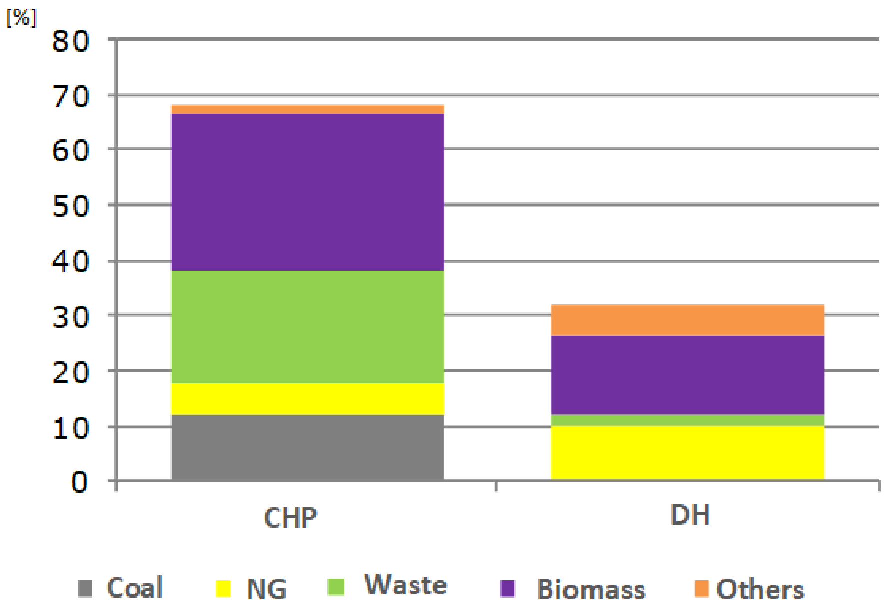

Figure 1.2: Illustration of the district heating production share, in percentages [Energistyrelsen, 2017]

As Figure 1.2 show, natural gas(NG) is equal to 15.7 % of the fuel used for producing heat, coal is 12.1 %, and oil is 0.5 % of the used fuel. These are the fossil fuels that releases CO_2 into the atmosphere. The engines and boilers that are powered by these fuels, will have to be replaced or converted by a sustainable alternative. The sustainable alternatives are production units that are either CO_2 free, or CO_2 neutral. CO_2 free production units are solar collectors, heat pumps, electric boilers etc. The reason for the heat pumps and electric boilers will be categorized as CO_2 free production units, is that the goal of being 100% CO_2 free in the electricity sector, and thereby the input electricity to the heat pumps and electric boilers will be from sustainable electricity [Klima-, Energi- og Forsyningsministeriet, 2018].

The CO_2 neutral production unit is biomass boilers, the reason for calling a biomass boiler a CO_2 neutral production unit, even tho it produces CO_2 when it incinerates biomass, is due to that, the CO_2 the biomass releases is equal to the amount of CO_2 it absorbed from the atmosphere to grow [Energistyrelsen, 2015]. A problem of changing all CHPs to biomass powered plants will be that there is a limited biomass resource, due to the time it takes for plants to grow, and it would not be sustainable due to the deforestation. Also if the demand gets higher compared to the supply the cost of biomass is likely to increase.

Furthermore, there are waste incineration plants, that incinerates biodegradable waste to produce heat to a district heating grid, and thereby reduces the amount of waste[Miljøstyrelsen, 2019]. Also replacing all the heat producing units by waste incineration plants, would be not be a possibility due to waste is not an unlimited resource.

sustainable alternatives for the CHP production units that are running by fossil fuels are, biomass boilers and turbines, which is fueled by straw, wood chips, wood pellets and wood waste, they could also be replaced by bio gas plants and waste incineration. The heat production only units could be replaced by solar collectors, which gets heat from solar radiation, and electric heat pumps, geothermal and electric boilers.

If all the heat only production units were replaced by heat pumps, the heat prices would follow the electricity prices. Furthermore, the electricity demand will increase, due to all the extra electricity needed to produce that amount of heat, which could result in an increasing electricity price, which means that when the electricity prices are high, the cost of producing heat will be high as well, e.i. the heat prices will be fluctuating. Furthermore, heat pumps has an high investment cost[Energistyrelsen, 2018b], and therefore it would not be favorable to over dimension.

The problem of changing to solar collectors would be that they are weather dependant, so at cloudy days the solar collectors will not be able to fulfill the heat demand.

Therefore an interaction between the heat producing units are needed to secure hot water and space heat for the consumer at any point of the year.

By implementing heat storages these cases could be better suited to fulfill the annually heat demand, by producing excess heat when there are cheap electricity for the heat pumps, or when there is more heat produced from the solar collectors, than heat demand. This could help at some points, but if there is cloudy for a longer period of time, the heat storage would be empty. and the district heating would not be able to supply to the consumers.

2 Problem Statement

Based on the goal of phasing out fossil fuels from the heating sector to have a 0 % CO_2 emission, means that all units which is utilizing fossil fuel in their production of heat will have to be replaced by or converted to a green alternative.

This change from fossil fuels to green alternatives could result in a change in the market, e.g if the demand for biomass increases. Therefore it could be expensive and unrealistic if all natural gas and coal based production units were replaced by biomass, since it is a limited resources, also a high increase in biomass demand, could result in large deforestation and an increasing cost of biomass

Furthermore, solar collectors are dependent on the weather and heat pumps are dependent on the electricity prices, and an high investment will make it unfavorable. Therefore these renewable energy sources will not be able to secure an area without the interaction with other technologies, without increasing the costs.

Some renewable production units has a high upfront cost and can therefore be challenging to invest in, the high upfront cost can results long payback time. Therefore the heating prices are likely to increase for the consumers, until the investment has been payed off. An interaction between the different technologies will be made, to ensure that the heating demand will be fulfilled through out the year. Furthermore business economic calculations will be made to be able to find the best suited solution for the district heating company.

Research Question

How can the implementation of sustainable heat production units in the district heating sector, remove the CO_2 emissions, to achieve the goal of the heating sector being CO_2 free, seen from a business economical and technical perspective, without reducing the heating reliability for the consumers?

In order to answer the Research Question it has been divided into these three sub questions.

- What are the current situation of the district heating company?
- What can the heating companies do to remove their CO_2 emissions?
- How will the implementation of these technologies affect the company?

Delimitation

The delimitations that have been made in this study is:

- Frozen policy - All the costs, taxes, fuel/electricity prices and weather data are the same for each year.
- Solar collectors - The study are not implementing solar collectors.
- Electro fuels - The study is not looking into electro fuels.
- Production of units - The CO_2 that comes from building the production units will not be investigated

3 | Theory and Methods

For this project choice awareness theory is used as the theoretical basis for the analysis.

3.1 Choice awareness theory

The Analysis of the project is build around Choice awareness theory. Choice awareness theory is divided into 4 strategies [Henrik Lund, 2015], where the first 3 strategies are about designing the technical scenarios, finding the most feasible, and the and the regulations and market conditions that affect the scenarios. Whereas the 4.th strategy deals with who should make it happen [Henrik Lund, 2015]. is used to build the analysis for this project. The fourth strategy will not be used, because the analysis seeks to investigate, the things that should to be changed in order to reach the goal, and not who that should make it change.

3.1.1 First Strategy

The first strategy deals with the concept of giving more that one option for the given problem, in Section 5.2 the different scenarios are described and the annual heat production combined with investment are shown.

3.1.2 Second Strategy

The second strategy evaluates the economics and the emissions of the scenarios, in order to find the most feasible solution to the given problem. This is done in Subsection 5.2.1, where Annual cost of each scenario is shown, combined with the Investment, Net present value, Dynamic payback time, CO_2 emission and fuel usage.

3.1.3 Third Strategy

The third strategy takes the public regulations and market conditions into account, this is investigated looking at the current system, and how it would change if the prices and current conditions were to change. This has been done by making sensitivity analysis which is done in Section 5.3. The parameters that will be changed are:

- Biomass prices
- Electricity spot market prices
- Heat demand
- Discount rate

3.2 Case selection

The Reference in this project is based upon Støvring Krafvarmeværk, which is a district heating company who delivers 64,600 MWh heat annually. The heating system consist of 3 NG engines which each has an electricity capacity of 3.044 MW and a heat capacity of 4.14 MW. Furthermore, it has an oil boiler with a capacity of 6 MW, and two NG boiler with a total capacity of 17 MW, and a heat storage with a capacity of 195 MWh heat. The oil boiler is only used as back-up if the natural gas supply is unable to deliver[Støvring Kraftvarmeværk, 2019]. The reason for choosing the case of Støvring district heating is, that it is a decentralised CHP plant, with heat and electricity production based on fossil fuels [Støvring Kraftvarmeværk, 2019]. Therefore, by looking into the case of Støvring Krafvarmeværk, it could be able to implement the same technologies for companies with the same propperties as Støvring Kraftvarmeværk [Bent Flyvbjerg, 2006]

The replacement for this system will be found by implementing heat production units, that can remove the CO_2 emissions while delivering the annually heat demand. Furthermore, will there have to be backup units, in case of a shutdown from production unit, to ensure safety for the consumers.

3.3 Business economic calculation

To be able to evaluate which investments that are feasible, business economic calculations will be conducted. The investment that will provide the lowest dynamic payback time (DPT), combined with a low price per MWh heat, and the high present value will be the favored solution.

The Present Value (PV) will be calculated to see if the investment will provide a positive economic outcome for the company. The formula used to calculate the PV is: [OECD, 2018]

$$Present\ Value = \sum_{t=0}^{n} NP_t \cdot (1+i)^{-t} \tag{3.1}$$

Where the NP_t is the annual net payment, for t (year) 0 it is the investment of the technologies and for the following year, the NP_t will be the savings compared the the reference, hence the system before investing in new technologies. n is the total lifetime of the investment, and i is the discount rate [Henrik Lund, 2003]. The Discount rate used in the project is at 0.04 [Energistyrelsen, 2018a].

To determine when an investment has been payed back and starts to give a positive annual income the DPT is calculated, the formula used for calculating the DPT is given as:

[OECD, 2018]

$$\sum_{t=0}^{n} NP_t \cdot (1+i)^{-t} = 0 \tag{3.2}$$

When the sum of the annual net payments are equal to 0 the investment has been payed back.

The economic calculations will be with a time span of 25 years, and therefore if technologies have a lifetime above or below 25 years, will have a disadvantage if it was not taken into consideration. For the technologies with a longer lifetime than 25 years, a scrap value will be calculated. The formula for calculating the scrap value is:

$$\text{Scrap value} = \frac{\text{Investment}}{\text{Lifetime}} \cdot \text{Remaining lifetime} \tag{3.3}$$

The scrap value will therefore be added to the Present value at year 25. However, the scrap value will only be implemented in cases with production units that has a lifetime below or above 25 years.

Furthermore, the price per MWh heat will be calculated. This value gives a picture of what the consumers will pay per MWh heat, after the investment is payed back. it will be calculated by:

$$\text{Price per MWh heat} = \frac{\text{Annual production cost}}{\text{Annual heat demand}} \tag{3.4}$$

3.4 EnergyPRO

For this project EnergyPRO is chosen to be the modelling tool. The reason for choosing EnergyPRO is that it has a user-friendly setup, and gives a great overview of the system. Furthermore, EnergyPRO has the the ability to show production from each production unit and the amount of heat in the Storage for every hour throughout the year[EMD international, 2019]. EnergyPRO has the ability to calculate the cheapest production spread over a year, by calculating the cost for each production unit, at every hour by taking the fuel prices combined with the Spot market prices in to account.

EnergyPRO uses input data for an entire year, i.e EnergyPRO calculates the cheapest production for every day.[Poul Alberg Østergård et al, 2018]. Therefore, EnergyPRO will not produce heat in a specific hour if it is economical feasible to wait until the next hour. EnergyPRO knows when the electricity is cheapest possible and can therefore empty the storage a couple of days before, and then fill it completely with the cheapest production possible. Normally it will not be possible to project the prices that detailed.

The output data EnergyPRO delivers that will be used in this project, is the annual cost for the company, the annual production share for the production units and the CO_2 emission and the fuel usage.

4 Description of the current situation

In this chapter an overview of the current system together with the production units and the costs and taxes used as the input data for the reference and the scenarios.

4.1 Støvring District heating

The model of the medium sized district heating is based on Støvring district heating, which has a annual heat demand of 64,601 MWh. The production units used to fulfill this demand is 3 NG engines each one with a electricity capacity of 3,044 MW and a heat capacity of 4,100 MW. Furthermore, there is a NG boiler with a heating capacity of 15 MW and a heat storage, which is able to store 195 MWh heat [Støvring Kraftvarmeværk, 2019]. The numbers is summarized in Table 4.1.

	[MWh]		
Heat demand	64,601		
	Input [kW]	Capacity electricity [kW]	Capacity heat [kW]
NG engine 1	7,250	3,044	4,100
NG engine 2	7,250	3,044	4,100
NG engine 3	7,250	3,044	4,100
NG boiler	14,700		15,000
		Capacity [MWh]	
Storage		195	

Table 4.1: capacities of the production units for the current district heating system

The annual heat demand can be seen on Figure 4.1, it can be seen that in the cold months has a high heat demand, this is due to the more heat needed to keep the indoor room temperature at a certain degree. The spread of the heat demand is made by using degree days.

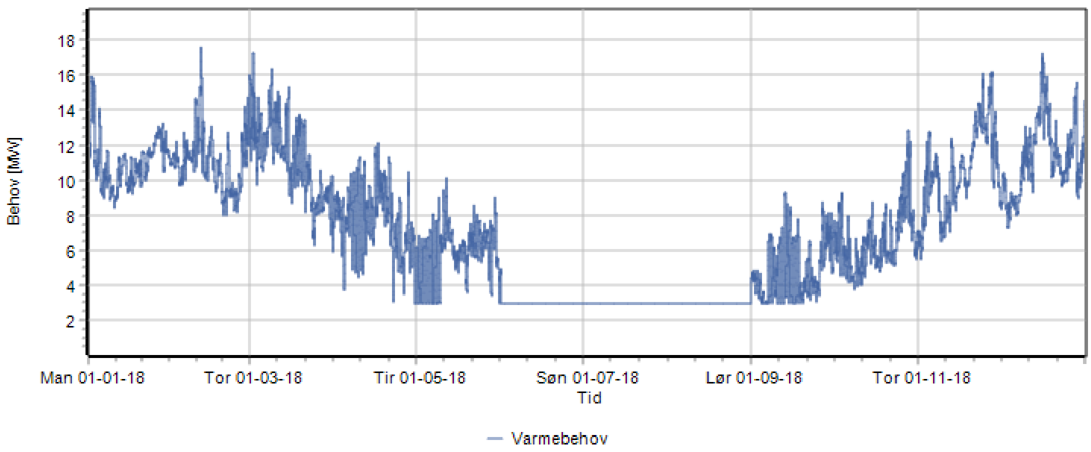

Figure 4.1: Annual heat demand for Støvring district heating consumers

The heat demand peak is at 17.5 MW, which can be seen on the figure are only short periods of the time period. Furthermore, is the lowest demand at 2.95 MW, which is in the summer periods which mainly is domestic hot water use.

4.1.1 Data used in scenarios

Oil Boiler

The costs for producing heat on the oil boiler are an Operation and maintenance (O&M) at 5 Dkk/MWh[PlanEnergi, 2018] an energy tariff at 43.6 Dkk/GJ and a CO_2 tax at 13.8 Dkk/GJ[pwc, 2019].

	Dkk	Unit
O&M	5	Dkk/MWh
Energy tariff	43.6	Dkk/GJ
CO_2 tax	13.8	Dkk/GJ

Table 4.2: Summary of the production O&M, taxes and tariffs for an oil boiler.

NG Boiler

For the heat production on the NG boiler the O&M is 5 Dkk/MWh[PlanEnergi, 2018] the energy tariff is 166.68 Dkk/MWh a CO_2 tax of 0.391 dkk/Nm^3 and a NO_X tariff of 0.008 Dkk/Nm^3 used natural gas[pwc, 2019].

	Dkk	Unit
O&M	5	Dkk/MWh
Energy tariff	166.68	Dkk/MWh
CO_2 tax	0.391	Dkk/Nm^3
NO_X tariff	0.008	Dkk/Nm^3

Table 4.3: Summary of the production O&M, taxes and tariffs for a NG boiler.

NG Engine

The heat and electricity production on the NG engine has an O&M at 52 Dkk/MWh[PlanEnergi, 2018], energy tariff at 2.199 Dkk/Nm^3 it also has an CO_2 NO_X and methane taxes on 0.391, 0.029 and 0.067 Dkk/Nm^3 respectively[pwc, 2019]. Furthermore, the price for selling electricity and using the electricity grid is included for the NG engine, a feed-in tariff at 2.455 Dkk/MWh a production fee to Energinet at 0.59 Dkk/MWh a spot fee to NordPool at 0.335 Dkk/MWh and a Fixed fee at 72,000 Dkk/Year.[PlanEnergi, 2018]

	Dkk	Unit
O&M	52	Dkk/MWh
Energy tariff	2.199	Dkk/Nm^3
CO_2 tax	0.391	Dkk/Nm^3
NO_X tariff	0.029	Dkk/Nm^3
Methane tariff	0.067	Dkk/Nm^3
Feed-in tariff	2.455	Dkk/MWh
Production fee Energinet	0.59	Dkk/MWh
Spot fee NordPool	0.335	Dkk/MWh
Fixed fee	72,000	Dkk/year

Table 4.4: Summary of the production O&M, taxes and tariffs for a NG engine.

5 | Analysis

Biomass fired production units will in this project be considered as CO_2 neutral energy source even tho biomass releases CO_2 when the it is burned. The reason for this is that the amount of CO_2 that is released into the atmosphere is equal to the amount of CO_2 that the plant took from the atmosphere in order to grow[Energistyrelsen, 2015]. Heat pumps will be be considered a renewable heat production unit, due to the input is electricity. Therfore, as mentioned in Chapter 1, the goal is to be 100 % fossil fuel free in 2050, i.e the electricity used in the heat pump will come from renewable energy units, such as wind turbines and photovoltaics.

5.1 Reference Scenario

In this section the Reference scenario will be shown, together with the output values for the production of heat, such as emissions, costs and production share.

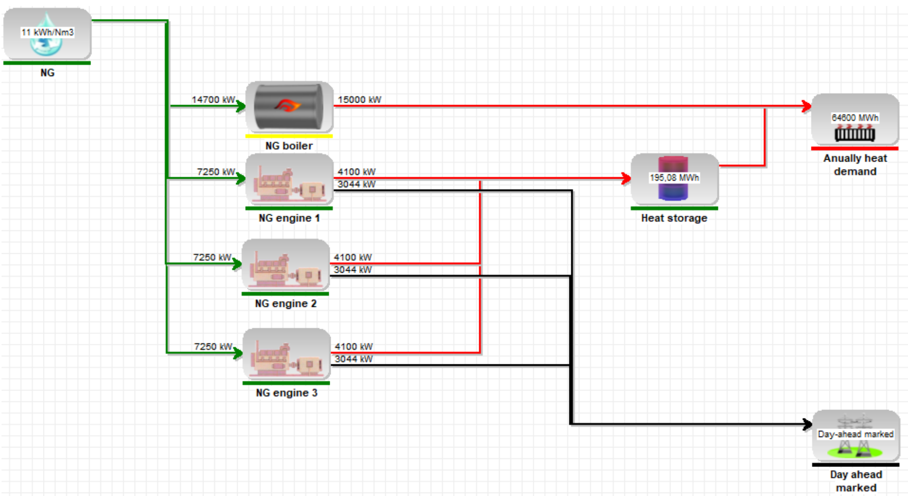

Figure 5.1: The EnergyPRO model of the Reference scenario

The annual production for the different heat producing units is for NG engine 1 19,668 MWh heat which is equal to 30.5 %, for NG engine 2 it is 19,270 MWh heat which is 29.8 % and for NG engine 3 it is 18,962 MWh heat equals to 29.4 % of the annually heat demand. The NG boiler produces the remaining 6,679 MWh heat which is 10.3 % of the annual heat demand. This is shown on Figure 5.2.

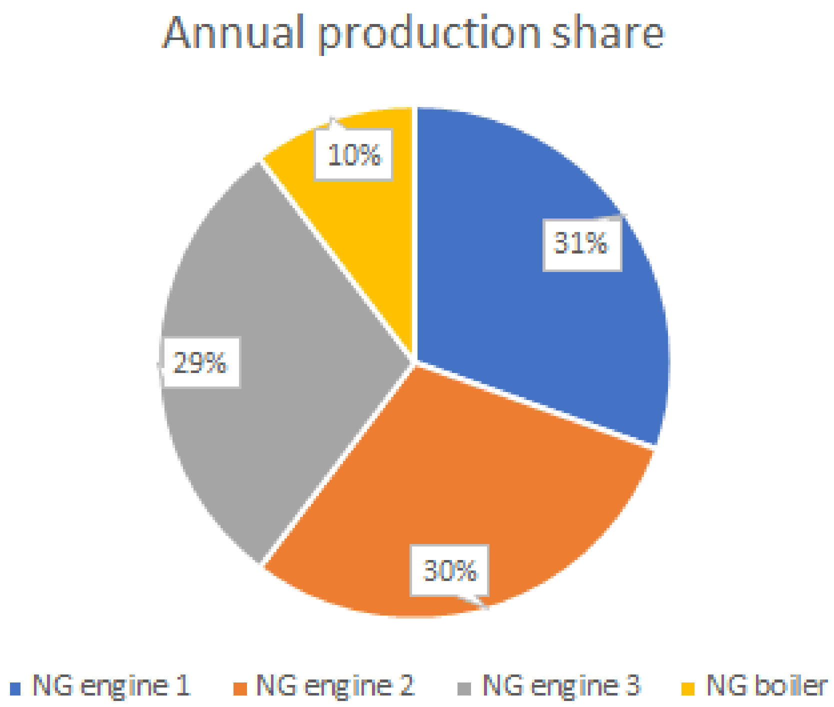

Figure 5.2: Production share for the Reference Scenario.

This production has an annual cost for the district heating company of 21.299 million dkk, where the total cost of producing is at 32.56 million dkk, and a sale of electricity gives an income of 11.26 million dkk. The total NG usage for producing this amount of heat is at 9,9 million Nm^3 which equals to 2.2 million tons of CO_2 emission. The numbers is summarised in Table 5.1.

Annual NG usage [Nm3]	9,906,131
Annual CO2 emission [ton]	2,232,091
Annual operation cost [dkk]	32,563,644
Electricity sale [dkk]	11,263,550
Annual cost [dkk]	21,229,719

Table 5.1: Output values for the Reference scenario

5.1.1 Validation of reference model

In this section a validation of the reference model will be made by comparing it to the a model made by PlanEnergi [PlanEnergi, 2018]. The numbers that will be compared are the annual heat production of the units, the annual cost for the heat company and the price for a MWh heat. In Table 5.2 a comparison of the heat production units and the cost of producing is shown.

	Unit	PlanEnergi	Reference model
NG engine	MWh/year	54,693	57,922
BG boiler	MWh/year	9,908	6,679
Annual cost	Dkk	20,900,000	21,299,719
Heat production price	Dkk/MWh	324	329.7

Table 5.2: Comparison of output values for the Reference model and the PlanEnergi model.

It can be seen that the difference in the production for the NG engine is at 3,229 MWh annually, and opposite for the NG boiler. Furthermore it can be seen that the annual cost is 399,719 Dkk higher for the reference model compared to the PlanEnergi model, which is equal to 1.9 %.

The model is therefore concluded to be able to produce a qualified overview of the system, and will therefore be used as the reference model.

5.2 Scenario selection

To remove the 9,906,131 Nm^3 of natural gas used in the reference scenario, investment in sustainable production units are necessary. The first investment that will be done in order to get rid of the CO_2 emission is an investment of a heat pump. The heat pump that has been found to be the most feasible for this system has a 1.9 MW electric input, and a coefficient of performance (COP) of 4.24, which has an investment of 41,700,000 Dkk. The annual production share of the system with the implementation of the heat pump is shown on Figure 5.3.

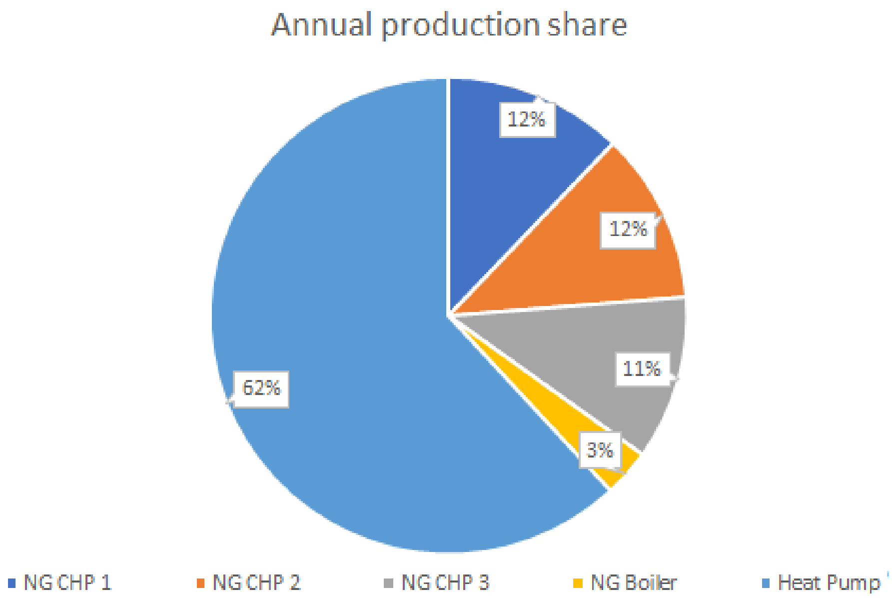

Figure 5.3: Annual heat production share for the system with the implementation of the heat pump(Scenario 1).

it can be seen that the heat pump produces 62 % of the annual heat production, and the annual cost of production is 15,127,917 Dkk. Furthermore, it can be seen that the CO_2 emission is reduced from 22,320.7 ton to 8,683.3 ton.

The system after the implementation of the heat pump can be seen on Figure 5.4

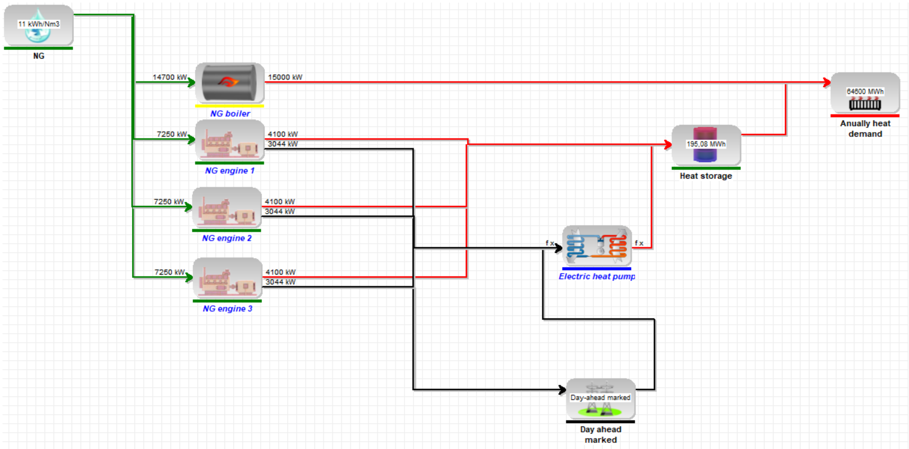

Figure 5.4: The EnergyPRO model of the system with the implementation of the heat pump.

The next step will be convert the heat production from the NG engines and the NG boiler to a green alternative, in order to reduce the CO_2 emissions to 0.

For this system the alternative production unit will be biomass fired CHPs and HOPs, to secure a stable heat production, and make certain that the heat demand will be fulfilled at any time. On Figure 5.5 the annual heat production share is shown for the system with an implementation of 3 Biomass CHPs and 1 biomass boiler, with an input capacity of the same size as the NG production units from the reference. The biomass boiler has a heat capacity of 10.21 MW and the biomass CHP has an electric capacity of 1.8125 MW and a heat capacity of 5.8 MW.

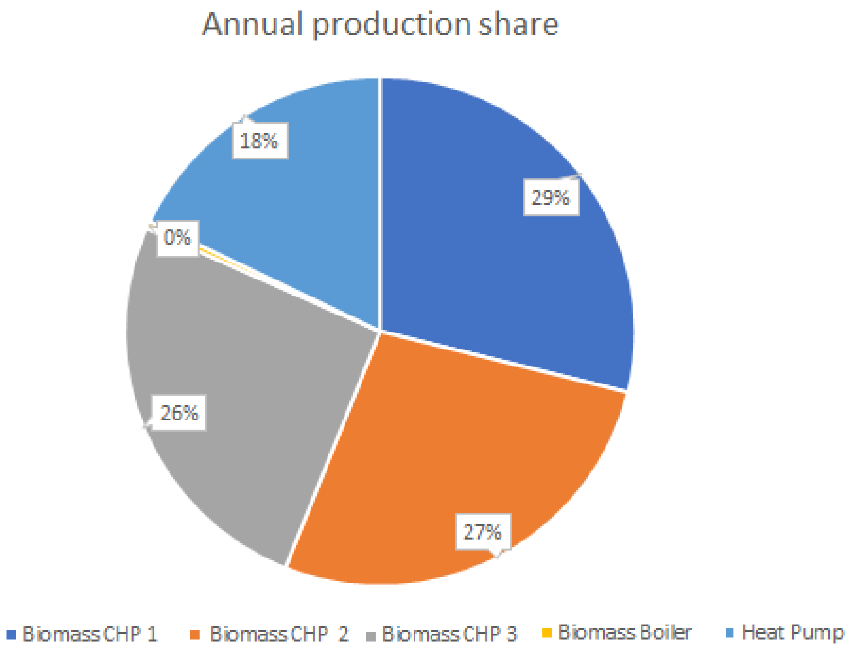

Figure 5.5: with heat pump, biomass boiler and 3 biomass CHP (Scenario 2).

The total investment for these units and the heat pump, is at 302 million Dkk. Furthermore, it can be seen on the figure that 82 % of the heat production is done by biomass fired units, which equals to an annually biomass usage of 25,629.7 ton.

By investing in 2 CHPs 1 HOP and the heat pump, the total investment is at 214 million Dkk. The annual production of this system can be seen on Figure 5.6.

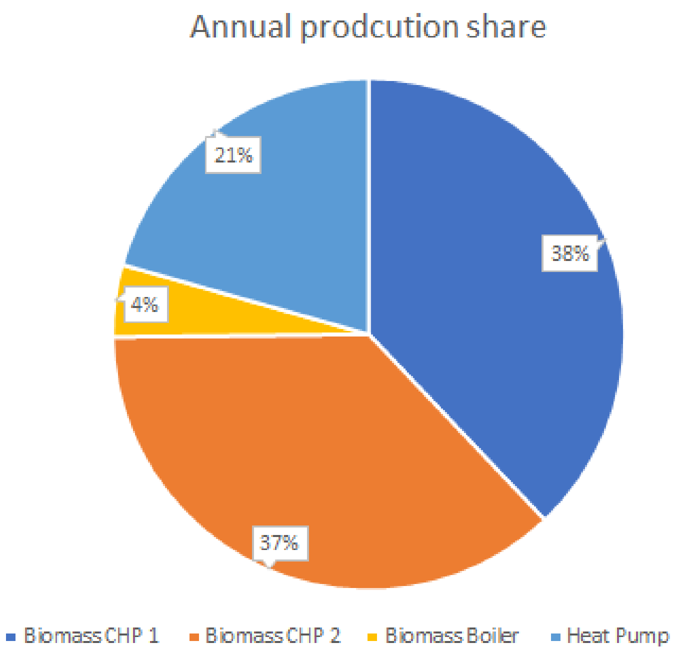

Figure 5.6: with heat pump, biomass boiler and 2 biomass CHP (Scenario 3).

For this system 79 % of the annual heat production is covered by Biomass and 21 % of the heat pump, which means that the system is 100 % fossil free. This scenario uses 24,505 tons biomass for the production.

For this system an investment in 1 CHP 1 HOP and the heat pump is made, with a total cost of 126.5 million Dkk. On Figure 5.7 the annual heat production share can be seen. It shows that the heat pump produces 29 % of the heat and 71 % comes from a biomass fired unit.

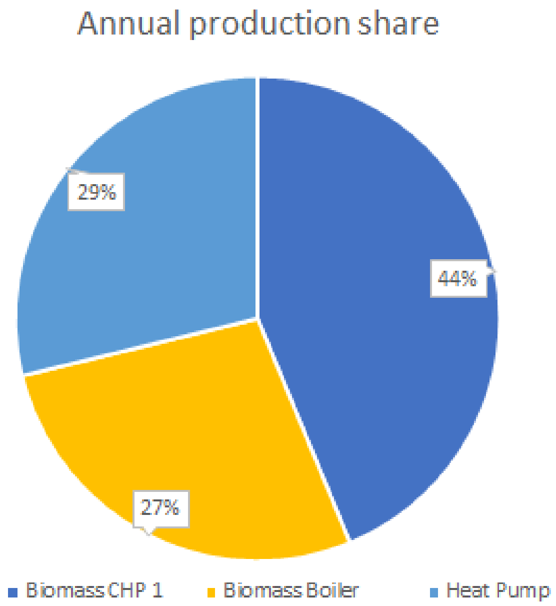

Figure 5.7: with heat pump, biomass boiler and 1 biomass CHP (Scenario 4).

The CHP and HOP uses 20,465.1 ton biomass annually, which is 4,039.9 ton less than the scenario with 2 biomass CHPs.

5.2.1 Economics

For all Scenarios the NPV after 25 years has been calculated and shown in Table 5.3. Furthermore, has the DPT for the investments that was payed off before year 25 found.

	Reference	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Annual cost (Dkk)	21,299,719	15,127,917	9,893,609	10,165,615	10,646,075
MWh price (Dkk)	329.71	234.18	153.15	157.36	164.80
Investment (Dkk)		41,700,000	302,294,015	214,405,890	126,517,765
NPV (Dkk)		40,266,703	-124,106,853	-40,468,027	39,914,313
DPT (years)		8.08	-	-	16.57
CO_2 (ton)	22,320.7	8,683.3	-	-	-
Biomass (ton)	-	-	25,629.7	24,505	20,465.1

Table 5.3: Key numbers for the scenarios

The scenario with a heat pump, 1 biomass CHP and a HOP (Scenario 4) is chosen to be the most feasible for this project, even tho the NPV for Scenario 1 is higher and the DPT is lower. The reason for this is that Scenario 1 is not 100 % fossil free, and has an emission of 8,683 tons CO_2 annually. Furthermore, it can be seen that Scenario 4 has a lower usage of biomass than Scenario 2 and 3.

Therefore, Scenario 4 will be considered the best option for this system. The Final system can be seen on Figure 5.8, where the NG engines, and the NG boiler is only used as back-up.

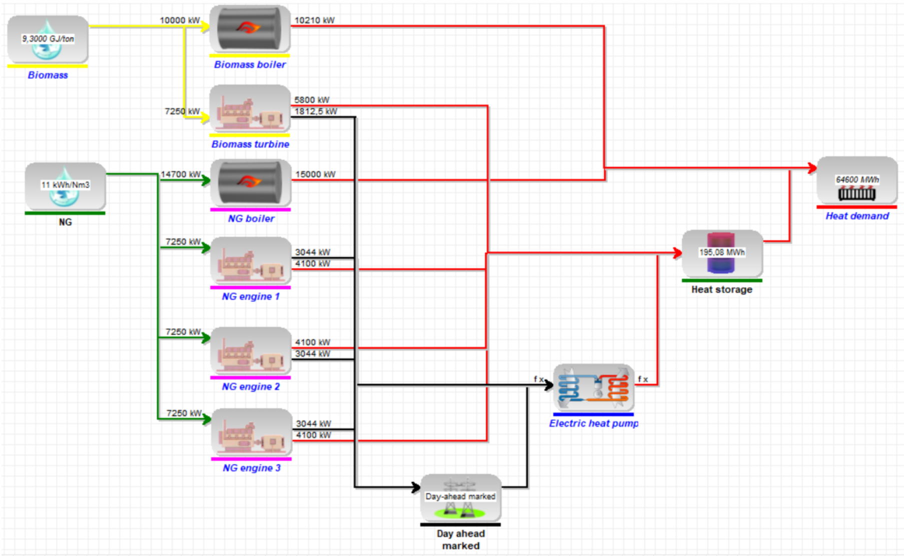

Figure 5.8

The NG engines and NG boiler is not running, unless there is a break down on the Biomass CHP, HOP or Heat pump, and the heat demand can not be fulfilled. Therefore the NG engines will be used as back-up to secure hot water and room heating for the consumers in case of a shut down.

5.3 Sensitivity analysis

In this section a sensitivity analysis is conducted to see how the system is affected by changes, and if the system is robust. The parameters that will be changed is biomass prices, spot market prices, heat demand, investment and discount rate.

5.3.1 Biomass prices

The first parameter that will be changed is the biomass price, this is done to see how the payback time and the NPV for the system will be. The biomass prices used in the sensitivity is shown in Table 5.4.

[Dkk/ton]	- 15 %	Reference	+ 15 %
Biomass Price	396.83	466.86	563.89

Table 5.4: Changing biomass prices used for sensitivity.

The reference biomass price is at 466.86, the lower price is 396.83 and the upper price is at 563.89 dkk. On Figure 5.9 it can be seen that the reference is unaffected by a change in biomass, hence none of the production units utilizes biomass. For the Scenario it can be seen that the price per MWh heat is related to the price for biomass, and when the biomass prices increases, so will the annual production cost for the scenario.

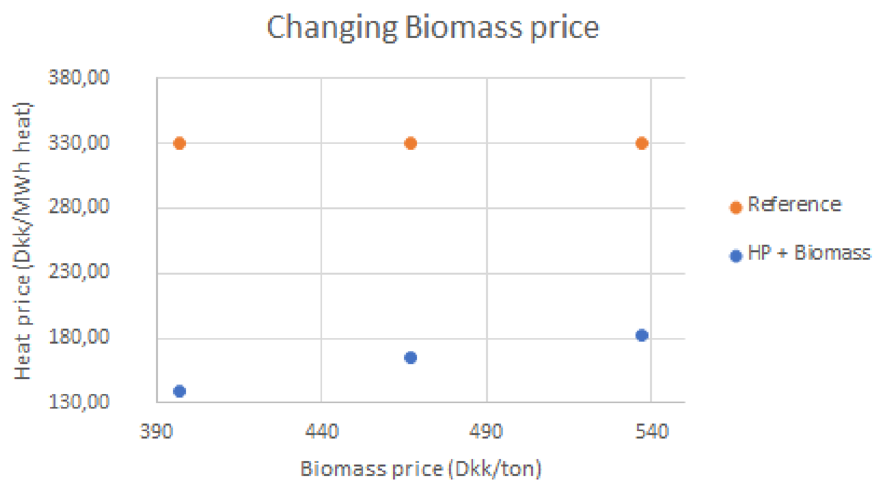

Figure 5.9: Illustrates the heating price with a changing biomass.

As for the price per MWh heat increases so does the DPT, due to less savings for the Heat pump, biomass CHP and HOP scenario compared to the reference. This is shown on Figure 5.10

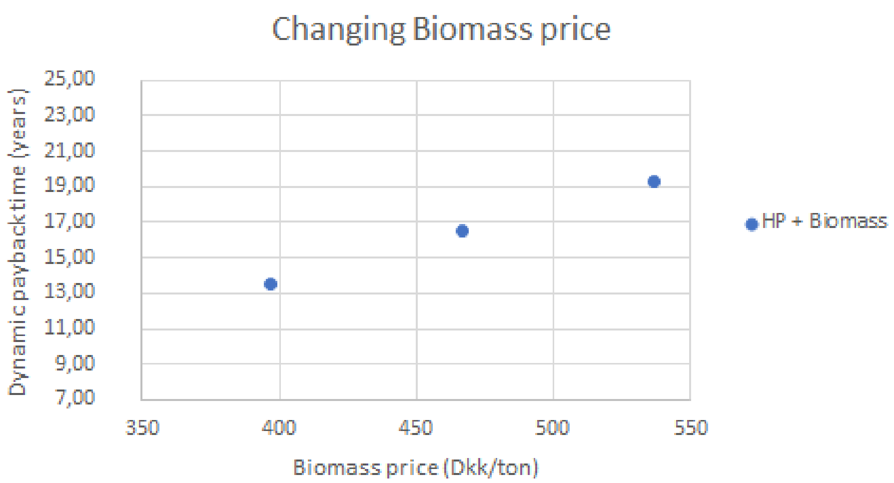

Figure 5.10: Shows the DPT for the scenario with a changing biomass cost.

On Figure 5.11 the NPV is shown. It can be seen that with an increase of 15 % biomass cost, the NPV of the investment is reduced 22,405,992 Dkk, which is a reduction of 44 %. This indicates that, this scenario is highly dependant on the biomass cost, to remain steady.

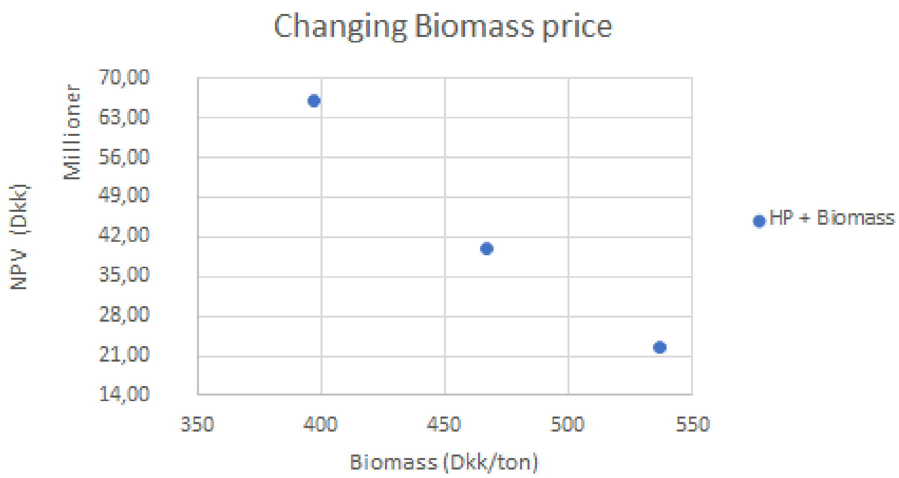

Figure 5.11: Illustrates the decrease of the NPV with an increasing biomass price.

5.3.2 Electricity Spot market prices

The Spot market price are changing for every hour throughout the year in the model, and has an average price at 223.84 Dkk/MWh, the price for every hour has been decreased and increased by 15 % to see the effect on the system.

[Dkk/MWh]	- 15 %	Reference	+ 15 %
avg. Spot market prices	190.26	223.84	257.41

Table 5.5: changing Spot market prices used for sensitivity.

On Figure 5.12 the heat price can be seen for the Reference and the HP, biomass CHP and HOP. It can be seen that the the Reference scenario is more affected by a changing spot market price. The reason for this is the high electricity production capacity in the Reference scenario, so when the prices are high it is favored to produce electricity and sell it.

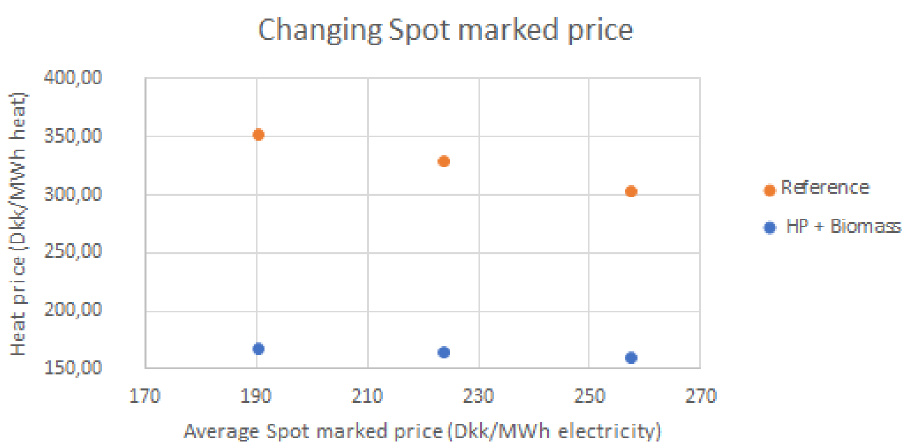

Figure 5.12: An overview of the heat prices when the spot market change.

For the HP + biomass scenario it can be seen that the heat price close to not affected, The reason for this can be seen on Figure 5.13, it shows that when the spot market prices are low, the HP produces almost half of the heat demand. Furthermore, when the electricity prices increases the Biomass Turbine and boiler production increases. The reason for the high increase on the biomass turbine, is due to possibility of selling electricity at the high spot market prices.

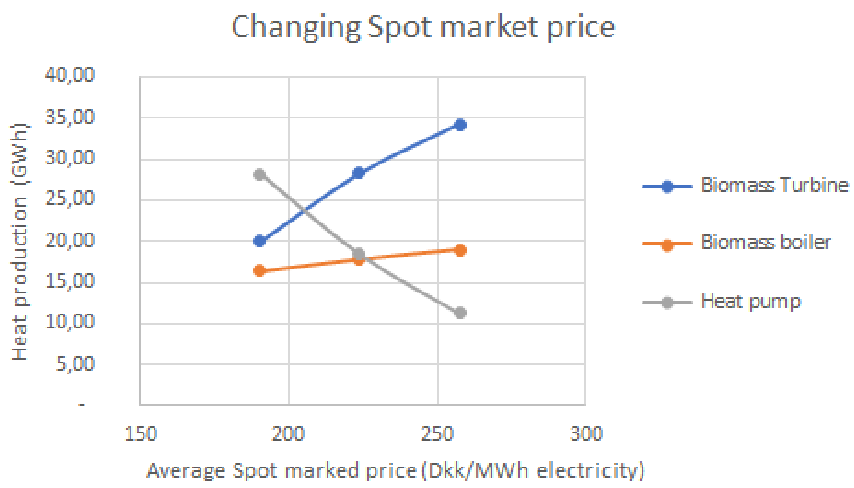

Figure 5.13: Annual heat production share with changing spot market prices.

5.3.3 heat demand

The annual heat demand will be changed to see if the system can deliver enough heat, this could happen if there is newcomers or a cold year. The change in the head demand is shown in Table 5.6.

[MWh]	- 15 %	Reference	+ 15 %
Annually Heat demand	54,911	64,600	74,291

Table 5.6: Changing heat demand used for sensitivity.

It can be seen on Figure 5.14 that when the increases, for the Reference the price pr. MWh increases from 325.14 to 333.54 Dkk when the annual heat demand increases from 54,911 to 74,291 MWh. For the HP + Biomass the price increase from 162.83 to 166.37 for the same increase in heat demand.

The change in heat demand has a smaller impact on the price per MWh for the HP + Biomass scenario compared to the Reference scenario.

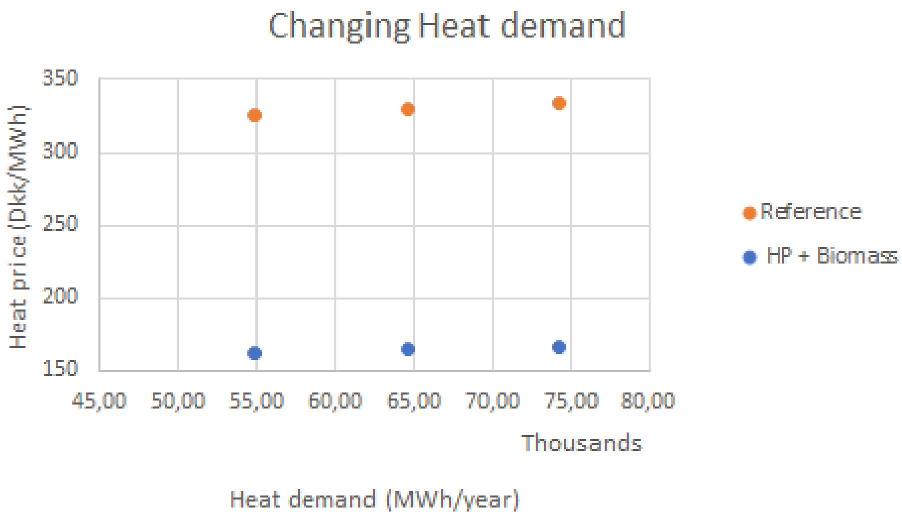

Figure 5.14: Heat price for a changing heat demand.

If the Annual heat demand increases to more than 75,000 MWh. The HP and biomass scenario can not cover the peak demands for the system, and the capacity has to be increased for the production units, or the backup NG boiler/engine has to produce heat.

On Figure 5.15 the NPV of the investment with a changing heat demand is shown. This shows that if the heat demand decreases, smaller production units would have been more favorable. It can be seen that the NPV increases when the heat demand increases, this is due to the price per MWh increases more for the Reference than the HP + biomass scenario. Therefore, the savings compared to the reference is higher, which will result in a higher NPV.

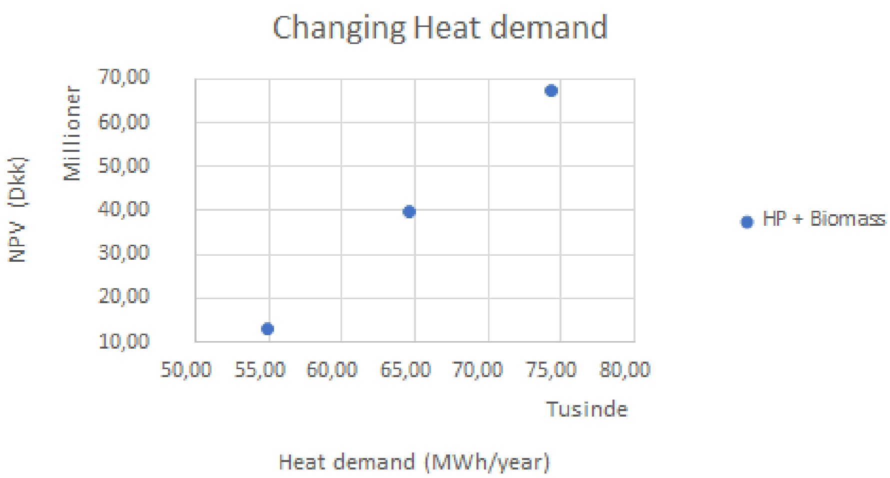

Figure 5.15: The NPV of the investment with a changing heat demand.

5.3.4 Discount rate

If case of the Discount rate would change, sensitivity has been made on it, to see if the investment was feasible. The discount rates is varied from 2 to 6 %.

			Reference		
Discount Rate	0.02	0.03	0.04	0.05	0.06

Table 5.7: The discount rates which is used in the sensitivity.

On Figure 5.16 it is shown that when the discount rate increases the NPV of the investment decreases. As shown on the figure the NPV decreases from 81.5 millions at a 2% discount rate to a NPV of 9.7 millions with a discount rate at 6 %. If the discount rate increases above 7 % the NPV at year 25 is below 0 Dkk. If the NPV decreases below 0 Dkk at year 25, the investment would not be feasible to make.

Figure 5.16: NPV with a changing discount rate.

As shown on Figure 5.16, the same case is for the Dynamic payback time, the DPT exceeds the lifetime of the investment, and it will therefore not be feasible to make this investment.

By changing the discount rate the dynamic payback time are affected, it can be seen on Figure 5.17 that the DPT increases exponential when the discount rate increases.

Figure 5.17: DPT with a changing discount rate.

It is shown that the discount rate at 2 % will result in a DPT of 13.7 years, and with a discount rate at 6 % the DPT is at 21.4 years, which means that a change in the discount rate can affect the investment for the district heating company

6 Discussion

In this Chapter the uncertainties in the project will be discussed. These uncertainties includes how EnergyPRO calculates the production for the time period. Furthermore, the implementation of the heat pump, and biomass CHP. And lastly it will discuss the frozen policy and production.

EnergyPRO

EnergyPRO operates by calculating the cheapest production for a year, as mentioned in Section 3.4 EnergyPRO knows all Spot market prices and demands throughout the entire modelling period. Therefore, there are uncertainties for how the system will produce in reality, when the future prices are not known.

Production units

Another uncertainty is the implementation of the heat pump, biomass boiler and CHP. In this project Solar collectors has not been utilized this might not be the case for all heating companies. The reason for this is to maintain a stable heat production that can fulfil the heat demand at any time. By replacing the heat pump with solar collectors, the heat capacity will be lower than the peak heat demand at certain periods, therefore it has been deselected. This is also the case for the biomass boiler.

The reason for keeping the biomass CHP, instead of implementing more biomass boilers and hp capacity, is to remain an electricity capacity. The reason for this is that the Danish Energy Agency projects the electricity consumption to increase [Danish Energy Agency, 2019]. Therefore, if all CHP plants replaced all their CHP units to heat only units, the electricity prices are likely to increase at times with low electricity production production from wind turbines and photovoltaics.

Input numbers

For the scenarios and the economic calculations the input values are used as frozen, which means that the taxes, weather data, costs and demands, has been constant for the 25 year period. It could have been more realistic to use the projection made from the Danish Energy Agency. The reason for not implementing the projection values is, that by using non progression values, it gives an overview of how the scenario will fit in the current system. Furthermore, would projected values have uncertainties too, therefore sensitivity analysis was made, to give see different outcomes.

Future work

As a future work it could be interesting to look in to the 4.th generation of district heating. The reason for this is to see how if other production units would be more feasible for the system. And see how the heat pump will produce with a lower forward temperature for the district heating grid. The reason for not implementing the 4.th generation of district heating in the project, was due to lack of time.

7 Conclusion

This project deals with the reduction of the CO_2 emission from the heating sector, by replacing the current fossil fuel based technologies with CO_2 free and CO_2neutral technologies, in the most feasible way. In order to replace these units, the district heating companies has to make investments, which can affect the company and the consumers.

Research Question

How can the implementation of sustainable heat production units in the district heating sector, remove the CO_2 emissions, to achieve the goal of the heating sector being CO_2 free, seen from a business economical and technical perspective, without reducing the heating reliability for the consumers?

In order to answer the research question three sub questions has been made, these sub question will be concluded upon.

- What are the current situation of the district heating company?

It can be concluded that the Støvring Kraftvarmeværk is 100 % fossil fuel based, and will therefore have to adapt in order to reach the goal of being CO_2 free. The current system supplies an annual heat demand of 64,600 MWh, with a production cost of 21,299,719, which results in an annual CO_2 emission for Støvring Kraftvarmeværk is at 2,232,091 tons.

- What can the heating companies do to remove their CO_2 emissions?

It can be concluded that the heating company can remove their CO_2 emission by implementing heat pumps, biomass- CHPs and boilers. By implementing a heat pump with an electric capacity of 1.9 MW input and a COP of 4.24. The investment of this heat pump reduced the annual CO_2 emission from 22,320.7 to 8,3683.3 ton. Furthermore, has an implementation of a biomass boiler and biomass chp been made. The heat capacity of the biomass boiler is at 10.21 MW, and the biomass CHP have an electric capacity of 1.8125 MW and a heat capacity of 5.8 MW. This implementation reduced the annual CO_2 emissions to 0, for the case of Støvring Kraftvarmeværk.

- How will the implementation of these technologies affect the company?

It can be concluded that the economics of the company can be improved by implementing the chosen production units. The Net present value of the total investment for the company is at 39,914,313 Dkk at year 25, and a dynamic payback time of 16.57 years. Therefore, after 16.57 years the investment is payed off, and the price per MWh heat for the consumers will be reduced from 329.71 dkk to 164.80 dkk.

It can therefore be concluded that implementation of a heat pump, biomass boiler and a biomass CHP can remove 100 % of the CO_2 emission this case, and is therefore able to reach the goal of being CO_2 free. Furthermore, can it be concluded that investment in these production units will give an positive NPV, a reduced heat price for the consumer and fulfil the annual heat demand of 64.600 MWh.

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