Pre-feasibility Study of a Waste to Energy Plant in Chisinau, Moldova

Linus Karlsson
Tomas Linderholm Jönsson
Abstract

Pre-feasibility Study of a Waste to Energy Plant in Chisinau, Moldova

Linus Karlsson, Tomas Linderholm Jönsson

The thesis outlined in this report has been done as a sub-project in cooperation between the municipalities Borlänge in Sweden and Chisinau in Moldova. The project aimed to explore the region's economic and environmental opportunities for waste incineration with energy recovery, also known as Waste to Energy.

At present, the solution to the waste situation is unmonitored landfills with smaller sorting operations. Environmentally, this is a poor solution and although there are plans for change, no specific strategy has been presented. Another important issue is Moldova's dependence on foreign produced energy. What makes the waste to energy so interesting for this region is that it contributes to an improvement in both of these issues by using the waste as fuel to reduce energy dependency.

The results of this study show that implementation of a waste incineration plant in the Chisinau energy system is economically and environmentally feasible, given the current conditions. The proposed plant is designed to annually handle 400,000 tonnes of waste, and would with the assumed waste composition deliver 560 GWh of district heat and 260 GWh of electric energy. This production provides an annual profit of 31.6 million Euro, which gives a positive net present value after the project amortization.

Compared with the city's current solution with landfills and gas turbines, the project also provides a significant environmental improvement. During the plant's design lifetime, greenhouse gas emissions are 6.8% with the assumption that only a portion of the carbon content of the waste is of fossil origin.
Sammanfattning

Examensarbetet som sammanfattas i denna rapport har gjorts som ett underprojekt i samarbetet mellan kommunerna Borlänge i Sverige och Chisinau i Moldavien. Syftet med projektet var att undersöka regionens ekonomiska och miljömässiga möjligheter för avfallsförbränning med energiutvinning, även känt som Waste to Energy.

I nuläget är lösningen på avfallssituationen obevakad deponi tillsammans med mindre sorteringsinsatser. Miljömässigt är detta en undermålig lösning, och trots det finns förändringsplaner har ännu ingen konkret strategi framlagts. En annan viktig fråga är Moldaviens beroende av utländskt producerad energi. Landets energisystem är beroende av importerad naturgas, och endast en liten del av landets elektriska energi produceras inhemskt. Det som gör avfallsförbränning med energiutvinning så intressant för denna region, är att den bidrar till en förbättring i båda dessa frågor genom att använda avfallet som bränsle för att minska energiberoendet.

Studien har gjorts utan en specifik avfalls komposition för regionen Chisinau. Med detta i åtanke har en dynamisk modell i flera steg tagits fram för att kunna erhålla nya resultat beroende på vilken avfalls komposition som specificeras.

Resultaten från denna studie visar att implementeringen av en avfallsförbränningsanläggning i Chisinaus energisystem är både ekonomiskt och miljömässigt genomförbart, med tanke på de nuvarande villkoren. Anläggningsförslaget är utformat för att årligen hantera 400000 ton avfall, och skulle med den antagna avfallssammansättningen leverera 560 GWh fjärrvärme och 260 GWh elektrisk energi. Denna produktion ger en årlig vinst på 31,6 M€, vilket ger ett positivt nettonuverande efter projektets avskrivningstid.

Jämfört med stadens nuvarande lösning med avfallsdeponi och gasturbiner, ger projektet även en avsevärd miljömässig förbättring. Under anläggningsens planerade livslängd blir växthusgasemissionerna 53,9 %, och endast 6,8 % med antagandet att endast en del av kolinnehållet i avfallet är fossilt.
Acknowledgements

This thesis has been carried out on behalf of Borlänge Energy in collaboration with the Chisinau city hall. Because the study involves a large number of analyzes, there are many who contributed their knowledge to enable us achieve our results.

First of all we’d like to thank Borlänge Energy, Ronny Arnberg and Christine Ambell for the opportunity to do this thesis under their wing. Their support and network of experts, as well their encouragement has been invaluable throughout our work process.

We’d also like to thank our subject examiner Kjell Pernestål, for his insight in project work as well as his expertise in all energy topics.

All the experts and officials who devoted their time and effort to help us:

Mattias Bjurman, Borlänge Energy

Rolf Hunt, Alstom Power

Simon Jansson, Ragn-Sells

Leif Kiessling, EcoEnergy

Patrik Stålberg, Swedish Embassy in Chisinau

Parsian Galina, Ministry of Economy Moldova

Vasile Leu, Termocom

Tatiana Cusnir, Chisinau city hall

Nelu Proca, Landlord & guide

And last but not least we’d like to thank our friend Rodica Afanasieva for her guiding, helping and setting us up with the right people during our stay in Chisinau.
Abbreviations

Plant terms

WTE Waste to Energy
MSW Municipal Solid Waste
CHP Combined Heat and Power Plant
HOB Heat Only Boiler
TPP Thermal Power Plant
SB Steam boiler
T[HP] High pressure turbine
T[LP] Low pressure turbine
CT Cooling tower
DH District heating

Emission terms

VOC Volatile Organic Compound
TOC Toxic Organic Compound
NOx Mono nitrous oxides
GHG Greenhouse Gas
SCR Selective Catalytic Reduction
SNCR Selective Non-Catalytic Reduction

Economical terms

GDB Gross Domestic Product
MDL Moldovan lei
NPV Net present value
IRR Internal rate of return

Organizations

IPCC Intergovernmental Panel on Climate Change
ANRE Moldovan Energy Regulatory Agency
Agentia Nationala pentru Reglementare in Energetica

Less recognized units

ha hectare
MPa 10⁶ Pascal, pressure unit
Table of contents

Abstract .......................................................................................................................... 1
Sammanfattning ............................................................................................................... 2
Acknowledgements ......................................................................................................... 3
Abbreviations ................................................................................................................ 4
Table of contents ............................................................................................................ 5
1 Purpose ...................................................................................................................... 10
2 Goals ......................................................................................................................... 10
3 Limitations ................................................................................................................ 11
4 Background ................................................................................................................. 12
  4.1 The Republic of Moldova ........................................................................................ 12
     4.1.1 Climate ......................................................................................................... 13
     4.1.2 Energy situation Moldova ............................................................................ 13
     4.1.3 The municipality of Chisinau ...................................................................... 14
4.2 The development of Waste to Energy technology in Sweden .............................. 17
4.3 EU Regulations - Incineration Directive 2000 76 ..................................................... 18
     4.3.1 Operating conditions .................................................................................. 18
     4.3.2 Emissions .................................................................................................... 18
5 Theory ......................................................................................................................... 19
  5.1 Waste incineration ................................................................................................. 19
     5.1.1 Furnaces ...................................................................................................... 19
     5.1.2 Moving grate .............................................................................................. 19
     5.1.3 Fluidized bed .............................................................................................. 20
5.2 Flue gas cleaning .................................................................................................... 21
     5.2.1 Particles filters ............................................................................................ 21
     5.2.2 Cyclones ....................................................................................................... 21
     5.2.3 Electrostatic precipitator ............................................................................. 21
     5.2.4 Electro venturi filter ................................................................................... 21
     5.2.5 Fabric filters ............................................................................................... 21
     5.2.6 Wet scrubbers ............................................................................................. 22
5.3 Flue gas treatment .................................................................................................. 22
     5.3.1 Dry treatment .............................................................................................. 22
     5.3.2 Semi-dry treatment ..................................................................................... 22
     5.3.3 Wet treatment ............................................................................................. 23
5.3.4 NO\textsubscript{x} reduction, DeNO\textsubscript{x} ................................................................. 23
5.4 Steam production ........................................................................................................... 25
5.4.1 Steam boiler .............................................................................................................. 25
5.4.2 Steam cycle .............................................................................................................. 25
5.4.3 Rankine cycle .......................................................................................................... 26
5.5 Cooling tower .............................................................................................................. 26
6 Method ............................................................................................................................ 27
6.1 Chemical Combustion ................................................................................................. 28
6.2 Flue Gas Composition ............................................................................................... 29
6.3 Steam cycle model in MATLAB .................................................................................. 30
  6.3.1 Optimization or finding the best profit with given test limitations ...................... 32
  6.3.2 Cooling demand .................................................................................................... 32
  6.3.3 Total energy production and profit ..................................................................... 32
6.4 Investment calculations .............................................................................................. 33
  6.4.1 Payback time ........................................................................................................ 33
  6.4.2 Net present value and internal rate of return .................................................. 33
6.5 Environmental comparison ........................................................................................ 34
  6.5.1 Waste to energy vs gas turbines & landfills ...................................................... 34
  6.5.2 WTE emissions .................................................................................................... 34
  6.5.3 Gas Turbine emissions ......................................................................................... 34
  6.5.4 Landfill emissions ............................................................................................... 34
  6.5.5 Comparison .......................................................................................................... 35
7 Conditions for design ..................................................................................................... 36
  7.1.1 Operating time .................................................................................................... 36
  7.1.2 Waste accumulation ........................................................................................... 36
  7.1.3 Waste composition .............................................................................................. 36
  7.1.4 Environmental regulations ................................................................................ 36
  7.1.5 Fitting the solution into the Chisinau energy system ........................................ 36
  7.1.6 Location & water supply .................................................................................... 36
  7.1.7 Cooling demand .................................................................................................. 36
  7.1.8 Economy ............................................................................................................. 37
  7.1.9 Staff and maintenance ....................................................................................... 37
8 Results .......................................................................................................................... 38
  8.1 Design – choice of components .............................................................................. 38

6
8.1.1 Operation ................................................................................................................. 38
8.1.2 Waste supply .......................................................................................................... 38
8.1.3 District heating system ............................................................................................ 38
8.1.4 Incineration grate .................................................................................................... 39
8.1.5 Steam cycle components ........................................................................................ 39
8.1.6 Location .................................................................................................................. 40
8.1.7 Flue gas chimney height ....................................................................................... 41
8.2 Calculation models results ....................................................................................... 42
8.3 Waste composition ..................................................................................................... 43
8.4 Elemental composition ............................................................................................... 43
8.5 Combustion – Heat Generation ................................................................................. 44
8.6 Flue gases ................................................................................................................... 45
  8.6.1 Generated flue gas flow ......................................................................................... 45
  8.6.2 Flue gas composition ............................................................................................. 45
  8.6.3 Energy output ........................................................................................................ 46
8.7 Steam cycle model in MATLAB ............................................................................. 47
  8.7.1 Most profitable steam cycle parameter combination ........................................... 47
  8.7.2 Production, heat and electricity .......................................................................... 49
  8.7.3 Duration chart ...................................................................................................... 51
8.8 Investment calculations ............................................................................................. 51
  8.8.1 Investment cost .................................................................................................. 51
  8.8.2 Yearly cash flow .................................................................................................. 52
  8.8.3 Payback time ...................................................................................................... 53
  8.8.4 Net present value, NPV ...................................................................................... 53
8.9 Environmental Comparison ..................................................................................... 57
9 Conclusions .................................................................................................................. 58
10 Potential for this WTE solution in Chisinau ............................................................. 59
11 Discussion ................................................................................................................... 60
  11.1 Potential sources of uncertainty ........................................................................... 60
    11.1.1 Waste composition, heat generation and flue gas ........................................... 60
    11.1.2 Steam cycle model ......................................................................................... 60
    11.1.3 District heating ............................................................................................... 61
    11.1.4 Economy ........................................................................................................ 61
    11.1.5 Environmental Comparison .......................................................................... 61
11.2 Further studies ........................................................................................................................................ 61
12 References.................................................................................................................................................. 62

Appendix I – Waste composition simulation software .................................................................................. 64
13 Appendix II - Heat generation & Flue gas composition ............................................................................. 67
  13.1 Determining the elemental composition of the fuel ............................................................................. 67
  13.2 Calculating the necessary combustion air supply .............................................................................. 67
  13.3 Using fuel and air data to calculate heat generation ........................................................................... 68
  13.4 Determining the flue gas composition ................................................................................................. 69
    13.4.1 Air surplus, \( l_\text{o} \) ......................................................................................................................... 69
    13.4.2 Theoretical flue gas flow, \( g_t \) ..................................................................................................... 69
    13.4.3 Real flue gas flow, \( g_v \) ............................................................................................................... 70
  13.5 Flue gas flow summary ......................................................................................................................... 70
  13.6 Flue gas heat capacity ........................................................................................................................ 71
  13.7 Heat exchange and losses .................................................................................................................. 71
14 Appendix III - Environmental Comparison ............................................................................................... 73
  14.1 Landfill emissions ................................................................................................................................ 73
  14.2 Gas turbine emissions ........................................................................................................................ 76
  14.3 WTE Emissions .................................................................................................................................. 76
15 Appendix IV- Method MATLAB model ................................................................................................. 77
  15.1 Main theory behind the MATLAB model ........................................................................................... 77
    15.1.1 Pre heating of combustion air ....................................................................................................... 77
    15.1.2 Finding the best characteristics and corresponding profit ........................................................... 77
    15.1.3 Isentropic efficiency ..................................................................................................................... 77
    15.1.4 Feed water tank ............................................................................................................................ 78
    15.1.5 Two stage DH heat exchanger ........................................................................................................ 78
    15.1.6 Condensate tank .......................................................................................................................... 78
    15.1.7 Pre heating of feed water .............................................................................................................. 78
    15.1.8 Energy and mass balance or conservation .................................................................................. 79
    15.1.9 Energy outtake .............................................................................................................................. 79
    15.1.10 Complete MATLAB code ......................................................................................................... 80
16 Appendix V – Results MATLAB-model ................................................................................................. 81
  16.1 Node characteristic ........................................................................................................................... 81
  16.2 Monthly production result .................................................................................................................. 87
17 Appendix VI – Results Investment calculations .................................................................................... 88

8
17.1  Cash flow calculations ........................................................................................................ 88
17.1.1  Chemical usage .............................................................................................................. 88
17.1.2  Cost of landfilling residues from the incineration .......................................................... 88
17.1.3  Worker salaries .............................................................................................................. 88
17.1.4  Carbon dioxide tax ........................................................................................................ 89
17.1.5  Support fuel .................................................................................................................. 89
17.2  Net present value NPV ..................................................................................................... 89
18  Appendix 6 Authors ............................................................................................................. 93
1 Purpose
The primary purpose of this feasibility study is to estimate the potential of a Waste to Energy plant for the municipality of Chisinau with the following objectives:

- Decreasing the amount of landfill deposited waste
- Decreasing energy dependence by providing an energy generation system with a reliable source of fuel
- Reducing the emission of greenhouse gases

In order for Moldova to meet the requirements for membership in the European Union, all unmonitored waste landfill activities must stop. A Waste to Energy solution is a way of dealing with this waste problem. As a result it is also contributing to the solution of the energy dependence problem.

A secondary purpose with this study is to attract Swedish project managing companies to cooperate with the municipality of Chisinau, and investors to fund the project.

2 Goals
The main project goal is to produce a pilot study on the potential of a WTE plant in the Chisinau region. This can be done through the completion of these milestones.

1. Determine the availability of waste material over the year and estimate the amount of energy that can be extracted.
2. Investigate the demand of district heating and cooling in the Chisinau region.
3. Find a logistical solution for installing a new WTE plant into the Chisinau energy system, in terms of location and grid connection.
4. Develop a thermodynamically correct plant design model, adaptable to changes in waste composition and district heat demand, which can determine the most suitable thermal and electrical power output in terms of profit.
5. Obtain cost estimations for the specified plant design from component suppliers.
6. Create two models, one economical and one environmental, that use the output data from the plant design model to determine the feasibility in those respects.
3 Limitations

Waste to Energy (WTE) includes a number of different technologies for waste treatment with energy recovery, like incineration, gasification and pyrolysis. This study will only regard the incineration part of WTE. The two incineration technologies considered are the moving grate and the fluidized bed types. The different choices of components in the plant will be chosen with help from experts from WTE project managing companies.

The geographical limitation for the study will be the region covered by the heating system of Chisinau. According to Borlänge Energi, the annual available mass of waste is estimated to be about 400,000 tonnes. The waste materials taken into consideration are mainly waste from households and industries. In case that this amount of waste cannot be provided at a given time, it can temporarily be compensated for by the yearly surplus of straw from the agriculture sector. This means that there are reserves of fuel to cover potential differences between the supply and demand in incoming waste.

In the environmental comparison, the emissions of volatile organic compounds (VOC), toxic organic compounds (TOC) and metal oxides will not be studied as closely as the emissions of greenhouse gases (GHG), due to some inconclusiveness in the waste composition data.

In the design, due to the project time frame, no detailed calculations have been done on grid connection, cooling tower technology and means of waste accumulation.
4 Background
In the cooperation between the Municipalities of Chisinau and Borlänge there is an agreement of knowledge exchange that involves the energy field. For a number of years Borlänge Energy has recruited Master Students for minor field studies in Moldova, serving as a link between the countries in this cooperation.

4.1 The Republic of Moldova

![Map of Moldova](image)

Moldova is located in the central part of Europe, in the northeastern Balkans between Romania and Ukraine near the Black Sea. The total area of the country is 33,843.5 km² and it has a population of 4.2 million. The country separated from the Soviet Union in 1991 and has since then been a republic with a troubled political situation. It has among the lowest GDP in Europe and is considered to be one of the poorest countries in Europe. Sweden and Moldova have collaborated since 1996, where the focus has been on democratic governance, strengthening the competitiveness of the rural areas and reducing the energy dependence from neighboring countries.

At the same time Moldova has expressed the interest for future membership in the EU, where a sustainable economy is one of the prerequisites. In order to strengthen its economy Moldova needs to increase its industrial production, which depends on energy prices.

A group of unexploited resources that still has potential for utilization is domestic, industrial and agricultural waste.

Today Moldova imports more than 90 % of its energy consumption. This leads to significant energy vulnerability due to the dependence on other countries. Most of the Moldovan local energy production is located in the breakaway territory of Transnistria, which has become a significant problem for the Moldovan government. Two thirds of the consumed energy comes from Russian natural gas. The pipeline passes through Transnistria, where they are reluctant to pay for their gas consumption, which further degrades their relations. In 2006 Russia significantly raised the gas
prices, putting Moldova in an energy crisis where the need for locally produced energy has become an important issue.(1)

4.1.1 Climate
The climate in Moldova is characterized as temperate continental with long hot summers and mild short winters. The yearly average temperature for the Moldovan territory varies between +7.5°C in the northern parts and +10°C in the south. In January, the average is -4°C and in June the average is +21°C. The annual rainfall varies between 380-550 mm, where approximately 70% comes in the period from April to October. The average wind velocity is about 2-4 m/s. (2)

![Chisinau Climate Chart](image)

**Figure 2 - Chisinau Climate (3)**

4.1.2 Energy situation Moldova
In summary the Republic of Moldova has limited domestic reserves fossil fuels and the hydroelectric potential is low. The renewable energy field is in slow development in terms of thermal energy, wind power and bio fuels. This results in high dependence on energy trade from other countries. Russia and Ukraine are the most significant exporters and the import levels have varied between 94 % and 98 % of total consumption the recent years.

The energy system of the Republic of Moldova consists of 3 municipal Combined Heat Power Plants (CHP), 9 CHP plants connected to sugar factories, 2 Hydroelectric Power Plants and one large Thermal Power Plant (TPP) located in the Transnistrian region. The total installed capacity of these plants is approximately 3000 MW, and out of this the TPP contributes with 2520 MW. The usage of the plant has declined over time, and now only about 1600 MW of the installed capacity is used.

Since most of the power plants use natural gas or residual fuel oil as a fuel, the domestic energy production is also dependent on these export countries. In the beginning of 2006 the price for 1000 m$^3$ of Russian natural gas increased from 80 US$ to 110 US$, and to 160 US$ six months later. The increase of prices has since then continued and for 2011 ANRE has predicted it to be about 310 US$, which is close to the European market price. There are also some predictions saying the price will be 410$ in the beginning of 2012. (4)(5)
4.1.3 The municipality of Chisinau
The city of Chisinau has 665,000 inhabitants, and the total population of the municipality is 789,000. The total area of the municipality is 571.6 km$^2$ divided into 5 larger districts. (6)

4.1.3.1 Energy situation Chisinau
Most of the domestic energy in Chisinau comes from two CHP plants, CHP-1 and CHP-2, along with a number of HOB plants. CHP-1 has an installed 66 MW electric and 296 MW thermal capacity, while CHP-2 has an installed 240 MW electric and 1,397 MW thermal capacity. CHP-1 is 55 years old, and in 2010 it produced electricity at the cost of 1525 MDL/MWh and heat at 455 MDL/MWh. CHP-2 is 35 years old, and in 2010 it produced electricity at the cost of 1105 MDL/MWh and heat at 364 MDL/MWh. The sales prices are individual for each plant, but for CHP-1 both electricity and heat production costs are higher than these. (7)

Production data for the plants is shown in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>CHP-1</th>
<th>CHP-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td></td>
<td>2010</td>
<td>2010</td>
</tr>
<tr>
<td>Total produced electrical energy</td>
<td>GWh</td>
<td>94.93</td>
<td>782.42</td>
</tr>
<tr>
<td>Own consumption of electricity -total</td>
<td>GWh</td>
<td>12.51</td>
<td>112.98</td>
</tr>
<tr>
<td>Electric energy sold - total</td>
<td>GWh</td>
<td>82.00</td>
<td>665.50</td>
</tr>
<tr>
<td>Total produced thermal energy</td>
<td>GWh</td>
<td>285.62</td>
<td>1388.99</td>
</tr>
<tr>
<td>Electricity sales price</td>
<td>MDL/MWh</td>
<td>1398.30</td>
<td>1292.20</td>
</tr>
<tr>
<td>Heat sales price</td>
<td>MDL/MWh</td>
<td>498.94</td>
<td>429.52</td>
</tr>
</tbody>
</table>

The utilized power for CHP-1 is declining. 2010 it delivered on average 10.8 MW electricity and 28.0 MW thermal with an overall plant efficiency of 76.6 %. For CHP-2 the number was 89.3 MW electric and 136.2 MW thermal with an overall plant efficiency of 72.0 %. (8)
According to ANRE calculations the amount of gas needed for the production at CHP-1 and CHP-2 was 68.2 * 10^6 m³ and 294.5 * 10^6 m³ in 2010 while the gas price was 249 US$ per 1000 m³. (5)

4.1.3.2 Waste management in Chisinau
Waste management is a growing problem since most of the waste is deposited in landfills and only a small fraction is recycled. In the case that Moldova becomes the topic of discussion for involvement in the European Union, this issue needs to be addressed. In any other case it is still a part of Moldova’s sustainable development. Table 2 shows the recent development of the Moldovan waste management.

The current annual domestic solid waste generation in the Chisinau area is 400 kg/inhabitant, or a total generation of 320,000 Tonnes for the entire municipality. The generated waste is deposited on uncontrolled landfills, of which half are authorized by the environmental government. (9)

According to the sanitation department, “Autosalubritate”, an average of 4000 - 4500 m³ of this waste is collected daily. This is done by approximately 100 transport vehicles gathering waste from 10,000 containers in the region. (10)

In addition to this, there is an untapped resource of straw that is neither recycled nor used as an agricultural fertilizer.

Table 2 - Solid & Liquid waste in urban areas, Moldova (11)

<table>
<thead>
<tr>
<th></th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transported m³/year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Household waste</td>
<td>1143.5</td>
<td>1200.0</td>
<td>1268.5</td>
<td>1353.6</td>
<td>1790.6</td>
<td>2130.8</td>
<td>2210.2</td>
<td>2302.6</td>
</tr>
<tr>
<td>Liquid waste</td>
<td>20.8</td>
<td>24.3</td>
<td>23.9</td>
<td>27.8</td>
<td>28.9</td>
<td>42.0</td>
<td>57.4</td>
<td>56.9</td>
</tr>
<tr>
<td>Area of neutralization</td>
<td>148.8</td>
<td>154.4</td>
<td>166.9</td>
<td>180.2</td>
<td>195.0</td>
<td>190.1</td>
<td>199.2</td>
<td>206.5</td>
</tr>
</tbody>
</table>

4.1.3.3 District heating in Chisinau
There is heat demand for a major part of the year, but it is most significant between October and the beginning of April. The maximum delivered heat is around 515 Gcal/h or about 600 MW thermal power. Figure 4 shows the thermal power utilization over the last years. The two CHP plants and the two HOB plants have an installed thermal capacity of around 200 Gcal/h or 2600 MW.
Termocom is the company responsible for the distribution and the supply is divided so that 74% of heat and water goes to domestic buildings, 10% goes to businesses, 9% goes to municipal buildings and 7% to government buildings. The primary distribution network consists of 234 km double pipe system, while the total network length is 730 km. Heat losses in the network has been a significant problem, and even though the losses are reduced every year level is still at 22%.

Since 2001 Termocom has been heavily indebted, and has accumulated a debt equivalent to 3.5% of the national gross domestic product (GDP). This is due to the fact that the municipality of Chisinau has not set the heating tariffs at a sustainable level. This debt has impacted the economy of Moldova and threatens its energy security. The average wage level in Chisinau between January-September 2010 was 3,653 MDL or 292 US$ per month. (5)
The district heating water supply of Chisinau operates at relatively high temperatures and pressures; Table 3. In comparison with Swedish systems the temperature is about 20 to 30 °C higher.

Table 3 - District heating grid data, Chisinau as obtained from Termocom (13)

<table>
<thead>
<tr>
<th>Heating grid by source</th>
<th>Indicator</th>
<th>Units</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHP-1</td>
<td>Pressure (feed pipe)</td>
<td>MPa</td>
<td>1.16</td>
</tr>
<tr>
<td></td>
<td>Pressure (return pipe)</td>
<td>MPa</td>
<td>0.294</td>
</tr>
<tr>
<td></td>
<td>Mass flow</td>
<td>m³/h</td>
<td>2500</td>
</tr>
<tr>
<td></td>
<td>Temperature schedule</td>
<td>°C</td>
<td>130/70</td>
</tr>
<tr>
<td>CHP-2</td>
<td>Pressure (feed pipe)</td>
<td>MPa</td>
<td>1.18</td>
</tr>
<tr>
<td></td>
<td>Pressure (return pipe)</td>
<td>MPa</td>
<td>0.177</td>
</tr>
<tr>
<td></td>
<td>Mass flow</td>
<td>m³/h</td>
<td>13435</td>
</tr>
<tr>
<td></td>
<td>Temperature schedule</td>
<td>°C</td>
<td>130/70</td>
</tr>
<tr>
<td>West HOB</td>
<td>Pressure (feed pipe)</td>
<td>MPa</td>
<td>1.28</td>
</tr>
<tr>
<td></td>
<td>Pressure (return pipe)</td>
<td>MPa</td>
<td>0.314</td>
</tr>
<tr>
<td></td>
<td>Mass flow</td>
<td>m³/h</td>
<td>3094</td>
</tr>
<tr>
<td></td>
<td>Temperature schedule</td>
<td>°C</td>
<td>130/70</td>
</tr>
<tr>
<td>South HOB</td>
<td>Pressure (feed pipe)</td>
<td>MPa</td>
<td>0.912</td>
</tr>
<tr>
<td></td>
<td>Pressure (return pipe)</td>
<td>MPa</td>
<td>0.216</td>
</tr>
<tr>
<td></td>
<td>Mass flow</td>
<td>m³/h</td>
<td>2121</td>
</tr>
<tr>
<td></td>
<td>Temperature schedule</td>
<td>°C</td>
<td>130/70</td>
</tr>
<tr>
<td>East HOB (taken out of service)</td>
<td>Pressure (feed pipe)</td>
<td>MPa</td>
<td>No data</td>
</tr>
<tr>
<td></td>
<td>Pressure (return pipe)</td>
<td>MPa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mass flow</td>
<td>m³/h</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temperature schedule</td>
<td>°C</td>
<td>130/70</td>
</tr>
</tbody>
</table>

4.2 The development of Waste to Energy technology in Sweden

In the late 1940’s the interest in district heating started to arise in Swedish municipalities. A preexisting waste burning activity on the landfills led to the idea to combine the two to activities to a combine waste disposal and heat generating system. The biggest expansion of this combined system then started in the 1970’s due to the worldwide energy crisis and regulating laws concerning landfilling of waste.

WTE got a setback in 1985 due to the rising concern about pollutants being emitted to the air from the power plants. This resulted in a ban of new construction of plants and a study whose purpose was to investigate solutions to the problem. The result of the study was that it is possible to build plants with sufficient cleaning of the flue gases and the law was repealed the year after. The increased production of energy from waste between 1985 and 2003 is shown in Table 4.(14)
Table 4 WTE in Sweden 1985 – 2003 (14)

<table>
<thead>
<tr>
<th>Year</th>
<th>Amount Burned [tonnes]</th>
<th>Energy Production [MWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>1 400 000</td>
<td>2 600 000</td>
</tr>
<tr>
<td>1990</td>
<td>1 700 000</td>
<td>4 300 000</td>
</tr>
<tr>
<td>1995</td>
<td>1 800 000</td>
<td>5 000 000</td>
</tr>
<tr>
<td>1999</td>
<td>1 900 000</td>
<td>5 000 000</td>
</tr>
<tr>
<td>2002</td>
<td>2 800 000</td>
<td>8 600 000</td>
</tr>
<tr>
<td>2003</td>
<td>3 100 000</td>
<td>9 300 000</td>
</tr>
</tbody>
</table>

4.3 EU Regulations - Incineration Directive 2000 76

One of the premises of the planned WTE-solution is that it must follow EU standards and regulations concerning incineration of municipal waste. The "Incineration Directive 2000 76" regulates the process from planning and operation of the WTE plant.

4.3.1 Operating conditions

To ensure a complete combustion of the waste the plant must follow regulations concerning operating conditions. The temperature in the combustion chamber must be 850 °C after the last injection of combustion air and if the temperature drops under 850 °C auxiliary burners must be used. The auxiliary burners should also ensure that the right startup temperature is reached. (15)

4.3.2 Emissions

The allowed emissions to air from a WTE plant are divided into different time intervals. The daily average can be seen in Table 5. For the planned WTE plant the values in Table 5 are the guidelines for emissions. (15)

Table 5 Incineration-Directive-2000-76 (15), Annex V

<table>
<thead>
<tr>
<th>Air Emission Values, Daily average</th>
<th>mg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total dust</td>
<td>10</td>
</tr>
<tr>
<td>Organic carbon</td>
<td>10</td>
</tr>
<tr>
<td>Hydrogen chloride (HCl)</td>
<td>10</td>
</tr>
<tr>
<td>Hydrogen fluoride (HF)</td>
<td>1</td>
</tr>
<tr>
<td>Sulfur dioxide (SO₂)</td>
<td>50</td>
</tr>
<tr>
<td>NOₓ</td>
<td>200</td>
</tr>
</tbody>
</table>
5 Theory

5.1 Waste incineration

Incinerating waste is just one of many ways to recover its energy content. Whether the main reason for incineration is waste disposal or energy recovery it is a good way of handling both issues. Using waste as a source of fuel for incineration is different from oil and natural gas due to its difference in composition and calorific value. It is usually a combination of industrial, domestic and agricultural waste, and the composition differs depending on what types of waste are available. The calorific value of paper is around 3.5-3.7 MWh/tonne, food contains around 2 MWh/tonne, plastics contain 8-10 MWh/tonne while the average calorific value for combustible fuel used in reports by ANRE is just above 8 MWh/tonne. Compared to Sweden, the Moldovan waste has a lower calorific value due to a higher fraction of organic material. (16)

5.1.1 Furnaces

There are two main types of furnaces used for combined heat and power plants where waste is the fuel. The more common type is called moving grate incinerator and the other type is the fluidized bed. A few other means of energy extraction from waste also exist, but they are not developed enough to be considered for this study.

5.1.2 Moving grate

The moving grate is the most common type of incinerator. It is durable, and allows variations in waste composition.

The temperature in this type of furnace is usually between 850-1100 °C. A crane is used to feed waste onto the grate in the furnace. The grate consists of separate adjustable parts which move the waste further in, drying and distributing it evenly before incineration. The combination of a high temperature and a well mixed fuel contributes to an efficient combustion process, even though the waste has not been prepared or separated.

Maximizing the efficiency of the incineration requires 4000-6000 m³ of air per tonne of waste. Most of this, the primary air, is provided from below the grate. The primary air also cools the grate, improving its mechanical strength. Secondary and tertiary air and resupplied flue gas is sent into the furnace at high speeds. This facilitates complete combustion of the flue gases and ensures a surplus of oxygen in the furnace.

![Figure 5 - Moving Grate](image)
After the grate, the flue gases are cooled by water passing through tubes in the furnace walls, where the heat is transferred to steam. From here the flue gases are passed to a flue gas cleaning system.

The ashes from the spent fuel are extinguished and taken care of. They are generally reduced to 3-5 % of the volume and 15-20 % of the original weight when they are taken away to a secure deposit. (16)

In order to get an efficient combustion with low emissions of carbon monoxide and hydrocarbons it is important to maintain the waste level on the grate and monitor the feeding speed so that the fuel is fully combusted when it is discarded. It is also important to maintain the right temperature and oxygen levels in the injected air to avoid the formation of NO₃ molecules.

5.1.3 Fluidized bed

Waste incineration in a fluidized bed is done in a bed of sand where the waste is only a small fraction of the material in the furnace. The sand itself is often a reactive component which lowers emissions of sulfur oxides. The bed is placed on a perforated plate, which the combustion air is blown through. In this type of furnace the temperature is usually around 900 °C. The two main types in commercial use are the bubbling fluidized bed and the circulating fluidized bed.

Compared to the moving grate, this technology does not allow the same variation in waste humidity, size and composition. This is because the fuel needs to be in motion during incineration. The same waste that could be incinerated in a moving grate often needs to go through a preparation process on its way to a fluidized bed incinerator. (17)

---

Figure 6 - Circulating fluidized bed
5.2 Flue gas cleaning

5.2.1 Particles filters
Particle filters can be divided into four different types: cyclone, electrostatic precipitator, fabric filter and wet scrubber. The methods are described below and showed in Figure 7 and Figure 9.

![Figure 7 Cyclone, Electrostatic precipitator, Fabric filter](image)

5.2.2 Cyclones
In the cyclone the centrifugal force is used to separate out particles by forcing the flue gas in a circular motion and hitting the wall of the cyclone. The particles fall down and the flue gas is leaving the cyclone in the top. (17)

5.2.3 Electrostatic precipitator
The flue gas is led trough two electrodes which have a high DC voltage between them. The voltage gives the particles a negative charge. The charge particles are separated out from the flue gas with a positive charged electrode that the particles stick to. This treatment can be used early in the process due to the temperature resistance. (17)

5.2.4 Electro venturi filter
An electro venturi filter is a wet electrostatic precipitator that instead of a positive electrode uses positive charged water molecules in a mist that entrap the negatively charged particles. (17)

5.2.5 Fabric filters
The bag filter is a textile particle filter that captures particles in a net of textile bags. When the bags are full of particles they can be cleaned, using methods like shaking, reverse air blowing, pulse jet and sonic cleaning. The most common one is the pulse jet method, where a pulse of high pressure air is forced in the opposite direction of the flue gas. The shock wave releases the particle cake from the bag filter and will be gathered in the bottom of the filter housing. (14)
5.2.6 **Wet scrubbers**

By spraying the flue gas with a liquid you can separate the particles from the flue gas. The particles can be separated with different mechanisms where impact and diffusion are the main two. The solution containing the particles falls down and is collected in the bottom of the housing. (17)

5.3 **Flue gas treatment**

The raw flue gas from waste incineration contains a variety of substances that are toxic to the environment. The most common are HCl, SO2, HF, dioxin, mercury and heavy metals. To reduce the content of these toxins, different treatment methods are used. The different methods can be divided in two groups, NOx reduction and absorbent usage.

There are three different main types that use absorbents to reduce the content of HCl, SO2, dioxin, and mercury in the flue gas, dry, semidry and wet treatment. The two main absorbents utilized are lime and activated carbon. Absorbents react with the toxins and the byproduct can be gathered in a particle filter. (14)

5.3.1 **Dry treatment**

The dry treatment contains of a reactor that adds the absorbent in a dry form to the flue gas and particle filter that separates the toxins and absorbents from the flue gas. A fraction of the absorbent can be recycled in the process.

\[
\begin{align*}
\text{Ca(OH)}_2 + \text{SO}_2 & \rightarrow \text{CaSO}_3 + \text{H}_2\text{O} \quad (i) \\
\text{Ca(OH)}_2 + \text{SO}_2 + \frac{1}{2}\text{O}_2 & \rightarrow \text{CaSO}_4 + \text{H}_2\text{O} \quad (ii) \\
\text{Ca(OH)}_2 + 2\text{HCl} & \rightarrow \text{CaCl}_2 + 2\text{H}_2\text{O} \quad (iii) \\
\text{Ca(OH)}_2 + 2\text{HF} & \rightarrow \text{CaF}_2 + 2\text{H}_2\text{O} \quad (iv)
\end{align*}
\]

This method results in a dry residue that consists of the filter masses which must be safely deposited on a regulated and controlled landfill. (14)

5.3.2 **Semi-dry treatment**

The semidry treatment contains of a reactor that adds the absorbent as a slurry with water, to the flue gas and particle filter that’s separate the toxins and absorbents from the flue gas. The heat in the flue gas vaporizes the water and the absorbents react with the toxins, Figure 8.

\[
\begin{align*}
\text{Ca(OH)}_2 + \text{SO}_2(g) & \rightarrow \text{CaSO}_3(s) + \text{H}_2\text{O}(g) \quad (v) \\
\text{Ca(OH)}_2 + 2\text{HCl}(g) & \rightarrow \text{CaCl}_2 + 2\text{H}_2\text{O}(g) \quad (vi)
\end{align*}
\]

This method results with a dry residue that consists of the filter masses which must be safely deposited on a regulated and controlled landfill.
5.3.3 Wet treatment

Wet treatment is a more advanced method than the two aforementioned. With this method the toxins are washed out from the raw flue gas in several steps. If the raw flue gas has a high dust particle content it must pass through a particle filter before the wet treatment. In the first step of the treatment the flue gas is cooled down in a quencher to the saturation temperature. The next step is a scrubber which contains a water solution with a low pH value resulting in the capture of HCl, HF, mercury and heavy metals in the solution. The third step raises the pH level by using lime. The lime reacts with SO₂ and forms a calcium sulfite which oxidizes to calcium sulfate. After the wet treatment steps there is still a concentration of dioxins in the flue gas. The treatment therefore needs a bag filter containing activated carbon. This method gives a residue of contaminated water that must be taken care of in an industrial water cleaning system. The dioxin containing filter masses can be incinerated to get rid of the dioxins. (14)

5.3.4 NOₓ reduction, DeNOₓ

To reduce the content of NOₓ compounds in the raw flue gas, two different methods can be used: selective catalytic reduction (SCR) and selective non catalytic reduction (SNCR). The main components used for reduction of NOₓ are ammonia (NH₃) and urea (CO(NH₂)₂). (17)
\[2\text{NH}_3 + 2\text{NO} + \frac{1}{2}\text{O}_2 \rightarrow 2\text{N}_2 + 3\text{H}_2\text{O} \quad (vii)\]

\[\text{CO(NH}_2)_2 + 2\text{NO} + \frac{1}{2}\text{O}_2 \rightarrow 2\text{N}_2 + \text{CO}_2 + 2\text{H}_2\text{O} \quad (viii)\]

### 5.3.4.1 SCR - Selective Catalytic Reaction

SCR is a catalytic method using ammonia (\(\text{NH}_3\)) as a reductant and vanadium and titanium oxide in a catalyst. The NO\(_x\) compounds are reduced to water and nitrogen. The catalysis process requires a particle free flue gas with a temperature of 200°C. This results in that the flue gas need to be reheated after the particle filter and the method is therefore energy demanding. SCR can also reduce the content of dioxin.\(^{(17)}\)

\[4\text{NO} + 4\text{NH}_3 + \text{O}_2 \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O} \quad (ix)\]

\[6\text{NO} + 4\text{NH}_3 \rightarrow 5\text{N}_2 + 6\text{H}_2\text{O} \quad (x)\]

\[2\text{NO}_2 + 8\text{NH}_3 + \text{O}_2 \rightarrow 3\text{N}_2 + 6\text{H}_2\text{O} \quad (xi)\]

### 5.3.4.2 SNCR- Selective Non Catalytic Reaction

SNCR is a non catalytic method using ammonia (\(\text{NH}_3\)) or urea (\(\text{CO(NH}_2)_2\)) as reductants. The NO\(_x\) compounds are reduced to water and nitrogen with the help of heat from the incineration. SNCR demands a temperature of 850°C to 1100°C. In comparison with the SCR, the SNCR is a simpler method but it uses more reductants and it therefore has a lower investment cost but higher operating costs. \(^{(17)}\)

\[4\text{NO} + 4\text{NH}_3 \rightarrow 4\text{N}_2 + 6\text{H}_2\text{O} \quad (xii)\]

\[6\text{NO}_2 + 8\text{NH}_3 \rightarrow 7\text{N}_2 + 12\text{H}_2\text{O} \quad (xiii)\]
5.4 Steam production

5.4.1 Steam boiler
The steam boiler is where the heat exchange between the flue gas and the boiler water takes place. The feed water is first exposed to the heat of the flue gas in an economizer before it is vaporized in an evaporator. The steam is then passed through a super heater increasing its temperature and by controlling this process one can get the desired steam properties.

5.4.2 Steam cycle
The name combined heat and power plant (CHP) comes from the fact that the steam energy is used to produce electric power and hot water. The main source of energy in the obtained steam comes out of the condensation process. Extracting this energy can be done in different ways. Either the steam is run through a back pressure turbine where it condensates against the district heating grid or another pressurized water source. Otherwise a condensing turbine is used where a low pressure water source or a cooling tower is used to cool the steam. The steam is passed through one or more turbines, with intermediate super heaters in between them. Increased pressure and temperature in the process affect the obtained electrical power in relation to thermal power, but it also puts greater strain on the components of the plant. A temperature of 400 °C and 40 bar pressure is one of the commonly used combinations to minimize investment costs. Temperatures higher than 400 °C may cause high temperature corrosion and forces the boiler to have steel alloy super heater tubes to withstand the strain. Pressures below 40 bar lower the requirements for pretreatment of the feed water. (17)

---

Figure 10 - Simple Steam Boiler Schematic (10)

Figure 11 - Simple steam cycle schematic

<table>
<thead>
<tr>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Steam Boiler</td>
</tr>
<tr>
<td>2. Condensing turbine</td>
</tr>
<tr>
<td>3. Backpressure turbine</td>
</tr>
<tr>
<td>4. Cold water condenser</td>
</tr>
<tr>
<td>5. Hot water condenser</td>
</tr>
<tr>
<td>6. Direct condenser</td>
</tr>
<tr>
<td>7. Circulation pump</td>
</tr>
<tr>
<td>8. District heating grid</td>
</tr>
</tbody>
</table>
5.4.3 Rankine cycle
When calculating the theoretical energy output of power generation this thermodynamic flow cycle is used to describe it. The cycle describes the thermodynamic properties of an energy carrier according to what amount of heat is added and extracted.

In a co-generation plant there are certain limitations set to the cycle, depending on internal and external factors. Internal factors are for instance the durability of components and the size of the plant. A number of external factors are local climate, fuel quality and external cooling sources such as district heating grids and cooling towers.

An example of a Rankine cycle with two turbines, a reheating step and district heating connection is illustrated in Chart 1. Here the limitations are set to 400 °C and 40 bar. The theoretical electricity output is described in two cases by the green and blue lines. The difference between the cases is determined by what limitations are set by the district heating grid. In the green process the steam needs a higher temperature, which limits the electrical output.

![Chart 1 - T-s Chart of a Rankine cycle with intermediary heating. Show different turbine extraction pressures.](image)

5.5 Cooling tower
There are different cooling tower solutions for a power plant. The two main types are open and closed systems and these two can be wet or dry. In a dry system air is used as a cooling medium to cool the working medium and in a wet system water is used. An open wet system requires a cooling water source and is there for limited. A closed dry system requires air as a cooling medium and is therefore not as limited as an open wet system. (17)
6 Method

The specifications for this assignment have been chosen to reduce regional landfilling of by 400,000 tonnes/year using waste incineration technology.

In order to properly dimension a waste incineration plant, data needs to be gathered for several calculations.

This study has been done in three steps:

Gathering conditions for a WTE plant in Chisinau:

- Waste management and composition
- Energy prices
- Possible locations for a plant
- Connection to heat and electricity grid
- Emission regulations
- Efficiency of current energy producing plants

Analyzing gathered data using Swedish WTE expertise. Consultations come from Borlänge Energi, EcoEnergy, Ragn-Sells Miljökonsult AB, ÅF, von Roll, Siemens Turbo Machinery and Alstom Power Sweden to choose:

- Incineration technology
- Number and size of boilers
- Turbine and generators
- Flue gas treatment
- Cooling tower
- NOx reduction
- Treatment of ashes and residues

Concluding suitable plant dimensions and estimation of economical and environmental benefits:

- Summary of total investment costs for suggested plant components
- Plant output in relation to energy demand
- Profitability
- Sensitivity analysis regarding different interest and discount rates
- Calculation of total emissions
- Environmental comparison to landfilling
6.1 Chemical Combustion
The heat generation in the incineration process is determined by a number of important reactions. Using data on waste composition and average chemical elements in waste components, the fractions of carbon, hydrogen and water can be calculated. Knowing the flow of fed in waste, and the fractions of the chemical compounds, allows for calculations of the heat generation in the combustion process.

Firstly, a certain amount of water in the fuel needs to evaporate before the fuel can combust. In order for the water in the fuel to evaporate it first needs to be heated to 100 °C. The energy needed to heat water from 20-100°C is 334 kJ/kg and evaporation requires 2257 kJ/kg.

Secondly, the amount of molecular carbon and hydrogen in the fuel are the main contributors to the heat generation. The majority of the energy released while incinerating waste comes from two important chemical reactions:

\[
\begin{align*}
C + O_2 &\rightarrow CO_2 + 33,913 \text{ (kJ/kg) Carbon combusted} \\
2 \text{H}_2 + O_2 &\rightarrow \text{H}_2\text{O} + 142,770 \text{ (kJ/kg) Hydrogen combusted}
\end{align*}
\]

The molecular carbon and hydrogen react with the oxygen in the combustion air releasing their molecular binding energy into the flue gas.

Thirdly, since a waste combustion process requires a lot of air, there will be a surplus of nitrogen and oxygen that do not react in the combustion process but are heated to the same temperature as the flue gas.

Specific heat capacities:

\[
\begin{align*}
C_p [\text{N}_2] &= 1.04 \text{ kJ/ (kg*K)} \\
C_p [\text{O}_2] &= 0.919 \text{ kJ/ (kg*K)}
\end{align*}
\]

Finally, some heat is lost from the incomestible materials that leave the grate. In the combustion model, an average heat capacity is calculated for the inert components in the incineration process. The residue temperature is estimated to 100 °C when it leaves the grate, and this heat is considered as a loss.

In Appendix II the thermal output of these processes are calculated and summarized.
6.2 Flue Gas Composition

The flue gas is responsible for the energy transfer from the incineration process into the steam cycle. In order to obtain the flue gas energy, the combustion temperature is calculated. This describes the highest theoretical temperature reached in an adiabatic combustion process, for a specific fuel source.

\[ T_{g} = \frac{H_1 + I_v \cdot c_{pl} \cdot t_1}{g_v \cdot c_{pg}} \quad (xvi) \]

- \( T_{g} \) = Theoretical flue gas temperature
- \( H_1 \) = Calorific value of fuel
- \( I_v \) = Airflow (real)
- \( c_{pl} \) = Specific heat capacity (Air)
- \( t_1 \) = Air temperature
- \( g_v \) = Flue gas flow (real)
- \( c_{pg} \) = Specific heat capacity (Flue gas)

The temperature distribution in a furnace can be distributed as illustrated in Figure 12. The highest temperature in the furnace, close to the grate, will be close to the calculated theoretical one. The dimensions of the furnace and boiler, along with the grate air supply and auxiliary burners, will determine what temperature the flue gas will have at the steam heat exchange.

When designing the heat exchange system between furnace and boiler the goal is to maximize the boiler efficiency, while still operating at sustainable temperatures. The two most important limitations are set by the furnace heat resistance, which sets the highest temperature, and flue gas treatment requirements, which sets the lowest temperature. Usually, the flue gas needs to be treated in the temperature range between 155 – 130 °C. After this, a portion of the remaining flue gas energy content is used for pre-heating combustion air. At between 50 – 70 °C the rest of the energy is released through the chimney.
The main flue gas components in a WTE combustion process needed for heat transfer and emission calculations are: O₂, CO₂, H₂O, SO₂ and N₂. The amounts generated depend on the elemental composition of the waste and the amount of air supplied to the incineration process. (17)

6.3 Steam cycle model in MATLAB

To be certain that the best characteristics and configuration of the components in the steam cycle will be chosen, a calculation model was made in the program MATLAB. The model varies the characteristics and configurations and determines which version is the most profitable in regard to sales of electricity and district heating. The annual production is divided into 12 months with different operating conditions. The two main physical relations that are used in the optimization program are mass balance and energy balance. The sum of energy flow into one node is equal to the sum of energy flow out of it, and the same applies to the mass flow. The system is approximated as an ideal system where no energy is lost. See Appendix IV for the complete code and further explanation of the model. The optimization program is based on a schematic picture of the steam cycle that is showed in Figure 13 and explained in Table 6.

![Figure 13 - Steam cycle model](image-url)
<table>
<thead>
<tr>
<th>Node</th>
<th>Description</th>
<th>Node</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Steam boiler outlet / HP-turbine inlet</td>
<td>16</td>
<td>Condensate tank</td>
</tr>
<tr>
<td>2</td>
<td>HP-turbine outlet / Intermediate super heater inlet</td>
<td>17</td>
<td>Condensate</td>
</tr>
<tr>
<td>3</td>
<td>Intermediate super heater outlet / LP-turbine inlet</td>
<td>18</td>
<td>Pre heated condensate</td>
</tr>
<tr>
<td>4</td>
<td>LP-turbine exhaust / FW-tank pre heater</td>
<td>19</td>
<td>Pre heated condensate</td>
</tr>
<tr>
<td>5</td>
<td>LP-turbine exhaust</td>
<td>20</td>
<td>Pre heated condensate / FW-tank inlet</td>
</tr>
<tr>
<td>6</td>
<td>Low temp DH heat exchanger</td>
<td>21</td>
<td>FW-tank pre heater condensate</td>
</tr>
<tr>
<td>7</td>
<td>FW-tank pre heater</td>
<td>22</td>
<td>FW-tank inlet</td>
</tr>
<tr>
<td>8</td>
<td>FW-tank pre heater condensate</td>
<td>23</td>
<td>Feed water tank</td>
</tr>
<tr>
<td>9</td>
<td>High temp DH heat exchanger</td>
<td>24</td>
<td>Economizer inlet</td>
</tr>
<tr>
<td>10</td>
<td>High temp DH heat exchanger condensate</td>
<td>25</td>
<td>Steam boiler inlet</td>
</tr>
<tr>
<td>11</td>
<td>Low temp DH heat exchanger condensate</td>
<td>26</td>
<td>DH incoming</td>
</tr>
<tr>
<td>12</td>
<td>Condensate tank inlet</td>
<td>27</td>
<td>DH incoming</td>
</tr>
<tr>
<td>13</td>
<td>LP-turbine exhaust</td>
<td>28</td>
<td>DH Low temp heated</td>
</tr>
<tr>
<td>14</td>
<td>CT condensate</td>
<td>29</td>
<td>DH High temp heated / DH outgoing</td>
</tr>
<tr>
<td>15</td>
<td>Condensate tank inlet from CT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.3.1 **Optimization or finding the best profit with given test limitations**
The model varies four parameters in a reasonable range of values to optimize profit.

1. The mass flow to the cooling tower, CT, node 13
   - The minimum is 0 and the maximum is the fraction that corresponds to the difference between the heat demand in the grid and heat production capacity.

2. The pressure drop after the high pressure turbine, T[HP], node 2
   - The pre-determined node 6 decides the minimum pressure in node 2. The minimum pressure in node 2 is the minimum pressure for node 3, corresponding to an isentropic rise from node 6 to temperature for node 3. The maximum pressure is the pressure for the steam boiler outlet.

3. The mass flow through the district heating grid heaters, DH, node 6 and 9
   - The minimum mass flow fraction is 0 and the maximum is what’s left from number 1.

4. The pressure and the following characteristics in the drain that preheats the water before the feed water tank, FW, node 4
   - The minimum pressure for the drain to the second pre heater is the minimum pressure for node 6. The maximum pressure is the pressure for the steam boiler outlet. The mass flow in the pre heater drains is what’s left from number 1 and 3.

The pre-determined nodes and conditions are illustrated in Table 7.

**Table 7 - Pre-determined nodes and range limit**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Steam boiler outlet</td>
<td>40</td>
<td>400</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Super heater inlet</td>
<td></td>
<td></td>
<td></td>
<td>Pressure [6.18-40]</td>
</tr>
<tr>
<td>3</td>
<td>Super heater outlet 40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 &amp; 7</td>
<td>Pre-heaters</td>
<td></td>
<td></td>
<td></td>
<td>Pressure [0.5-40]</td>
</tr>
<tr>
<td>6</td>
<td>LP-turbine outlet</td>
<td>0.5</td>
<td>100</td>
<td></td>
<td>Mass flow [0-1]</td>
</tr>
<tr>
<td>13</td>
<td>CT inlet</td>
<td></td>
<td></td>
<td></td>
<td>Mass flow [0-1]</td>
</tr>
<tr>
<td>25</td>
<td>Economizer inlet</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Steam Boiler inlet</td>
<td>40</td>
<td>250</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>DH Inlet</td>
<td>2.35</td>
<td>70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>DH Outlet</td>
<td>11.33</td>
<td>130</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.3.2 **Cooling demand**
In the summer months, May to September, the potential thermal power output exceeds the grid’s heat demand. If full capacity production is desired during these months the excess heat must be taken care of in a cooling system. The MATLAB program calculates a minimum cooling demand for every month.

6.3.3 **Total energy production and profit**
The total steam production is calculated with the efficiencies calculated in a combustion model. The total steam production determines with the thermal and electric efficiencies the production of heat and electricity production. The total profit is calculated with the current prices for heat and electricity. The highest total profit from results in the best set up of the tested parameters.
6.4 Investment calculations

In order to determine if an investment is economically feasible, different investment calculation methods are used. In this study, the payback time and Net Present Value (NPV) methods are used. To be able to do the investment calculations, the interest rates and discount rates are assumed and varied to make sensitivity analyses. The ranges of assumptions are displayed in Table 8. The calculations will be done with and without taxes included and three different results will be changed to make another level of sensitivity analysis, see Table 9. The economic lifetime is estimated to 20 years. For the economical calculations, the conditions of 2011 will be used without estimating future economical development.

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Range</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest rate</td>
<td>4 %, 6 %, 8 %</td>
<td>10 % higher costs</td>
</tr>
<tr>
<td>Discount rate</td>
<td>8 %, 10 %, 12 %</td>
<td>10 % higher investment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 % less yearly profit</td>
</tr>
</tbody>
</table>

6.4.1 Payback time

The payback time is the time the investment takes to pay off. The calculation is based on the total investment cost and the yearly cash flow.

\[
\frac{Investment \ cost}{Yearly\ cash\ flow} = \text{Payback Time} \quad (xvii)
\]

6.4.2 Net present value and internal rate of return

The net present value method (NPV) determines the feasibility of an investment with a pre-determined discount rate or yearly rate of return. An investment is good if the NPV-value is positive. The investments internal rate of return (IRR) will be the equal to the discount rate if the NPV-value is zero.

\[
\sum_{n=0}^{y} \frac{CF}{(1 + r)^n} = PV 
\]

\[
I - PV = NPV 
\]

\[
NPV > 0 \rightarrow \text{GOOD INVESTMENT} \\
\]
\[
r = \text{Discount rate} \\
y = \text{Economic lifetime, depreciation time} \\
I = \text{Investment cost} \\
CF = \text{Yearly Cash Flow} 
\]
6.5 Environmental comparison

6.5.1 Waste to energy vs gas turbines & landfills
The environmental impact from WTE comes from a number of emissions of GHG-gases, pollutants and hazardous compounds from the waste. In order to compare WTE to the present system, one needs to compare the emissions of the waste incineration to the current landfill solution and the energy production in the gas turbine driven CHP:s.

To calculate these emissions a number of reports, from the Intergovernmental Panel on Climate Change (IPCC) on emissions from landfills and combustion of waste and natural gas, are used. Since no waste composition studies have been done for the Chisinau area there are sources of uncertainty in these numbers, but it is useful to get a general idea.

6.5.2 WTE emissions
From the elemental composition of the waste and the air flow in the system, the flue gas data is calculated. To get the emissions into the air, some subtractions are made for the fractions of unburned organic material and the flue gas cleaning system.

Flow of CO₂:

\[
\dot{m}_{CO_2} = \dot{m}_f \times \frac{\%COC \times \% DO \times \%C}{100} \times \frac{M_{CO_2}}{M_C} \times \frac{n_{CO_2}}{n_C} \quad (17)
\]

\% COC = Combusted organic compounds \quad \% DO = Dry organic matter \quad \% C = Carbon

\(\dot{m}_X = \text{Mass flow of } X\quad M_X = \text{Molar mass of } X\quad n_X = \text{Number of moles of compound } X\)

6.5.3 Gas Turbine emissions
The theoretical CHP plant emissions for the comparison are calculated using data from the Moldovan National Agency of Energy (ANRE). The data contains the annual CHP efficiency and natural gas use. In order to make a fair comparison, the amount of utilized natural gas is determined to match the production of the proposed WTE plant. The US Environmental Protection Agency has reports on emissions per cubic meter of fuel used in a standard gas turbine. See Appendix III.

6.5.4 Landfill emissions
From landfills, the majority of emissions are methane gases. To estimate the amount of emitted gases from the Chisinau landfills, an IPCC landfill emission report is used. (20)

As the degradable carbon fraction of different waste components decompose they emit methane, and using the waste composition one can calculate the summarized landfill decomposition and emissions.

The landfills differ from WTE and gas turbines since the decomposition is an ongoing process, and the waste is not rendered inert at any certain point. Therefore the waste from the first year will add a somewhat smaller amount of emissions to the emissions of the second year’s waste, resulting in an exponential increase of methane emissions. This may have a major impact on the comparison.
6.5.5 Comparison
The main comparison in this report is the greenhouse gas impact of the different emissions, where the landfill and gas turbines are added and plotted against the WTE solutions.

The calculation of emitted VOC, TOC and heavy metals is unreliable due to the fact that no waste composition analysis has been done yet. Therefore it has significant sources of error, arguably rendering it too unreliable to bring into the comparison.
7 Conditions for design
In order to properly choose components for a Waste to Energy plant there is a number of parameters and conditions to consider. Since this is a master thesis with a limited timeframe, most components have been chosen using help from experts and consultants in their respective areas.

7.1.1 Operating time
It is preferable to find the most reliable system that minimizes unplanned downtime. A general requirement of operation is around 8000 hours per year where most of the downtime is planned during the summer when the heat demand is low.

7.1.2 Waste accumulation
The initial and most pressing issue is the accumulation of municipal solid waste (MSW). A yearly 320,000-400,000 tonnes needs a proper treatment system.

7.1.3 Waste composition
The choice of incineration method is influenced by the variations in energy content, moisture, toxic materials and particle size. Incineration methods that handle large variations are often more expensive but do not require preparatory treatment of waste. Due to the variations in energy content, it is important to dimension the components to withstand peak temperatures higher than the regular operation temperature.

7.1.4 Environmental regulations
If the design choice is to use a waste recovery solution, like incineration, there are EU directives on emissions that need to be taken into account. The levels of CO₂, NOₓ, SOₓ, TOC, VOC and GHG need to fulfill the demands of the directives. In order to ensure that the emissions are kept below the regulation values, one needs to have a certain safety margin to compensate for the fuel variations.

7.1.5 Fitting the solution into the Chisinau energy system
The proposed solution needs to meet the demands set by the district heating grid, mainly in terms of pressure and temperature. This puts restrictions on the turbine output, and therefore also the electrical output.

7.1.6 Location & water supply
Compared to other types of power plants, a WTE plant requires a large area of land. The location also affects the costs of grid installation. Some types of components require a significant source of water to operate, such as wet flue gas cleaning systems with scrubbers. If the location of the plant is not close to a natural source of water, these components are rarely feasible.

7.1.7 Cooling demand
During a majority of the 8000 hours in operation the demand of district heat exceeds the production of heat from the WTE plant. The demand is lower during the summer months May to September. During these months the plant can theoretically deliver the whole demand of heat. When the plant consists of two production lines the possibility to meet the declining demand in the summer can be met in a sufficient way.

A lower production than full capacity leads to a demand of another waste management solution during the summer months. If a continuous production at full capacity is desired, the excess heat must be taken care of in a cooling tower or re-cookers in the district heating grid.
7.1.8 Economy
The difference in price between heat and electricity must be taken into account when designing the plant. The ideal output ratio between heat and electricity is calculated to maximize profit.

When the theoretical design is done its economical feasibility must be discussed with professionals responsible for similar projects, so that the chosen components do not lead to unnecessary investment costs.

When doing calculations on pay back times, the interest rate and desired discount rate are just as important as getting the right component prices. Since they can be rather difficult to predict a set of scenarios will be set up with different probable rates.

7.1.9 Staff and maintenance
By choosing reliable components one can reduce the need for maintenance which will result in less downtime and lower staff costs.
8 Results
The result is divided in two different sections: Design – choice of components and calculation model results.

8.1 Design – choice of components

![Design Model Parameters](image)

1. Waste Supply
2. District Heating System
3. Incineration Grate
4. Steam Boiler
5. Flue Gas Cleaning System

Figure 14 - Design Model Parameters

8.1.1 Operation
In this design, as well as most new WTE plant designs, all calculations are done for 8000 production hours per year.

8.1.2 Waste supply
The current yearly waste accumulation is approximately 320,000 tonnes, and is expected to grow to 400,000 tonnes over the coming years. There is also a reliable source of straw that could be used to balance out any gaps in the waste supply. Since the planned operation time used in calculations will be 8000 hours, the hourly waste feed will be 50 tonnes/h.

Storage is done in a bunker designed to hold enough waste for three days of production. The waste density is approximated to 250 kg/m³, therefore the waste bunker needs to be 14,400 m³.

The calorific value is 2.6 MWh/tonne pure waste or 2.8 MWh/tonne with mixed in straw, but these values depend on the waste composition used in the simulation program.

8.1.3 District heating system
The DH water supply of Chisinau operates at relatively high temperatures and pressures; Table 3. This affects the potential electrical output of the proposed plant. With low incoming DH temperatures it is possible to extract more of the steam energy in the turbines. It also allows for flue gas condensation, through which more electrical energy can be obtained. In this case, given the DH data obtained from Termocom, the design will not include flue gas condensation.

In order to raise the electrical output of the steam cycle, the DH heat exchanger is fed steam from two exhausts in the turbine. The first exhaust is fed to a heat exchanger that raises the DH
temperature to 130 °C while the second one raises it to 100 °C. The goal is to maximize the amount of steam extracted in the second step to get the best possible electrical output, while still satisfying the DH demand. This is done by extracting steam at the lower possible pressure.

### 8.1.4 Incineration grate

In this study the choice of incineration technology is the moving grate method. The reason for this is its ability to handle different waste compositions and the fact that it doesn’t require any pre-treatment of the waste. A rule of thumb for moving grates is that a single grate has a maximum feed capacity of 40 tonnes/h. With this in mind and also for production safety reasons, there will be two separate grate and boiler lines and for economical reasons they will have the same thermal capacity of 70 MW. (21)

To ensure production temperatures according to environmental regulations and to minimize the costs of operation, one should choose the solution that requires as little fuel, electricity and chemicals as possible. Auxiliary burners require oil or gas for support incineration, chemicals are used for the flue gas treatment and electricity is used for pumps and running mechanical components etc.

### 8.1.5 Steam cycle components

A theoretical steam cycle model has been constructed in MATLAB, to help with the choice of components and technical specifications for them. The steam boilers, turbines, generator, cooling tower, district heating heat exchanger, condensate tank and feed water tanks have all been designed according to waste and DH conditions. Some have predetermined values and some have dynamic values adapting to the other components. See Figure 13 & Table 7.

#### 8.1.5.1 Steam Boiler [SB]

The desired thermal capacity of the boilers has been determined from the feed flow and calorific value of the waste. To prepare for a probable future increase of waste amount and energy density, as well as unpredicted thermal spikes, a capacity margin is added to the theoretical value. This results in a proposed thermal capacity of 140MW, divided into two 70MW lines.

#### 8.1.5.2 Turbines T[HP] & T[LP] and Generator [G]

The theoretical model has two back pressure turbine steps with an intermediary superheating step between them. Larger power plants with energy dense fuels usually have more steps, but they also come with higher investment costs that do not necessarily pay back in smaller plants.

The monthly average electrical output of the proposed plant will be around 32 MW. The chosen generator type is designed to operate efficiently at these conditions. The proposed solution is two Siemens SST-300 systems. (22)

#### 8.1.5.3 Cooling Tower [CT]

In the summer season the maximum thermal power output exceeds the DH demand. Since the primary goal is to treat all the incoming waste, this becomes a problem without another source of cooling. In this case the maximum cooling demand will be 45 MW. In the case that only one production line is used during August, the demand will instead be about 5 MW. (23)

Given the conditions of the proposed location, a GEA dry system cooling tower, Air Cooling Condenser (ACC), will be proposed. These can be placed next to the power plant or as re-coolers in the district heating grid. (24)
8.1.5.4 Flue gas treatment and particle separation
The choice of flue gas treatment system depends on the environmental regulations, the water supply at the suggested location and the potential for a wastewater treating system. In this case, according to the information about the location in Botanica, a wet system is not feasible. The proposed solution is a semi dry treatment system with hydrated lime as reductant. A suggested type is the Alstom NID-system (19). This system demands a particle filter, in this case a bag filter with activated carbon. (25)

8.1.5.5 Nitrogen reduction - SNCR DeNOx
Out of the two types of DeNOx technology the SNCR is chosen for its simplicity and low investment cost. The system will use ammonia as reductant and the aforementioned particle separation is suitable for this technology. (21)

8.1.6 Location
The most suitable plant location, suggested by all interviewed Moldovan officials, is the site of Centralka Termica Est (CHP EAST)(26)(27). This plant was taken out of service in 1999, and the area of the site is 12.9 ha. It is connected to the district heating grid and has a thermal capacity of 380 Gcal/h, or around 440 MW. This location is close to the city center, is grid connected with a gas source for auxiliary burners and has a large enough site for the project. (28)

![Map of proposed location](image)

Figure 15 - Proposed location. CHP East, Coordinates: 46°58'19"N 28°54'56"E (28)
8.1.7 Flue gas chimney height

The location and its population density, along with flue gas flow and climate conditions set the requirements for the chimney height of the plant.

In this study, the chimney height estimation is done using a stock height calculation document provided by the Swedish Environmental Protection Agency. (29)

The input data in these calculations are flue gas flows, temperatures and geographical data obtained for the location from Google Earth.

\[
H_o = H_{ref} + \Delta H_{sd} + \Delta H_{tb} + \Delta H_{bd} \ [m] \\
\]

\[
H_o = \text{Building height [m]} \\
H_{ref} = \text{Reference Height of the chimney [m]} \\
\Delta H_{sd} = \text{Height additions due to draft in the lee of the chimney [m]} \\
\Delta H_{tb} = \text{Height additions due to terrain and buildings [m]} \\
\Delta H_{bd} = \text{Height additions due to draft at adjacent buildings [m]} \\
\]

\[
H_o = 60 + 0 + 17 + 0 = 77 \ [m] 
\]
8.2 Calculation models results

The WTE plant design in this study has been done knowing that the waste composition has not yet been analyzed for the Chisinau area. With this in mind a sort of multistep dynamic model has been produced to be able to change all the results depending on what waste composition is specified. The waste composition used for this draft of the study is from a similar project in Donetsk, Ukraine. Using the waste composition in a WTE simulation program provided by Avfall Sverige, the elemental composition is gained. Using this information and theoretical combustion chemistry (30), an Excel model has been made to calculate the heat generation and flue gas content. A majority of the combustion energy is converted to a flow of saturated steam at 400°C, 40bar, which is then used in a MATLAB steam cycle model. This model optimizes the output of thermal and electrical power to maximize profit using current Moldovan energy prices, while delivering thermal power according to the Chisinau district heating grid specifications. The calculated flue gas flow is used in the WTE simulation program to obtain emitted flue gases after treatment.

In Figure 16, the different model steps are shown with different colors.
8.3 Waste composition

At the time of writing, there were no conclusive studies on the Chisinau waste composition. Until such a study is done or experts can make proper waste estimations, data from a similar study for Donetsk, Ukraine, will be used. (31)

![Waste Composition](chart2.png)

**Chart 2 - Waste composition, Donetsk, Ukraine (31)**

Comments

There are two important considerations to be made when using this data for Chisinau.

Firstly, the residue category is difficult to classify when using the data for an elemental composition simulation. Since it stands for such a significant fraction of the waste, it has been divided among the other components according to their respective fractions. This results in a low moisture waste composition with higher calorific value than what is expected in reality. However, since the elemental fractions in the dry mass will still be the same, this data can still be used for further calculations.

Secondly, compared to Donetsk, Chisinau has less industrial production which is likely to result in lower calorific value due to the higher fraction of food waste.

These considerations lead to an assumption that the Donetsk data will result in a relatively high heat generation. This can be seen as a theoretical maximum value, which is unlikely to occur, but needs to be considered for dimensioning of plant components.

Knowing that the waste composition is expected to change before the real project planning process is initiated; the calculation model is made dynamic with the waste composition as the in-parameter.

8.4 Elemental composition

The elemental composition simulation shows a relatively energy dense substance, which is likely to have a calorific value of around 3 MWh/tonne.
Table 10 - Elemental Composition

<table>
<thead>
<tr>
<th>Main Components</th>
<th>Weight %</th>
<th>Ash composition</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content</td>
<td>36.904</td>
<td>Na₂O</td>
<td>8.277</td>
</tr>
<tr>
<td>Ash Content</td>
<td>24.229</td>
<td>K₂O</td>
<td>8.415</td>
</tr>
<tr>
<td>Elemental composition</td>
<td></td>
<td>CaO</td>
<td>39.312</td>
</tr>
<tr>
<td>Carbon</td>
<td>59.721</td>
<td>MgO</td>
<td>6.089</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>8.548</td>
<td>SiO₂</td>
<td>20.575</td>
</tr>
<tr>
<td>Oxygen</td>
<td>29.063</td>
<td>Al₂O₃</td>
<td>6.357</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1.919</td>
<td>Fe₂O₃</td>
<td>6.633</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.223</td>
<td>TiO₂</td>
<td>0.226</td>
</tr>
<tr>
<td>Halogens</td>
<td></td>
<td>MnO</td>
<td>0.288</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0.556</td>
<td>BaO</td>
<td>0.058</td>
</tr>
<tr>
<td>Fluorine</td>
<td>244.355</td>
<td>SnO</td>
<td>0.049</td>
</tr>
<tr>
<td>Bromine</td>
<td>4.125</td>
<td>P₂O₅</td>
<td>2.904</td>
</tr>
</tbody>
</table>

Comments
In practice, the moisture content is expected to be higher, which would result in a lower heat generation value due to the lower combustion temperature. To counteract this, a set of combustion temperature scenarios will be set up when calculating the flue gas heat transfer.

8.5 Combustion – Heat Generation
The elemental fractions have been multiplied with the waste feed flow, resulting in an elemental feed to the combustion grate. The significant exothermic reactions provide the positive thermal impact values, while heating the inert elements represents most of the negative values.

Table 11 - Heat Generation: Results of combustion calculations

<table>
<thead>
<tr>
<th></th>
<th>Flow [kg/s]</th>
<th>Thermal contribution [kJ/kg]</th>
<th>Thermal Impact [kJ/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content</td>
<td>5.13</td>
<td>-2591.40</td>
<td>-13282.29</td>
</tr>
<tr>
<td>Ashes (inert)</td>
<td>2.12</td>
<td>-69.17</td>
<td>-146.87</td>
</tr>
<tr>
<td>Reaching comb. temp</td>
<td>6.64</td>
<td>-616.63</td>
<td>-2583.46</td>
</tr>
<tr>
<td>Coal</td>
<td>3.85</td>
<td>33913.00</td>
<td>130447.29</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0.55</td>
<td>142770.00</td>
<td>78603.32</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.12</td>
<td>-945.49</td>
<td>-116.85</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.01</td>
<td>10467.00</td>
<td>150.56</td>
</tr>
<tr>
<td>Excess oxygen</td>
<td>7.00</td>
<td>-836.29</td>
<td>-5850.48</td>
</tr>
<tr>
<td>Inert N₂</td>
<td>61.60</td>
<td>-945.49</td>
<td>-58245.30</td>
</tr>
</tbody>
</table>

Average thermal Power output [MW] | 128.98
Comments
While the carbon and hydrogen processes generate around 210 MW heat, the heating of excess air and vaporization of water are costly for the process. Higher waste moisture content would increase the vaporization costs, but since the fraction of combustible materials would also be lower the air supply would decrease slightly.

8.6 Flue gases

8.6.1 Generated flue gas flow
Most of the flue gases originate from the air flow, $I_w$, which facilitates combustion. In combustion processes with energy dense fuels the air flow will be almost twice as high, in terms of air mass per fuel mass, compared to waste combustion. This is due to the fact that only around half of the fuel mass is combustible. The total flue gas flow, $g_v$, is used to calculate the energy transfer in the flue gas.

Table 12 - Results of flue gas flow calculations

<table>
<thead>
<tr>
<th></th>
<th>$I_w$</th>
<th>$g_v$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airflow (theoretical)</td>
<td>3.955</td>
<td>4.802</td>
</tr>
<tr>
<td>Airflow factor</td>
<td>1.550</td>
<td>6.977</td>
</tr>
<tr>
<td>Airflow (real)</td>
<td>6.130</td>
<td>96.908</td>
</tr>
<tr>
<td>Air surplus</td>
<td>2.175</td>
<td>0.591</td>
</tr>
<tr>
<td>Air density</td>
<td>$p_i$</td>
<td>1.204</td>
</tr>
<tr>
<td>Air volume</td>
<td>$V_i$</td>
<td>13.889</td>
</tr>
<tr>
<td>Fuel flow</td>
<td>$q_w$</td>
<td>348 868</td>
</tr>
<tr>
<td>Flue gas flow (theoretical)</td>
<td>$g_{v_t}$</td>
<td>269 083</td>
</tr>
<tr>
<td>Flue gas flow (real)</td>
<td>$g_v$</td>
<td>50 896</td>
</tr>
<tr>
<td>Flue gas flow (total)</td>
<td>96.908</td>
<td>6 412</td>
</tr>
<tr>
<td>Hourly flue gas flow (total)</td>
<td>348 868</td>
<td></td>
</tr>
<tr>
<td>Hourly flue gas flow (total)</td>
<td>269 083</td>
<td></td>
</tr>
<tr>
<td>$CO_2$</td>
<td>50 896</td>
<td></td>
</tr>
<tr>
<td>Fossil $CO_2$</td>
<td>6 412</td>
<td></td>
</tr>
</tbody>
</table>

Comments
The $CO_2$ flow has been determined using its weight fraction in the flue gas multiplied by the hourly flue gas flow. This is later used in the environmental comparison calculations.

8.6.2 Flue gas composition
The flue gas composition is obtained from the results of the previously calculated combustion process, excess air flow and water vaporization. Using weight fractions and densities, $p$, along with their respective heat capacities, $C_p$, the average enthalpies of the flue gases can be calculated for different temperatures.
Table 13 - Results of flue gas composition calculations. Shows average densities and heat capacities of the flue gas components.

<table>
<thead>
<tr>
<th>Flue Gases</th>
<th>O₂</th>
<th>CO₂</th>
<th>H₂O</th>
<th>SO₂</th>
<th>N₂</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight fraction</td>
<td>0.082</td>
<td>0.148</td>
<td>0.052</td>
<td>0.000</td>
<td>0.712</td>
<td></td>
</tr>
<tr>
<td>ρ [kg/m³]</td>
<td>1.429</td>
<td>1.977</td>
<td>0.597</td>
<td>3.049</td>
<td>1.251</td>
<td>1.333</td>
</tr>
<tr>
<td>Cₚ [kJ/(kg*K)]</td>
<td>0.919</td>
<td>0.844</td>
<td>1.930</td>
<td>0.640</td>
<td>1.040</td>
<td>1.042</td>
</tr>
<tr>
<td>h [70] [kJ/kg]</td>
<td>64.531</td>
<td>61.091</td>
<td>130.667</td>
<td>44.570</td>
<td>72.500</td>
<td>72.828</td>
</tr>
<tr>
<td>h [90] [kJ/kg]</td>
<td>82.969</td>
<td>78.545</td>
<td>168.000</td>
<td>57.305</td>
<td>93.214</td>
<td>93.635</td>
</tr>
<tr>
<td>h [100] [kJ/kg]</td>
<td>92.188</td>
<td>87.273</td>
<td>186.667</td>
<td>63.672</td>
<td>103.571</td>
<td>104.039</td>
</tr>
<tr>
<td>h [130] [kJ/kg]</td>
<td>119.844</td>
<td>113.455</td>
<td>242.667</td>
<td>82.773</td>
<td>134.643</td>
<td>135.251</td>
</tr>
<tr>
<td>h [155] [kJ/kg]</td>
<td>144.266</td>
<td>140.273</td>
<td>291.778</td>
<td>101.699</td>
<td>161.518</td>
<td>162.943</td>
</tr>
<tr>
<td>h [850] [kJ/kg]</td>
<td>868.750</td>
<td>938.295</td>
<td>1773.056</td>
<td>656.250</td>
<td>935.179</td>
<td>969.267</td>
</tr>
<tr>
<td>h [1000] [kJ/kg]</td>
<td>1035.938</td>
<td>1129.318</td>
<td>2130.000</td>
<td>785.469</td>
<td>1115.357</td>
<td>1158.317</td>
</tr>
<tr>
<td>h [1400] [kJ/kg]</td>
<td>1491.250</td>
<td>1657.273</td>
<td>3165.000</td>
<td>1135.938</td>
<td>1610.000</td>
<td>1680.410</td>
</tr>
</tbody>
</table>

8.6.3 Energy output
Since waste is a relatively unpredictable source of combustion fuel, the temperatures of the flue gases are likely to vary. To get an idea of the variations of energy densities in the flue gases three different cases have been set up, ranging from the unlikely case of reaching the highest combustion temperature to the lowest temperature allowed. Most of the flue gas energy is extracted in the boiler, and the rest of it are either used for pre-heating or lost in filtration and exhaust air. The efficiency of the boiler is determined from what fraction of the total flue gas energy is converted to the steam cycle.

Table 14 - Results of flue gas energy output calculations. Range between 850-1400°C.
* : The case given by the thermal output of the heat generation.

<table>
<thead>
<tr>
<th>Flue Gases</th>
<th>h [850°C] - Case</th>
<th>h [1000°C] - Case</th>
<th>h: From to Heat gen*</th>
<th>h [1400°C] – Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>h Flue gas</td>
<td>1014.15 kJ/kg</td>
<td>1212.62 kJ/kg</td>
<td>1330.91 kJ/kg</td>
<td>1763.48 kJ/kg</td>
</tr>
<tr>
<td>P Flue gas</td>
<td>98.28 MW</td>
<td>117.51 MW</td>
<td>128.98 MW</td>
<td>170.90 MW</td>
</tr>
<tr>
<td>Boiler [ΔT</td>
<td>ηboiler] [850-155°C]</td>
<td>η₉b = 89.6</td>
<td>η₉b = 91.3</td>
<td>[T Spec - 155]</td>
</tr>
<tr>
<td>h Boiler</td>
<td>844.10 kJ/kg</td>
<td>1042.57 kJ/kg</td>
<td>1160.86 kJ/kg</td>
<td>1593.43 kJ/kg</td>
</tr>
<tr>
<td>P Boiler</td>
<td>81.80 MW</td>
<td>101.03 MW</td>
<td>112.50 MW</td>
<td>154.42 MW</td>
</tr>
<tr>
<td>Filter losses [155-130°C] [155-130°C]</td>
<td>[155-130°C]</td>
<td>[155-130°C]</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>27.69 kJ/kg</td>
<td>27.69 kJ/kg</td>
<td>27.69 kJ/kg</td>
<td>28.89 kJ/kg</td>
</tr>
<tr>
<td></td>
<td>2.65 MW</td>
<td>2.65 MW</td>
<td>2.65 MW</td>
<td>2.80 MW</td>
</tr>
<tr>
<td>Air pre-heat [130-70°C] [130-70°C]</td>
<td>[130-70°C]</td>
<td>[130-70°C]</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>65.15 kJ/kg</td>
<td>65.15 kJ/kg</td>
<td>65.15 kJ/kg</td>
<td>65.15 kJ/kg</td>
</tr>
<tr>
<td>Regained preheat</td>
<td>6.31 MW</td>
<td>6.31 MW</td>
<td>6.31 MW</td>
<td>6.31 MW</td>
</tr>
<tr>
<td>Exhaust</td>
<td>7.37 MW</td>
<td>7.37 MW</td>
<td>7.37 MW</td>
<td>7.37 MW</td>
</tr>
<tr>
<td>Total P boiler</td>
<td>88.11 MW</td>
<td>107.35 MW</td>
<td>118.81 MW</td>
<td>160.73 MW</td>
</tr>
</tbody>
</table>
Comments
These are just examples of what values the MATLAB model uses to calculate the boiler efficiency and power output. The filtration, pre-heating and exhaust temperatures will always be the same, but the initial temperature will differ according to the calorific value of the waste.

8.7 Steam cycle model in MATLAB
The output from the MATLAB code is the theoretically most profitable steam cycle parameter configuration and the monthly energy production with that configuration. The monthly configuration is displayed in Appendix V.

8.7.1 Most profitable steam cycle parameter combination
The most profitable parameters optimized in MATLAB for the winter months are displayed in Table 15. The steam cycle is a theoretical and ideal system adapted to limitations of the system.

Figure 17 - Steam cycle configuration
Table 15 - Node configuration, Winter

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>400.00</td>
<td>40.00</td>
<td>3214.37</td>
<td>1.00</td>
<td>6.77</td>
</tr>
<tr>
<td>2</td>
<td>203.14</td>
<td>6.18</td>
<td>2856.59</td>
<td>1.00</td>
<td>6.97</td>
</tr>
<tr>
<td>3</td>
<td>400.00</td>
<td>6.18</td>
<td>3270.43</td>
<td>1.00</td>
<td>7.70</td>
</tr>
<tr>
<td>4</td>
<td>277.37</td>
<td>2.57</td>
<td>3024.76</td>
<td>0.05</td>
<td>7.70</td>
</tr>
<tr>
<td>5</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.48</td>
<td>7.70</td>
</tr>
<tr>
<td>6</td>
<td>100.00</td>
<td>0.50</td>
<td>2682.40</td>
<td>0.47</td>
<td>7.70</td>
</tr>
<tr>
<td>7</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.01</td>
<td>7.70</td>
</tr>
<tr>
<td>8</td>
<td>85.00</td>
<td>1.02</td>
<td>356.00</td>
<td>0.01</td>
<td>0.99</td>
</tr>
<tr>
<td>9</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.47</td>
<td>7.70</td>
</tr>
<tr>
<td>10</td>
<td>100.00</td>
<td>1.02</td>
<td>419.10</td>
<td>0.47</td>
<td>1.31</td>
</tr>
<tr>
<td>11</td>
<td>70.00</td>
<td>0.32</td>
<td>293.02</td>
<td>0.47</td>
<td>0.96</td>
</tr>
<tr>
<td>12</td>
<td>70.00</td>
<td>1.02</td>
<td>293.08</td>
<td>0.47</td>
<td>0.96</td>
</tr>
<tr>
<td>13</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
</tr>
<tr>
<td>14</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
</tr>
<tr>
<td>15</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
</tr>
<tr>
<td>16</td>
<td>85.00</td>
<td>1.02</td>
<td>356.00</td>
<td>0.95</td>
<td>0.99</td>
</tr>
<tr>
<td>17</td>
<td>85.00</td>
<td>7.80</td>
<td>356.53</td>
<td>0.95</td>
<td>0.99</td>
</tr>
<tr>
<td>18</td>
<td>92.98</td>
<td>7.80</td>
<td>390.04</td>
<td>0.95</td>
<td>1.45</td>
</tr>
<tr>
<td>19</td>
<td>92.98</td>
<td>7.80</td>
<td>390.04</td>
<td>0.95</td>
<td>1.45</td>
</tr>
<tr>
<td>20</td>
<td>123.08</td>
<td>7.80</td>
<td>517.23</td>
<td>0.95</td>
<td>1.81</td>
</tr>
<tr>
<td>21</td>
<td>123.17</td>
<td>2.57</td>
<td>517.23</td>
<td>0.05</td>
<td>1.62</td>
</tr>
<tr>
<td>22</td>
<td>123.17</td>
<td>7.80</td>
<td>517.64</td>
<td>0.05</td>
<td>1.62</td>
</tr>
<tr>
<td>23</td>
<td>123.09</td>
<td>7.80</td>
<td>517.25</td>
<td>1.00</td>
<td>1.80</td>
</tr>
<tr>
<td>24</td>
<td>123.09</td>
<td>40.00</td>
<td>519.54</td>
<td>1.00</td>
<td>1.80</td>
</tr>
<tr>
<td>25</td>
<td>250.00</td>
<td>40.00</td>
<td>1085.69</td>
<td>1.00</td>
<td>2.79</td>
</tr>
<tr>
<td>26</td>
<td>70.00</td>
<td>2.50</td>
<td>293.20</td>
<td>NaN</td>
<td>0.95</td>
</tr>
<tr>
<td>27</td>
<td>70.00</td>
<td>11.33</td>
<td>293.92</td>
<td>NaN</td>
<td>0.95</td>
</tr>
<tr>
<td>28</td>
<td>100.00</td>
<td>11.33</td>
<td>419.87</td>
<td>NaN</td>
<td>1.31</td>
</tr>
<tr>
<td>29</td>
<td>130.00</td>
<td>11.33</td>
<td>546.97</td>
<td>NaN</td>
<td>1.63</td>
</tr>
</tbody>
</table>

Comments
The by the model chosen values for the nodes is the combination that gives the most profit. Due to the higher sales price for electricity the resulting final combination is the combination that produces the most electricity. As mentioned before the model optimizes production without regard for investment costs which leads to a system that may not be the most feasible for a real implementation.
A. The lowest fraction of the total mass flow, resulting in a thermal production corresponding to the demand of heat in the district heating grid is chosen by the model. For a winter month the need of cooling is zero.

B. The lowest tested pressure corresponds to the maximum energy outtake from the LP-turbine, and is therefore resulting in the best profit.

C. The mass flow chosen by the model is a mass flow that corresponds to the demanded heat in the district heating grid and the mass flow that leaves the best fraction to pre heating steps.

D. The pressure for the second pre heating step corresponds to the best combination with the mass flow, left for the pre heating steps and the highest possible temperature of the pre heated water. The pre heated water is not allowed to vaporize and therefore a limiting factor for the power in the pre heating steam.

8.7.2 Production, heat and electricity

The monthly production is shown in Figure 18 and the resulting yearly production is shown in Table 16. The monthly production fraction of the total energy input to the steam cycle is shown in Table 17.

![Monthly production chart]

**Figure 18 – Monthly thermal and electrical power output**

**Table 16 – Yearly energy output and profit**

<table>
<thead>
<tr>
<th>Type</th>
<th>Amount</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sold DH per year</td>
<td>564.09</td>
<td>GWh</td>
</tr>
<tr>
<td>Sold Electricity per year</td>
<td>258.19</td>
<td>GWh</td>
</tr>
<tr>
<td>Total profit</td>
<td>48.35</td>
<td>M€</td>
</tr>
<tr>
<td>Profit Heat</td>
<td>24.32</td>
<td>M€</td>
</tr>
<tr>
<td>Profit Electricity</td>
<td>24.03</td>
<td>M€</td>
</tr>
</tbody>
</table>
Table 17 – Production fractions of total energy input to the steam cycle

<table>
<thead>
<tr>
<th>Production fractions</th>
<th>Heat [%]</th>
<th>Electricity [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>72.16%</td>
<td>27.81%</td>
</tr>
<tr>
<td>February</td>
<td>72.16%</td>
<td>27.81%</td>
</tr>
<tr>
<td>March</td>
<td>72.16%</td>
<td>27.81%</td>
</tr>
<tr>
<td>April</td>
<td>72.16%</td>
<td>27.81%</td>
</tr>
<tr>
<td>May</td>
<td>65.72%</td>
<td>29.21%</td>
</tr>
<tr>
<td>June</td>
<td>41.23%</td>
<td>31.60%</td>
</tr>
<tr>
<td>July</td>
<td></td>
<td></td>
</tr>
<tr>
<td>August</td>
<td>32.28%</td>
<td>32.48%</td>
</tr>
<tr>
<td>September</td>
<td>49.38%</td>
<td>30.80%</td>
</tr>
<tr>
<td>October</td>
<td>72.16%</td>
<td>27.81%</td>
</tr>
<tr>
<td>November</td>
<td>72.16%</td>
<td>27.81%</td>
</tr>
<tr>
<td>December</td>
<td>72.16%</td>
<td>27.81%</td>
</tr>
</tbody>
</table>

Comments
The variation in the monthly production comes from the variation in temperature of the waste and air in the incineration process. The big dip in heat production in the June to September originates from a decline in heat demand. The rise of electricity production in the same time originates from more efficient production due to the cooling tower. The production during this time is also optimized for high electricity production, compared to rest of the year where the steam cycle is optimized for high profit regardless of production fraction. In July the production stops for revision.
8.7.3  Duration chart

The yearly production of heat in comparison to the district heat demand is shown in a duration chart, Chart 3.

![Duration Chart](chart3.png)

**Chart 3 - Duration chart district heating**

**Comments**

In comparison to the district heat demand the contribution from the WTE-plant is low over the total year. But the WTE-plant can theoretically provide the whole demand of heat for four months. During these months the plant has a need of cooling if operation at full capacity is wanted. The blue area represents the demand in district heating system with average losses. The yellow area represents the maximum capacity for the plant and therefore also the amount that needs to be cooled. In August, hour 7272 to 8000, the need of cooling can be reduced significant by only use one production line. The cooling demand can be reduced from around 40 MW to 5 MW in August.

8.8  Investment calculations

8.8.1  Investment cost

The investment cost for the project has been discussed with several Swedish energy project consultants. The estimated investment cost is around 144 M€, the partial costs are displayed in Table 18.
Table 18 - Investment cost

<table>
<thead>
<tr>
<th>Type</th>
<th>Investment Cost [M€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Funnel, Furnace, DeNox, Steam Boiler*</td>
<td>85.00</td>
</tr>
<tr>
<td>Bunker, &quot;House&quot; *</td>
<td>20.00</td>
</tr>
<tr>
<td>Steam Turbine, Generator, DH Condensers **</td>
<td>10.00</td>
</tr>
<tr>
<td>Flue gas cleaning system ***</td>
<td>13.11</td>
</tr>
<tr>
<td>Cooling Tower****</td>
<td>3.00</td>
</tr>
<tr>
<td>Unforeseen costs of 10% of total investment</td>
<td>13.11</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>144.22</td>
</tr>
</tbody>
</table>

* Anderz Wahlström . VonRoll
** Michael Mazur Siemens AB
*** Rolf Hunt ,Alstom
**** Simon Jansson ,Ragn-Sells Miljökonsult AB

Comments
The total investment cost is based on four different sources which can lead to a greater uncertainty then if only one source was used. But a project of this size involves several entrepreneurs that will lead to an uncertainty in the first investment cost estimation.

8.8.2 Yearly cash flow
The yearly income from sales of heat and electricity is one result from the Matlab calculation program. The resulting yearly cash flow is shown in Table 19 below. The individual components can be found in Appendix VI. Two scenarios are tested for the cash flow and payback time. The scenarios are with or without taxes. The payback time for this project is 4.57 years without taxes and 5.39 with taxes.

Table 19 - Cash Flow and Payback Time, no taxes

<table>
<thead>
<tr>
<th>Type . Without taxes</th>
<th>M€</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment</td>
<td>144.22</td>
</tr>
<tr>
<td>Incomes</td>
<td>48.35</td>
</tr>
<tr>
<td>Salaries</td>
<td>-0.42</td>
</tr>
<tr>
<td>Chemicals</td>
<td>-0.97</td>
</tr>
<tr>
<td>Landfill</td>
<td>-7.02</td>
</tr>
<tr>
<td>Maintenance</td>
<td>-7.21</td>
</tr>
<tr>
<td>Support fuel</td>
<td>-1.17</td>
</tr>
<tr>
<td>Cash flow per year</td>
<td>31.56</td>
</tr>
</tbody>
</table>

Comments
The calculated cash flow is used as ground for the NPV calculation.
8.8.3 Payback time

The different scenarios impact on the payback time is displayed in Table 21 and Table 20 below.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Payback time [Years]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original without tax</td>
<td>4.57</td>
</tr>
<tr>
<td>10% higher costs without tax</td>
<td>4.63</td>
</tr>
<tr>
<td>10% higher investment without tax</td>
<td>5.14</td>
</tr>
<tr>
<td>10% less profit without tax</td>
<td>5.40</td>
</tr>
</tbody>
</table>

Table 22 - Payback time scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Payback time [Years]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original with tax</td>
<td>5.39</td>
</tr>
<tr>
<td>10% higher costs with tax</td>
<td>5.84</td>
</tr>
<tr>
<td>10% higher investment with tax</td>
<td>6.09</td>
</tr>
<tr>
<td>10% less profit with tax</td>
<td>6.58</td>
</tr>
</tbody>
</table>

8.8.4 Net present value, NPV

In the NPV-calculation the interest and discount rate are included which leads to a longer time before the investment has paid off then the simpler method, payback time. The different variations of investment calculations are displayed in Chart 4, Chart 5, Chart 6 and Chart 7. The resulting accumulated profit is displayed in Table 23, Table 24 and Table 25. The time the investment requires to be profitable varies between 7 and 10.5 years depending on the rate scenario without taxes included. With taxes included the time is 8 to 15 years. The accumulated profit result varies between 59 M€ and 150 M€ depending on scenario without included taxes and 100 M€ and 19 M€ with taxes. The internal rate of return (IRR) for the three different interest scenarios without included taxes are displayed as the discount rate that gives zero accumulated profit after 20 years. The IRR varies between 19.6% and 17.6% without including taxes and 13.8% and 15.9% with taxes included.

![NPV - Interest rate 4% without taxes](chart4.jpg)

Chart 4 - NPV Interest rate 4%

53
Table 23 - Accumulated profit in project lifespan, 4% interest rate

<table>
<thead>
<tr>
<th>Accumulated profit</th>
<th>Without taxes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest rate</td>
<td>Discount rate</td>
</tr>
<tr>
<td>4 %</td>
<td>8 %</td>
</tr>
<tr>
<td>4 %</td>
<td>10 %</td>
</tr>
<tr>
<td>4 %</td>
<td>12 %</td>
</tr>
<tr>
<td>4 %</td>
<td>19.63 %</td>
</tr>
</tbody>
</table>

Chart 5 - NPV Interest rate 6%

Table 24 - Accumulated profit in project lifespan, 6% interest rate

<table>
<thead>
<tr>
<th>Accumulated profit</th>
<th>Without taxes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest rate</td>
<td>Discount rate</td>
</tr>
<tr>
<td>6 %</td>
<td>8 %</td>
</tr>
<tr>
<td>6 %</td>
<td>10 %</td>
</tr>
<tr>
<td>6 %</td>
<td>12 %</td>
</tr>
<tr>
<td>6 %</td>
<td>18.64 %</td>
</tr>
</tbody>
</table>
Chart 6 - NPV Interest rate 8%

Table 25 - Accumulated profit in project lifespan, 8% interest rate

<table>
<thead>
<tr>
<th>Accumulated profit</th>
<th>Without taxes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest rate</td>
<td>Discount rate</td>
</tr>
<tr>
<td>8 %</td>
<td>8 %</td>
</tr>
<tr>
<td>8 %</td>
<td>10 %</td>
</tr>
<tr>
<td>8 %</td>
<td>12 %</td>
</tr>
<tr>
<td>8 %</td>
<td>17.60 %</td>
</tr>
</tbody>
</table>

Chart 7 - NPV, without taxes and interest and scenarios
Chart 8 - Investment calculations with taxes

Comments

All the different discount and interest rate scenarios without taxes lead to a result that is feasible and gives the investor an opportunity for a higher discount rate. With the pre-determined discount and interest scenarios the profit can be lowered by reduced sale price of heat and electricity.

8.8.4.1 Internal rate of return

The different scenarios impact on the internal rate of return is displayed in Table 26 below. The highest IRR is 19.3 % and the lowest 9.54 %.

Table 26 - Internal rate of return, all scenarios

<table>
<thead>
<tr>
<th>10 % higher costs</th>
<th>Without Tax</th>
<th>10 % higher costs</th>
<th>With tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest rate [%]</td>
<td>IRR [%]</td>
<td>Interest rate [%]</td>
<td>IRR [%]</td>
</tr>
<tr>
<td>4</td>
<td>19.32</td>
<td>4</td>
<td>14.36</td>
</tr>
<tr>
<td>6</td>
<td>18.33</td>
<td>6</td>
<td>13.28</td>
</tr>
<tr>
<td>8</td>
<td>17.29</td>
<td>8</td>
<td>12.06</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>10 % higher investment</th>
<th>Without Tax</th>
<th>10 % higher investment</th>
<th>With tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest rate [%]</td>
<td>IRR [%]</td>
<td>Interest rate [%]</td>
<td>IRR [%]</td>
</tr>
<tr>
<td>4</td>
<td>16.96</td>
<td>4</td>
<td>13.55</td>
</tr>
<tr>
<td>6</td>
<td>15.94</td>
<td>6</td>
<td>12.43</td>
</tr>
<tr>
<td>8</td>
<td>14.83</td>
<td>8</td>
<td>11.15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>10 % less profit</th>
<th>Without Tax</th>
<th>10 % less profit</th>
<th>With tax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest rate [%]</td>
<td>IRR [%]</td>
<td>Interest rate [%]</td>
<td>IRR [%]</td>
</tr>
<tr>
<td>4</td>
<td>15.96</td>
<td>4</td>
<td>12.09</td>
</tr>
<tr>
<td>6</td>
<td>14.90</td>
<td>6</td>
<td>10.91</td>
</tr>
<tr>
<td>8</td>
<td>13.76</td>
<td>8</td>
<td>9.54</td>
</tr>
</tbody>
</table>
8.9 Environmental Comparison

The results of an environmental comparison with a 25 year timeframe show that the proposed WTE solution will significantly reduce GHG emissions compared to the current landfill and CHP solution, even though the total emissions of CO$_2$-equivalents from the proposed plant are initially larger. Since the waste deposition is larger than the decomposition, the growth of CH$_4$-emissions from landfills is exponential in this timeframe. See Appendix III for calculations.

The proposed plant is environmentally beneficial after 7 years, and after 20 years the GHG emissions of the plant are 54% compared to landfiling and gas turbine power generation. If only the fossil portion of emissions is accounted for, the global warming potential is only 7%.

![Emitted CO$_2$ - Equivalents](chart9.png)

*Chart 9 - Results of environmental impact comparison, (Calculations for the compared cases are found in Appendix III)*

**Comment**

An aspect to bear in mind is the fraction of CO$_2$-emissions that can be considered as renewable. In Sweden, only 12.6% of WTE carbon emissions are considered to come from fossil sources and the CO$_2$-emissions from incineration of organic waste can be considered as better than CH$_4$-emissions from landfills. With this in mind the environmental impact of the WTE plant is around 20% compared to the current situation. (32)

Another important aspect is the treatment of combusted materials in terms of emissions of toxic compounds. This study includes costs of supervised deposition of combusted materials, with the purpose of minimizing emissions of toxic compounds. So even though this study does not compare any numbers, the amounts of toxic compounds emitted from combustion of the waste can be compensated for by the prevention of waterborne emissions.
9 Conclusions
This study, with all of its conditions, shows that the best solution for Chisinau is a 140 MW WTE plant with specifications according to Table 27.

Table 27 - Finalized system design

<table>
<thead>
<tr>
<th>Finalized system design</th>
<th>Description</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Site of CHP East, Botanica, Chisinau</td>
<td>Connected to DH grid, waste logistics, large site</td>
</tr>
<tr>
<td>Bunker</td>
<td>14,400 m³</td>
<td>50 tonnes/h, 3 days of storage</td>
</tr>
<tr>
<td>Incineration</td>
<td>2 lines moving grate furnaces</td>
<td>Von Roll system Operation safety &amp; Thermal irregularities</td>
</tr>
<tr>
<td>Steam boiler</td>
<td>400 °C, 40 bar, 2 lines, 70 MW each</td>
<td>Investment &amp; maintenance costs, operation safety</td>
</tr>
<tr>
<td>Turbine &amp; generator</td>
<td>2 * 20 MW</td>
<td>Siemens suggestion: SST-300</td>
</tr>
<tr>
<td>Electrical output</td>
<td>258.19 GWh</td>
<td>Sale price: 99 €/MWh</td>
</tr>
<tr>
<td>Thermal output</td>
<td>564.09 GWh</td>
<td>Sale price: 43 €/MWh</td>
</tr>
<tr>
<td>Annual cash flow excl taxes</td>
<td>31.6 M€</td>
<td>Includes earnings, salaries, chemicals, ash deposition, maintenance &amp; support fuel</td>
</tr>
<tr>
<td>Flue gas treatment</td>
<td>Semi Dry, SNCR-DeNOx system</td>
<td>Alstom Semi Dry suggestion: NID™ system</td>
</tr>
<tr>
<td>Chimney height</td>
<td>77 m</td>
<td>Swedish standard for similar terrain</td>
</tr>
<tr>
<td>Emissions</td>
<td>407 000 tonnes of CO₂/year ~12.9 % Fossil CO₂</td>
<td>Designed to meet EU emission regulations</td>
</tr>
<tr>
<td>Cooling</td>
<td>GEA air cool condenser 44 MW cooling capacity</td>
<td>Designed to handle thermal spikes during summer</td>
</tr>
</tbody>
</table>
10 Potential for this WTE solution in Chisinau

The results of this study show that the implementation of a WTE plant in the Chisinau energy system is both economically and environmentally feasible, given the current conditions. The general opinion is very positive among the Chisinau government officials and experts, but the difficulty in funding the investment has also been pointed out.

Initiating a waste to energy project in Chisinau has been discussed for a number of years now, but still no project has managed to become reality. Several other energy projects have been in the final stages of discussion during the time of this study, but the waste situation seems to have a lower priority.

Politically, the public opinion on waste incineration is still negative due to lack of knowledge and previous projects that did not become reality. What needs to be pointed out is that the situation is different since the arrival of a Swedish embassy and the initiated cooperation between Chisinau and Borlänge. Swedish knowledge and experience in the waste to energy field should be used to influence the public opinion on waste incineration, so that the project will be politically feasible as well. It is also important to point out that the initiation of this project would be a positive step in the aspiration for membership in the EU, where a regulated waste treatment system is required.

Economically, although it is a good investment, it may be difficult to make this project an economical contender to the construction of a new modern gas powered CHP. To do this it will be important to focus on the fact that waste to energy is a sustainable energy source, that uses the waste problem as fuel to help solve the energy dependence problem. This may put this project ahead of a CHP project in terms of gaining international funding support, which is essential.

Environmentally, the implementation of this project would make a significant improvement to green house gas emissions compared to the current situation. The fossil CO₂ released from waste incineration is very low compared to the combination of landfill methane and CHP CO₂ emissions. Toxin emissions are often seen as the negative part of waste incineration. This project, with the implementation of a safe deposition system for incombustible compounds, will reduce waterborne toxin emissions compared to a landfill.

In summary, the feasibility of this project is clear with only a few obstacles that need to be considered.

- Gaining international funding for the project
- Focus on reliability and experience in the choice of consultants, suppliers and contractors
- Education of permanent staff for the plant, operation and waste accumulation
- Connection, expansion and renovation of the district heating grid
- Population spending power with the increasing heat prices
11 Discussion

11.1 Potential sources of uncertainty
The data used to do this study is taken from more than 10 different sources with varying scientific level. Some values are mathematical and proven, some are qualified estimations and some have been obtained through empirical studies. In the study we have viewed all our sources critically and verified that all the unit conversions have been done correctly. However, it is still difficult to claim that the results are entirely reliable with this wide spread of sources. Here is a list of thoughts that have emerged during the study.

11.1.1 Waste composition, heat generation and flue gas
First of all, the waste data needs to be addressed. The data used in the study is not going to accurately apply for the Chisinau area, but all experts interviewed about the matter have assured us the current waste composition is a “good enough” estimation. Another source of uncertainty is the residues fraction of the waste, Chart 2, which has not been explained. As previously mentioned this has been compensated for by spreading it over the other components. This is likely to result in a waste composition with higher combustible and moisture content than the real case, but we have found no better way. The result of this is a higher calorific value, and therefore a larger heat generation. The heat generation process also involves more chemical reactions than the ones included. They others, however, are rarely mentioned in practical studies and have therefore been disregarded.

Another source of uncertainty that has great impact is the actual combustion/flue gas temperature. The theoretical temperature can easily be calculated, but a more realistic temperature is very difficult to estimate without expertise. Therefore several cases have been presented in the study to somehow capture the span of possible energy levels.

For the flue gas composition, like the heat generation, only the amounts of the important energy carrying components have been calculated.

11.1.2 Steam cycle model
First off, the model has several defined values that could have been made dynamic with a larger project timeframe. Such values are the number of turbines and the superheated steam data, set at 400°C and 40 bar, which sets limits to the potential electrical output.

Secondly, the steam cycle is considered as a simplified thermodynamically ideal system with no thermal losses in pipes, tanks and condensers. If desired, this could be compensated by adding an extra steam cycle loss. Also, apart from assuring steam and water flows are always saturated, no time has been spent on flow turbulence and the corrosion it may cause.

Thirdly, instead of estimating continuous mathematical functions which could be optimized with high accuracy, the model runs a chosen set of discrete values against each other. This means that the model is unlikely to deliver the exact optimal value, but recalculating with new value intervals will get you close enough.
11.1.3 District heating
Concerning district heating data, the high temperatures are the most important thing to address. These temperature conditions limit the electrical output due the limits allowed in the turbines, and the fact that flue gas condensation is not feasible.

The district heat demand has been calculated from the sales average of the last three years, and in the study all heat delivery calculations is based on that same demand.

11.1.4 Economy
When consulting four different experts on WTE design components, the price estimations will vary from source to source which greatly impacts pay back rates. Investment costs of real projects of this size are in the order of 100 - 200M€.

The waste is seen as a free source of fuel, where gathering does not involve any additional costs since it is already put on landfills.

For the investment analysis, no estimations have been made regarding the development of inflation, energy prices, consumption goods prices, salaries and international economical relations.

11.1.5 Environmental Comparison
In the environmental comparison the WTE emissions have been done theoretically, the gas turbine emissions are estimated using data from the US Government, while landfill emissions are estimated using a model done by IPCC. That is not ideal, but it gives a good idea of the way the two cases compare.

11.2 Further studies
In order to get an accurate result you need accurate input values. For this model to deliver the most truthful result possible some further studies need to be done. The most significant areas have been narrowed down to the following:

  - Future development of economical parameters specific for Moldova
    - Inflation
    - Energy prices
    - Consumption goods prices
    - Salaries
    - Consumer affordability
    - International economical relations
  - Future development of district heating in Chisinau
    - Demand
    - Losses
    - Renovation
    - Expansion
  - Waste
    - Detailed waste composition
    - Future waste accumulation
    - Potential for sorting and recycling
12 References
http://www.regeringen.se/sb/d/5472/a/43789.

2. AllMoldova.com. AllMoldova.com. [Online] [Citat: den 18 01 2010.] 

3. Climate Charts. Climate Charts. [Online] [Citat: den 15 06 2011.] HTTP://WWW.CLIMATE-
CHARTS.COM/LOCATIONS/M/MD33815.PHP.


HTTP://WWW.STATISTICA.MD/.


den 18 01 2012.] 


14. Sverige, Avfall. Avfall blir värme och el -En rapport om avfallsförbränning. u.o. : Avfall Sverige, 
2005. ISSN 1103-4092.


16. Renhållningsföreningar, RVF - Svenska. Avfall blir värme och el. ISSN 1103-4092.


PNG.


27. PARSIAN, Mrs. Galina Albertovna. Ministry of Economy of the Republic of Moldova Head of the Thermal Power Department. 05 2011.


Appendix I – Waste composition simulation software
The program used for simulating elemental composition has been obtained from Avfall Sverige. The results of the simulation done using the Donetsk data are shown in Figure 19, Figure 20, Figure 21 & Figure 22. Since the real waste composition is likely to have higher moisture content, the data from this simulation is only used for calculations of the highest theoretical heat generation.

![Bränsle till förbränning](image)

**Figure 19 - Elemental Composition**
### Resultat Modell 1

#### Beteckning:

<table>
<thead>
<tr>
<th>Produktion</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Panneffekt</td>
<td>143,0 MW</td>
</tr>
<tr>
<td>Energi produktion</td>
<td>2,9 MWh/ton</td>
</tr>
<tr>
<td>Energi produktion</td>
<td>1143,8 GWh per år</td>
</tr>
</tbody>
</table>

#### Gasdata

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>O2-halt</td>
<td>6,0 vol-% våt gas</td>
</tr>
<tr>
<td>O2-halt</td>
<td>7,2 vol-% torr gas</td>
</tr>
<tr>
<td>CO2-halt</td>
<td>11,4 vol-% torr gas</td>
</tr>
<tr>
<td>Fukhalt</td>
<td>16,9 vol-%</td>
</tr>
<tr>
<td>Rökgasflöde</td>
<td>278339 m³/h</td>
</tr>
<tr>
<td>Rökgasflöde</td>
<td>231364 m³/h torr gas</td>
</tr>
<tr>
<td>Rökgasflöde</td>
<td>318861 m³/h torr gas vid 11% O₂</td>
</tr>
<tr>
<td>SO2-halt e. Panna</td>
<td>257 mg/m³ torr gas vid 11% O₂</td>
</tr>
<tr>
<td>HCl-halt e. Panna</td>
<td>322 mg/m³ torr gas vid 11% O₂</td>
</tr>
<tr>
<td>HF-halt e. Panna</td>
<td>19 mg/m³ torr gas vid 11% O₂</td>
</tr>
<tr>
<td>HBr-halt e. Panna</td>
<td>0 mg/m³ torr gas vid 11% O₂</td>
</tr>
</tbody>
</table>

#### Askbalans

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Slagg och pannaska</td>
<td>7083 kg/h TS inklusive oförbränt</td>
</tr>
<tr>
<td>Spärfilterstoft</td>
<td>796 kg/h TS inklusive oförbränt</td>
</tr>
<tr>
<td>Spärfilterstoft</td>
<td>1438 kg/h TS inklusive oförbränt och additiv</td>
</tr>
<tr>
<td>Stoftutslapp</td>
<td>1,59 kg/h TS</td>
</tr>
</tbody>
</table>

#### Stökiometri i spärrfiltret

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SR totalt [Ca/(S+0.5*(Cl+F+Br))]</td>
<td>1,9 mol/mol</td>
</tr>
</tbody>
</table>

---

Figure 20 - Simulated flue gas generation. The values in this model were only used to get idea of the theoretical emissions.
### Spårelement

<table>
<thead>
<tr>
<th>Spårelement</th>
<th>I slagg och pannaska</th>
<th>I spärfilteraska</th>
<th>I stoftutsläppet</th>
<th>Fördelning i %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>gt T$/kgår</td>
<td>gt T$/kgår</td>
<td>Slagg och</td>
<td>Spättfilter</td>
</tr>
<tr>
<td>Antimon (Sb)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>47,0</td>
</tr>
<tr>
<td>Arsenik (As)</td>
<td>3</td>
<td>196</td>
<td>19</td>
<td>69</td>
</tr>
<tr>
<td>Bly (Pb)</td>
<td>795</td>
<td>40006</td>
<td>1790</td>
<td>20245</td>
</tr>
<tr>
<td>Kadmium (Cd)</td>
<td>13</td>
<td>757</td>
<td>37</td>
<td>425</td>
</tr>
<tr>
<td>Kobolt (Co)</td>
<td>3</td>
<td>198</td>
<td>4</td>
<td>45</td>
</tr>
<tr>
<td>Koppar (Cu)</td>
<td>1020</td>
<td>57776</td>
<td>1126</td>
<td>12975</td>
</tr>
<tr>
<td>Krom (Cr)</td>
<td>1746</td>
<td>98916</td>
<td>2897</td>
<td>33330</td>
</tr>
<tr>
<td>Kyckelsilver (Hg)</td>
<td>0</td>
<td>4</td>
<td>10</td>
<td>111</td>
</tr>
<tr>
<td>Mangan (Mn)</td>
<td>42</td>
<td>2372</td>
<td>69</td>
<td>799</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>335</td>
<td>19002</td>
<td>371</td>
<td>4288</td>
</tr>
<tr>
<td>Tallium (Tl)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Vanadin (V)</td>
<td>4</td>
<td>228</td>
<td>4</td>
<td>51</td>
</tr>
<tr>
<td>Zink (Zn)</td>
<td>2198</td>
<td>124542</td>
<td>12159</td>
<td>139803</td>
</tr>
</tbody>
</table>

* inklusive gasformigt Hg

Figure 21 – Data on flue gas filtration.

### Utsläpp till luft

<table>
<thead>
<tr>
<th>Spårelement</th>
<th>Utsläpp (ug/m³n)</th>
<th>Utsläpp (tg %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimon (Sb)</td>
<td>0,0</td>
<td>0,0</td>
</tr>
<tr>
<td>Arsenik (As)</td>
<td>0,3</td>
<td>0,0</td>
</tr>
<tr>
<td>Bly (Pb)</td>
<td>39,8</td>
<td>0,0</td>
</tr>
<tr>
<td>Kadmium (Cd)</td>
<td>0,7</td>
<td>0,0</td>
</tr>
<tr>
<td>Kobolt (Co)</td>
<td>0,1</td>
<td>0,0</td>
</tr>
<tr>
<td>Koppar (Cu)</td>
<td>25,5</td>
<td>0,0</td>
</tr>
<tr>
<td>Krom (Cr)</td>
<td>43,6</td>
<td>0,0</td>
</tr>
<tr>
<td>Kyckelsilver (Hg)</td>
<td>10,0</td>
<td>0,0</td>
</tr>
<tr>
<td>Mangan (Mn)</td>
<td>1,0</td>
<td>0,0</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>8,4</td>
<td>0,0</td>
</tr>
<tr>
<td>Tallium (Tl)</td>
<td>0,0</td>
<td>0,0</td>
</tr>
<tr>
<td>Vanadin (V)</td>
<td>0,1</td>
<td>0,0</td>
</tr>
<tr>
<td>Zink (Zn)</td>
<td>219,8</td>
<td>0,0</td>
</tr>
<tr>
<td>Klor (HCl)</td>
<td>6,4</td>
<td>0,0</td>
</tr>
<tr>
<td>Fluor (HF)</td>
<td>1,0</td>
<td>0,0</td>
</tr>
<tr>
<td>Brom (HBr)</td>
<td>0,1</td>
<td>0,0</td>
</tr>
<tr>
<td>Svavel (SO2)</td>
<td>5,1</td>
<td>0,0</td>
</tr>
</tbody>
</table>

* inklusive gasformigt Hg

Figure 22 - Emissions into air
13 Appendix II - Heat generation & Flue gas composition

Determining the amount of energy converted from waste to steam is done in a number of steps. All the methods used, apart for some of the authors’ assumptions, can be found in Henrik Alvarez energy engineering literature, Energiteknik. (30)

1. Determine elemental composition of the fuel
2. Calculate necessary combustion air supply
3. Use fuel and air data to calculate heat generation
4. Determine flue gas composition
5. Summarize flue gas flow
6. Flue gas heat capacity
7. Heat exchange and losses

13.1 Determining the elemental composition of the fuel

This is given by the waste to energy simulation software, where a given waste composition yields an elemental composition. See Figure 19 (in Swedish). The most important elemental contents are the carbon, hydrogen, oxygen, nitrogen and sulfur. The rest are used to calculate the heat loss in from the ashes that are removed from the furnace.

13.2 Calculating the necessary combustion air supply

The necessary air supply for the combustion process can be summarized, with a slight simplification, as the oxygen needed for complete combustion and the nitrogen that comes along with it in the combustion air. From the elemental composition of the dry, ash-free fraction of the waste is singled out and the combustible elemental fractions are determined. These require different amounts of oxygen.

Table 28 - Elemental composition of the combustible fuel gives the theoretical air supply needed for combustion

<table>
<thead>
<tr>
<th>Main components</th>
<th>weight %</th>
<th>Elements</th>
<th>kg/m³/kg fuel</th>
<th>kg/kg of fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>36.904</td>
<td>Carbon</td>
<td>59.721</td>
<td>0.597</td>
</tr>
<tr>
<td>Ash (of dry)</td>
<td>24.229</td>
<td>Hydrogen</td>
<td>8.548</td>
<td>0.085</td>
</tr>
<tr>
<td>Dry ash free</td>
<td>47.808</td>
<td>Oxygen</td>
<td>29.063</td>
<td>0.291</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nitrogen</td>
<td>1.919</td>
<td>0.019</td>
</tr>
<tr>
<td>Elemental composition air</td>
<td></td>
<td>Sulfur</td>
<td>0.223</td>
<td>0.002</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>75.54</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>24.46</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elemental analysis</th>
<th>% of ashes</th>
<th>kmol/kg fuel</th>
<th>kg/kg of fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>27.695</td>
<td>0.0231</td>
<td>0.7385</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>3.964</td>
<td>0.0099</td>
<td>0.3171</td>
</tr>
<tr>
<td>Oxygen</td>
<td>13.478</td>
<td>-0.0042</td>
<td>-0.1348</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.890</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.104</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sum</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

| Theoretical air supply | 3.955 kg/kg of fuel |

67
After calculating the theoretical airflow, the real airflow and flue gas flow is calculated. The real airflow is determined by multiplying the theoretical one with the specific airflow factor, $n$, which is 1.5-1.6 for waste. This also gives the air surplus, $\lambda$, from which the excess oxygen can be derived.

### 13.3 Using fuel and air data to calculate heat generation

The elemental composition of the waste and the air flow are the two important factors when determining the heat generation. The flow of waste is 50 tonnes/hour = 13.88 kg/s. To counteract the heat generation from the combustion of the waste, the negative processes are:

- Heating inert ashes, moisture, nitrogen and excess oxygen
- Vaporization of the moisture
- Reaching the waste’s combustion temperature, which is considered to be 250 °C

The net heat generation is then calculated by multiplying the waste fractions with the total flow, as well as the thermal impact it has on the process.

Before doing that, however, the specific heat capacities of the excess air and the ashes need to be gathered.

Specific heat capacities of N and O are gathered from literature:

\[ C_p [N_2] = 1.04 \text{ kJ/(kg*K)} \]

\[ C_p [O_2] = 0.919 \text{ kJ/(kg*K)} \]

\[ C_p [Ash] = 0.814 \text{ kJ/(kg*K)} \] (Explained below)

For the inert ashes the elemental composition is used for the most important ash components, and their individual heat capacities are multiplied with their elemental fractions. See Table 29. It was not possible to find heat capacities for the ash compounds. Instead they were estimated using the specific heat capacity of every element, and the molar mass fraction of the molecules. (33)

**Table 29 - $C_p$-estimations. The specific heat capacities for elemental components give $C_p$ for each compound.**

<table>
<thead>
<tr>
<th></th>
<th>Weight % of ash</th>
<th>Of total waste</th>
<th>$C_p$ kJ/(kg*K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na$_2$O</td>
<td>8.276</td>
<td>0.082</td>
<td>0.0126</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>8.415</td>
<td>0.084</td>
<td>0.0128</td>
</tr>
<tr>
<td>CaO</td>
<td>39.311</td>
<td>0.393</td>
<td>0.0600</td>
</tr>
<tr>
<td>MgO</td>
<td>6.089</td>
<td>0.060</td>
<td>0.009</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>20.575</td>
<td>0.205</td>
<td>0.031</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>6.357</td>
<td>0.063</td>
<td>0.010</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>6.632</td>
<td>0.066</td>
<td>0.010</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>95.658</strong></td>
<td><strong>0.957</strong></td>
<td><strong>0.146</strong></td>
</tr>
</tbody>
</table>

When the necessary heat capacities have been gathered the heat generation can be calculated. The heat generated in the furnace is calculated through the thermal impact that every waste component has on the process. See Table 30. In this calculation process the thermal impact of every individual process, multiplied by its flow, is added up to get a summarized heat generation. The processes are
combustion, vaporization and heating of inert compounds. This summarized heat generation in can be compared to the power input from the waste flow to get the incineration grate efficiency, \( \eta_{\text{grate}} \).

**Table 30 - Heat Generation: Results of combustion calculations**

<table>
<thead>
<tr>
<th></th>
<th>Flow [kg/s]</th>
<th>Thermal contribution [kJ/kg]</th>
<th>Thermal Impact [kJ/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content</td>
<td>5.13</td>
<td>-2591.40</td>
<td>-13282.29</td>
</tr>
<tr>
<td>Residues (Inert)</td>
<td>2.12</td>
<td>-69.17</td>
<td>-146.87</td>
</tr>
<tr>
<td>Reaching comb temp</td>
<td>13.89</td>
<td>-616.63</td>
<td>-2583.46</td>
</tr>
<tr>
<td>Carbon</td>
<td>3.85</td>
<td>33913.00</td>
<td>130447.29</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0.55</td>
<td>142770.00</td>
<td>78603.32</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.12</td>
<td>-945.49</td>
<td>-116.85</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.01</td>
<td>10467.00</td>
<td>150.56</td>
</tr>
<tr>
<td>Excess oxygen</td>
<td>7.00</td>
<td>-836.29</td>
<td>-5850.48</td>
</tr>
<tr>
<td>Inert N(_2)</td>
<td>61.60</td>
<td>-945.49</td>
<td>-58245.30</td>
</tr>
<tr>
<td><strong>Average thermal Power output [MW]</strong></td>
<td></td>
<td></td>
<td>128.98</td>
</tr>
</tbody>
</table>

13.4 Determining the flue gas composition

Knowing the incoming flow of combustible elements and the theoretical air supply, the real flue gas flow can be calculated. This is done through a number of calculations:

1. Air surplus, \( l_0 \)
2. Theoretical flue gas flow, \( g_t \)
3. Real flue gas flow, \( g_v \)

13.4.1 Air surplus, \( l_0 \)

The part of the air supply, where not even the oxygen takes part in the combustion process.

\[
l_0 = l_v - l_t \quad (AI-t)
\]

13.4.2 Theoretical flue gas flow, \( g_t \)

The theoretical airflow allows the combustion of the combustible elements, which yields the theoretical flue gas flow.

<table>
<thead>
<tr>
<th>Flue gas from combustion</th>
<th>kmol/kg fuel</th>
<th>kmol/s</th>
<th>kg/s</th>
<th>ton/h</th>
<th>weight %</th>
<th>% with air surplus</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO(_2)</td>
<td>0.023079166</td>
<td>0.32054397</td>
<td>14.1039346</td>
<td>50.7741645</td>
<td>21%</td>
<td>15%</td>
</tr>
<tr>
<td>H(_2)O</td>
<td>0.040322236</td>
<td>0.56</td>
<td>10.0805591</td>
<td>36.2900126</td>
<td>15%</td>
<td>10%</td>
</tr>
<tr>
<td>O(_2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7%</td>
</tr>
<tr>
<td>N(_2)</td>
<td>0.108642413</td>
<td>1.5089224</td>
<td>42.2498273</td>
<td>0.10356854</td>
<td>64%</td>
<td>67%</td>
</tr>
<tr>
<td>SO(_2)</td>
<td>3.23652E-05</td>
<td>0.00044952</td>
<td>0.02876904</td>
<td>0.099378</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Total</td>
<td>0.17207618</td>
<td>2.38991589</td>
<td>66.46309</td>
<td>239.267124</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>
13.4.3 Real flue gas flow, $g_v$

The real flue gas flow is obtained by adding the air surplus and the flue gas flow.

$$g_v = g_t + l_o \quad (AI-ii)$$

13.5 Flue gas flow summary

After the flue gas calculations, the total flows of the combustion gases as well as the air surplus are obtained. Table 31 shows the amounts in relation to the incoming waste flow as well as the expected hourly flue gas flow, CO$_2$-flow and the fraction that originates from fossil sources. This fraction comes from a Swedish WTE emission standard, which estimates an average fossil carbon content of 12.6%. The CO$_2$-emission values are later used in the environmental comparison.

Table 31 - Results of the flue gas flow calculations

<table>
<thead>
<tr>
<th></th>
<th>$l_t$</th>
<th>$n$</th>
<th>$l_v$</th>
<th>$l_o$</th>
<th>$\rho_t$</th>
<th>$V_t$</th>
<th>$q_w$</th>
<th>$\beta_t$</th>
<th>$\beta_v$</th>
<th>$G_t$</th>
<th>$CO_2$</th>
<th>Fossil CO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airflow (theoretical)</td>
<td>3.955</td>
<td>1.550</td>
<td>6.130</td>
<td>2.175</td>
<td>1.204</td>
<td>5.091</td>
<td>13.889</td>
<td>4.802</td>
<td>6.977</td>
<td>96.908</td>
<td>348868.707</td>
<td>6412.968</td>
</tr>
<tr>
<td>Airflow factor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airflow (real)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air surplus</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air density</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air volume</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel flow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flue gas flow (theoretical)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flue gas flow (real)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flue gas flow (total)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hourly flue gas flow (total)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$CO_2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fossil CO$_2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
13.6 Flue gas heat capacity
Knowing the composition of the flue gases, the average specific heat capacity can be calculated using standard \(c_p\)-values for each specific gas component. The average values are calculated at certain temperatures that will be relevant to the heat exchange process.

<table>
<thead>
<tr>
<th>Component</th>
<th>(O_2)</th>
<th>(CO_2)</th>
<th>(H_2O)</th>
<th>(SO_2)</th>
<th>(N_2)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight fraction</td>
<td>0.072</td>
<td>0.146</td>
<td>0.104</td>
<td>0.000</td>
<td>0.673</td>
<td></td>
</tr>
<tr>
<td>Density [kg/m(^3)]</td>
<td>1.429</td>
<td>1.977</td>
<td>0.597</td>
<td>3.049</td>
<td>1.251</td>
<td>1.297</td>
</tr>
<tr>
<td>(c_p) [kJ/(kg*K)]</td>
<td>0.919</td>
<td>0.844</td>
<td>1.930</td>
<td>0.640</td>
<td>1.040</td>
<td>1.091</td>
</tr>
<tr>
<td>(h\ [70]) [kJ/kg]</td>
<td>64.531</td>
<td>61.091</td>
<td>130.667</td>
<td>44.570</td>
<td>72.500</td>
<td>76.009</td>
</tr>
<tr>
<td>(h\ [90]) [kJ/kg]</td>
<td>82.969</td>
<td>78.545</td>
<td>168.000</td>
<td>57.305</td>
<td>93.214</td>
<td>97.726</td>
</tr>
<tr>
<td>(h\ [100]) [kJ/kg]</td>
<td>92.188</td>
<td>87.273</td>
<td>186.667</td>
<td>63.672</td>
<td>103.571</td>
<td>108.584</td>
</tr>
<tr>
<td>(h\ [130]) [kJ/kg]</td>
<td>119.844</td>
<td>113.455</td>
<td>242.667</td>
<td>82.773</td>
<td>134.643</td>
<td>141.160</td>
</tr>
<tr>
<td>(h\ [155]) [kJ/kg]</td>
<td>144.266</td>
<td>140.273</td>
<td>291.778</td>
<td>101.699</td>
<td>161.518</td>
<td>170.051</td>
</tr>
<tr>
<td>(h\ [850]) [kJ/kg]</td>
<td>868.750</td>
<td>938.295</td>
<td>1773.056</td>
<td>656.250</td>
<td>935.179</td>
<td>1014.148</td>
</tr>
<tr>
<td>(h\ [1000]) [kJ/kg]</td>
<td>1035.938</td>
<td>1129.318</td>
<td>2130.000</td>
<td>785.469</td>
<td>1115.357</td>
<td>1212.622</td>
</tr>
<tr>
<td>(h\ [1400]) [kJ/kg]</td>
<td>1491.250</td>
<td>1657.273</td>
<td>3165.000</td>
<td>1135.938</td>
<td>1610.000</td>
<td>1763.484</td>
</tr>
</tbody>
</table>

13.7 Heat exchange and losses
The heat exchange process is where all the flue gas energy is put to use in different steps. When designing the heat exchange system between furnace and boiler the goal is to maximize the boiler efficiency, while still operating at sustainable temperatures. The two most important limitations are set by the furnace heat resistance, which sets the highest temperature, and flue gas treatment requirements, which sets the lowest temperature. Usually, the flue gas needs to be treated in the temperature range between 155 - 130°C. After this, a portion of the remaining flue gas energy content is used for pre-heating combustion air. At between 50 - 70°C the rest of the energy is released through the chimney.

To illustrate different possible furnace designs that would lead to different flue gas temperature distributions, a few scenarios of initial heat exchange temperatures have been set up. See Table 33. The range of possible temperatures is 850-1400°C, where the lower limit is set by emission regulations and the highest limit is the highest theoretical combustion temperature. Apart from the initial temperatures, the temperatures are pre-determined.

A majority of the heat converts to the steam cycle in the boiler. After this it enters the flue gas treatment, where the heat between 155-130°C is consider filter losses. Before the gases are released through the chimney, the heat between 130-70°C is used to preheat the combustion air. Since this portion improves the combustion it is not considered a loss.

By adding boiler and air pre-heating energies, on obtains the boiler efficiency, \(\eta_b\).
<table>
<thead>
<tr>
<th>Flue Gases</th>
<th>h [850] – Case</th>
<th>h [1000] - Case</th>
<th>h: From to Heat gen</th>
<th>h [1400] – Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>h Flue gas</td>
<td>1014,15 kJ/kg</td>
<td>1212,62 kJ/kg</td>
<td>1330,91 kJ/kg</td>
<td>1763,48 kJ/kg</td>
</tr>
<tr>
<td>P Flue gas</td>
<td>98,28 MW</td>
<td>117,51 MW</td>
<td>128,98 MW</td>
<td>170,90 MW</td>
</tr>
<tr>
<td>**Boiler [ΔT</td>
<td>ηboiler]**</td>
<td><strong>[850-155°C]</strong></td>
<td><strong>[1000-155°C]</strong></td>
<td><strong>[T Spec - 155]</strong></td>
</tr>
<tr>
<td>h Boiler</td>
<td>844,10 kJ/kg</td>
<td>1042,57 kJ/kg</td>
<td>1160,86 kJ/kg</td>
<td>1593,43 kJ/kg</td>
</tr>
<tr>
<td>P Boiler</td>
<td>81,80 MW</td>
<td>101,03 MW</td>
<td>112,50 MW</td>
<td>154,42 MW</td>
</tr>
<tr>
<td>Filter losses</td>
<td><strong>[155-130°C]</strong></td>
<td><strong>[155-130°C]</strong></td>
<td><strong>[155-130°C]</strong></td>
<td><strong>[155-130°C]</strong></td>
</tr>
<tr>
<td></td>
<td>27,69 kJ/kg</td>
<td>27,69 kJ/kg</td>
<td>27,69 kJ/kg</td>
<td>28,89 kJ/kg</td>
</tr>
<tr>
<td>Air Preheat</td>
<td><strong>[130-70°C]</strong></td>
<td><strong>[130-70°C]</strong></td>
<td><strong>[130-70°C]</strong></td>
<td><strong>[130-70°C]</strong></td>
</tr>
<tr>
<td></td>
<td>65,15 kJ/kg</td>
<td>65,15 kJ/kg</td>
<td>65,15 kJ/kg</td>
<td>65,15 kJ/kg</td>
</tr>
<tr>
<td>Regained preheat</td>
<td>6,31 MW</td>
<td>6,31 MW</td>
<td>6,31 MW</td>
<td>6,31 MW</td>
</tr>
<tr>
<td>Exhaust</td>
<td>7,37 MW</td>
<td>7,37 MW</td>
<td>7,37 MW</td>
<td>7,37 MW</td>
</tr>
<tr>
<td>Total P Boiler</td>
<td><strong>88,11</strong> MW</td>
<td><strong>107,35</strong> MW</td>
<td><strong>118,81</strong> MW</td>
<td><strong>160,73</strong> MW</td>
</tr>
</tbody>
</table>

Finally, the third scenario from Table 33 is chosen for further calculations. It is specifically calculated for the thermal output from the combustion calculations, Table 30.
14 Appendix III - Environmental Comparison

14.1 Landfill emissions

Landfill emissions are calculated by determining the annual amount of decomposed carbon, $DDOC_m$, and the CH$_4$ emissions it leads to. This is done by estimating the amount degradable organic carbon, $DOC$, in the waste, and eventually calculating what CH$_4$ generation potential, $L_0$, it has. Different types of waste decompose and emit CH$_4$ at different rates, $k$, which determines what amount of waste remains after a year of decay. Using the waste composition from the Donetsk project, (31), the degradable organic carbon content and CH$_4$ generation rates are determined.

Table 34 - Carbon decomposition rates in waste

<table>
<thead>
<tr>
<th>Values for CH$_4$ Emission Calculations</th>
<th>% of mass</th>
<th>DOC</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Textiles &amp; Paper</td>
<td>8.8</td>
<td>0.433523</td>
<td>0.04</td>
</tr>
<tr>
<td>Garden &amp; Non Food Organic Waste</td>
<td>9.8</td>
<td>0.091735</td>
<td>0.05</td>
</tr>
<tr>
<td>Food</td>
<td>39.5</td>
<td>0.38</td>
<td>0.06</td>
</tr>
<tr>
<td>Wood &amp; Straw</td>
<td>11.22</td>
<td>0.49098</td>
<td>0.02</td>
</tr>
</tbody>
</table>

The annual waste accumulation of 400’000 Mg is added to the remaining amount of waste on the landfill. The emissions are then calculated per year and summarized over a 25 year period, which is the chosen period for this comparison.

\[
DDOC_m = W \cdot DOC \cdot DOC_f \cdot MCF
\]  \hspace{1cm} (All-i)

$W =$ Annual mass of waste deposited, Gg 
$DOC =$ Average degradable organic carbon content of the waste, Gg C/Gg waste 
$DOC_f =$ Fraction of DOC that can decompose 
$MCF =$ CH$_4$ correction factor for aerobic decomposition, which depends on landfill type (fraction) $DDOC_m =$ Annual mass of DOC that is decomposable, Gg

\[
DDOC_m = DDOC_{m0} \cdot e^{-kt}
\]  \hspace{1cm} (All-ii)

$DDOC_m =$ Mass of degradable organic carbon decomposed in landfill after time $t$
$DDOC_{m0} =$ Initial mass of DDOC$_m$ that year 
$k =$ decomposition rate constant in y$^{-1}$ 
$t =$ time in years

\[
L_0 = DDOC_m \cdot F \cdot \frac{M[CH_4]}{M[C]}
\]  \hspace{1cm} (All ii)

$L_0 =$ CH$_4$ generation potential, Gg CH$_4$
$F =$ Standard fraction of CH$_4$ in generated landfill gas (volume fraction)
$\frac{M[CH_4]}{M[C]} =$ Molecular weight ratio between CH$_4$ and C

Table 35 - Carbon decomposition in waste
<table>
<thead>
<tr>
<th>Year</th>
<th>Textiles &amp; Paper</th>
<th>Garden &amp; Non Food</th>
<th>Food</th>
<th>Wood &amp; Straw</th>
</tr>
</thead>
<tbody>
<tr>
<td>k</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Fraction of Total Waste</td>
<td>0.088</td>
<td>0.098</td>
<td>0.395</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Remaining DOC [tonnes]</th>
<th>Remaining DOC [tonnes]</th>
<th>Remaining DOC [tonnes]</th>
<th>Remaining DOC [tonnes]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5125</td>
<td>5708</td>
<td>23005</td>
<td>6535</td>
</tr>
<tr>
<td>1</td>
<td>10049</td>
<td>11137</td>
<td>44670</td>
<td>12940</td>
</tr>
<tr>
<td>2</td>
<td>14781</td>
<td>16301</td>
<td>65074</td>
<td>19218</td>
</tr>
<tr>
<td>3</td>
<td>19326</td>
<td>21214</td>
<td>84290</td>
<td>25372</td>
</tr>
<tr>
<td>4</td>
<td>23694</td>
<td>25887</td>
<td>102386</td>
<td>31404</td>
</tr>
<tr>
<td>5</td>
<td>27890</td>
<td>30332</td>
<td>119429</td>
<td>37317</td>
</tr>
<tr>
<td>6</td>
<td>31921</td>
<td>34560</td>
<td>135479</td>
<td>43113</td>
</tr>
<tr>
<td>7</td>
<td>35795</td>
<td>38582</td>
<td>150594</td>
<td>48794</td>
</tr>
<tr>
<td>8</td>
<td>39517</td>
<td>42408</td>
<td>164829</td>
<td>54362</td>
</tr>
<tr>
<td>9</td>
<td>43092</td>
<td>46047</td>
<td>178236</td>
<td>59820</td>
</tr>
<tr>
<td>10</td>
<td>46528</td>
<td>49509</td>
<td>190861</td>
<td>65171</td>
</tr>
<tr>
<td>11</td>
<td>49829</td>
<td>52802</td>
<td>202751</td>
<td>70415</td>
</tr>
<tr>
<td>12</td>
<td>53000</td>
<td>55935</td>
<td>213949</td>
<td>75555</td>
</tr>
<tr>
<td>13</td>
<td>56047</td>
<td>58914</td>
<td>224495</td>
<td>80593</td>
</tr>
<tr>
<td>14</td>
<td>58975</td>
<td>61749</td>
<td>234426</td>
<td>85532</td>
</tr>
<tr>
<td>15</td>
<td>61787</td>
<td>64445</td>
<td>243779</td>
<td>90373</td>
</tr>
<tr>
<td>16</td>
<td>64490</td>
<td>67009</td>
<td>252588</td>
<td>95118</td>
</tr>
<tr>
<td>17</td>
<td>67086</td>
<td>69449</td>
<td>260883</td>
<td>99769</td>
</tr>
<tr>
<td>18</td>
<td>69581</td>
<td>71769</td>
<td>268696</td>
<td>104328</td>
</tr>
<tr>
<td>19</td>
<td>71978</td>
<td>73977</td>
<td>276053</td>
<td>108797</td>
</tr>
<tr>
<td>20</td>
<td>74281</td>
<td>76076</td>
<td>282982</td>
<td>113178</td>
</tr>
<tr>
<td>21</td>
<td>76493</td>
<td>78074</td>
<td>289508</td>
<td>117471</td>
</tr>
<tr>
<td>22</td>
<td>78619</td>
<td>79974</td>
<td>295653</td>
<td>121680</td>
</tr>
<tr>
<td>23</td>
<td>80662</td>
<td>81781</td>
<td>301441</td>
<td>125805</td>
</tr>
<tr>
<td>24</td>
<td>82624</td>
<td>83500</td>
<td>306891</td>
<td>129848</td>
</tr>
<tr>
<td>25</td>
<td>84509</td>
<td>85135</td>
<td>312024</td>
<td>133812</td>
</tr>
<tr>
<td>Year</td>
<td>Textiles &amp; Paper</td>
<td>Garden &amp; Non Food</td>
<td>Food</td>
<td>Wood &amp; Straw</td>
</tr>
<tr>
<td>------</td>
<td>------------------</td>
<td>------------------</td>
<td>------</td>
<td>-------------</td>
</tr>
<tr>
<td></td>
<td>DDOCm [tonnes]</td>
<td>CH$_4$ [tonnes]</td>
<td>DDOCm [tonnes]</td>
<td>CH$_4$ [tonnes]</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>201</td>
<td>134</td>
<td>278</td>
<td>186</td>
</tr>
<tr>
<td>2</td>
<td>595</td>
<td>397</td>
<td>822</td>
<td>548</td>
</tr>
<tr>
<td>3</td>
<td>1175</td>
<td>783</td>
<td>1617</td>
<td>1078</td>
</tr>
<tr>
<td>4</td>
<td>1932</td>
<td>1288</td>
<td>2651</td>
<td>1767</td>
</tr>
<tr>
<td>5</td>
<td>2861</td>
<td>1908</td>
<td>3914</td>
<td>2609</td>
</tr>
<tr>
<td>6</td>
<td>3955</td>
<td>2637</td>
<td>5393</td>
<td>3595</td>
</tr>
<tr>
<td>7</td>
<td>5207</td>
<td>3471</td>
<td>7078</td>
<td>4719</td>
</tr>
<tr>
<td>8</td>
<td>6610</td>
<td>4407</td>
<td>8960</td>
<td>5973</td>
</tr>
<tr>
<td>9</td>
<td>8160</td>
<td>5440</td>
<td>11028</td>
<td>7352</td>
</tr>
<tr>
<td>10</td>
<td>9849</td>
<td>6566</td>
<td>13274</td>
<td>8849</td>
</tr>
<tr>
<td>11</td>
<td>11674</td>
<td>7782</td>
<td>15689</td>
<td>10459</td>
</tr>
<tr>
<td>12</td>
<td>13627</td>
<td>9085</td>
<td>18264</td>
<td>12176</td>
</tr>
<tr>
<td>13</td>
<td>15706</td>
<td>10470</td>
<td>20992</td>
<td>13995</td>
</tr>
<tr>
<td>14</td>
<td>17903</td>
<td>11936</td>
<td>23865</td>
<td>15910</td>
</tr>
<tr>
<td>15</td>
<td>20216</td>
<td>13477</td>
<td>26877</td>
<td>17918</td>
</tr>
<tr>
<td>16</td>
<td>22638</td>
<td>15092</td>
<td>30020</td>
<td>20013</td>
</tr>
<tr>
<td>17</td>
<td>25167</td>
<td>16778</td>
<td>33288</td>
<td>22192</td>
</tr>
<tr>
<td>18</td>
<td>27798</td>
<td>18532</td>
<td>36675</td>
<td>24450</td>
</tr>
<tr>
<td>19</td>
<td>30526</td>
<td>20351</td>
<td>40175</td>
<td>26783</td>
</tr>
<tr>
<td>20</td>
<td>33348</td>
<td>22232</td>
<td>43783</td>
<td>29189</td>
</tr>
<tr>
<td>21</td>
<td>36261</td>
<td>24174</td>
<td>47493</td>
<td>31662</td>
</tr>
<tr>
<td>22</td>
<td>39260</td>
<td>26173</td>
<td>51301</td>
<td>34201</td>
</tr>
<tr>
<td>23</td>
<td>42343</td>
<td>28229</td>
<td>55201</td>
<td>36801</td>
</tr>
<tr>
<td>24</td>
<td>45506</td>
<td>30337</td>
<td>59190</td>
<td>39460</td>
</tr>
<tr>
<td>25</td>
<td>48745</td>
<td>32497</td>
<td>63262</td>
<td>42175</td>
</tr>
</tbody>
</table>
14.2 Gas turbine emissions
For the CHP plants in Chisinau the gas use, efficiencies and power production is documented annually by ANRE. For the comparison, the amount of gas needed to produce the equal power as the proposed WTE plant is calculated, using the data on plant efficiencies. The emissions from combustion of this amount of gas in then determined by using standard emissions factors for older gas turbines, provided by the US Environmental Protection Agency. (34)

Table 37 - Average annual emissions from an older type of gas turbine power plant. Calculations have been done with the same thermal and electrical output as the proposed WTE plant.

<table>
<thead>
<tr>
<th></th>
<th>Emissions kg/MJ of natural gas</th>
<th>Emissions [tonnes/year]</th>
<th>CO₂ eq. IPCC 100yr SAR+</th>
<th>GHG potential CO₂ equivalents [tonnes]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>4.73E-02</td>
<td>205283.10</td>
<td>1</td>
<td>205283.10</td>
</tr>
<tr>
<td>N₂O</td>
<td>1.29E-05</td>
<td>1.45</td>
<td>310</td>
<td>448.47</td>
</tr>
<tr>
<td>SO₂</td>
<td>1.46E-06</td>
<td>0.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH₄</td>
<td>3.70E-06</td>
<td>0.41</td>
<td>21</td>
<td>8.71</td>
</tr>
<tr>
<td>VOC</td>
<td>9.03E-07</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOC</td>
<td>4.73E-06</td>
<td>0.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM kond</td>
<td>2.02E-06</td>
<td>0.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM Filt</td>
<td>8.17E-07</td>
<td>0.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM tot</td>
<td>2.84E-06</td>
<td>0.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>205740.28</td>
</tr>
</tbody>
</table>

14.3 WTE Emissions
The emissions from the proposed WTE plant are obtained in two different ways. CO₂ and SO₂ are obtained through the combustion calculations done earlier. The emissions of oxides, volatile/toxic organic compounds and heavy metals are obtained using waste incineration simulation software provided by Swedish Waste Management, but since the waste composition analysis has not been done for Chisinau it is not quite reliable. See Appendix I – Waste composition simulation software for the data from the program. The emission simulations are done using promised filtration values and are then compared to the EU emission standards, since Swedish WTE plant delivery corporations can always provide solutions according to them.
15 Appendix IV- Method MATLAB model

The MATLAB-model is based on the steam cycle figure below, Figure 23 with old numbers.

15.1 Main theory behind the MATLAB model

15.1.1 Pre heating of combustion air
The MATLAB model calculates the power needed for pre heating the combustion air. The model uses average climate data and the needed power is subtracted from the available boiler power.

15.1.2 Finding the best characteristics and corresponding profit
The MATLAB model produces a matrix containing 11^3 different combinations of conditions for the steam cycle within the determined limits. The best combination is the combination that produces the most profit. During the winter months the combination with the highest profit is selected and during the summer month the model selects the combination resulting in the highest electric production efficiency.

15.1.3 Isentropic efficiency
The isentropic efficiency, \( n_{t,HP} \), for the HP turbine is pre-determined to 0.8 and the efficiency, \( n_{t,LP} \), for the LP turbine is calculated.

\[
 n_{t,LP} = \frac{h_4 - h_7}{h_4 - h_7,IS} \quad (AIV i)
\]

The pre-determined node 7 determines the efficiency for the whole LP turbine.
15.1.4 Feed water tank
The feed water tank gathers the water before it goes in to the steam boiler. The conditions for the
tank are calculated with the equations below.

\[
\begin{align*}
  h_{17} \cdot m_{17} &= h_{24} \cdot m_{24} + h_{30} \cdot m_{30} \\
  h_{17} &= \frac{h_{24} \cdot m_{24} + h_{30} \cdot m_{30}}{m_{24} + m_{30}}
\end{align*}
\]

\text{\textit{(AIV-ii)}}

\text{\textit{(AIV iii)}}

15.1.5 Two stage DH heat exchanger
The two pre determined steps of heating of the DH-water leads to a calculable difference between
the two steps. This difference correlates with the difference of needed mass flow in the two steps.
The mass flow in node 7 varies in the model.

\[
\text{\textit{Difference, D}} = \frac{h_{11} - h_{12}}{h_7 - h_{13}}
\]

\text{\textit{(AIV iv)}}

\[
m_{11} = D \cdot m_7
\]

\text{\textit{(AIV v)}}

15.1.6 Condensate tank
In the condensate tank the condensate from the two DH-condensers and the second pre heater
condenser gather. The conditions for the condensate tank are calculated below.

\[
\begin{align*}
  h_{14} \cdot m_{14} &= h_{12} \cdot m_{12} + h_{15} \cdot m_{15} + h_{10} \cdot m_{10} \\
  h_{10} &= h_{14} \\
  m_{14} &= m_{12} + m_{15} + m_{10}
\end{align*}
\]

\text{\textit{(AIV vi)}}

\text{\textit{(AIV vii)}}

\text{\textit{(AIV vii)}}

\[
\begin{align*}
  h_{14} &= \frac{h_{12} \cdot m_{12} + h_{15} \cdot m_{15}}{m_{12} + m_{15}}
\end{align*}
\]

\text{\textit{(AIV viii)}}

15.1.7 Pre heating of feed water
The two different pre heating steps of the feed water are designed to contribute for the half of the
pre heating each. The second steps characteristic is determined by the LP-turbine drain to the warm
DH-condenser. The model varies the pressure for the first step of the pre heating step and the
available mass flow for the pre heating steps.

\[
\begin{align*}
  h_5 \cdot m_5 &= h_9 \cdot m_9
\end{align*}
\]

\text{\textit{(AIV ix)}}
15.1.8 Energy and mass balance or conservation

The two main physical relations that are used in the MATLAB model are mass balance and energy balance. The sum of energy flow into one node is equal to the sum of energy flow out of it, and the same applies to the mass flow.

\[ P = \text{power} = W \]
\[ h = \text{enthalpy} = \frac{kW}{kg} \]
\[ \dot{m} = \text{mass flow} = \frac{kg}{s} \]

\[ P_{in} = h_{in} \cdot \dot{m}_{in} = h_{out} \cdot \dot{m}_{out} = P_{out} \quad (AIV \ x) \]

The conservation of mass and energy is used in three nodes and the calculations are displayed below.

\[ h_{28} \cdot \dot{m}_{28} = h_{9} \cdot \dot{m}_{9} - h_{10} \cdot \dot{m}_{10} + h_{16} \cdot \dot{m}_{16} \quad (AIV \ xi) \]

\[ h_{28} = \frac{h_{9} \cdot \dot{m}_{9} - h_{10} \cdot \dot{m}_{10} + h_{16} \cdot \dot{m}_{16}}{\dot{m}_{28}} \quad (AIV \ xi) \]

\[ h_{30} \cdot \dot{m}_{30} = h_{5} \cdot \dot{m}_{5} + h_{29} \cdot \dot{m}_{29} + h_{24} \cdot \dot{m}_{24} \quad (AIV \ xii) \]

\[ h_{24} = h_{30} \quad (AIV \ xiii) \]

\[ \dot{m}_{5} = \dot{m}_{30} \quad (AIV \ xiv) \]

\[ h_{30} = \frac{h_{5} \cdot \dot{m}_{5} + h_{29} \cdot \dot{m}_{29}}{\dot{m}_{5} + \dot{m}_{24}} \quad (AIV \ xv) \]

\[ h_{30} \cdot \dot{m}_{30} = h_{5} \cdot \dot{m}_{5} + h_{29} \cdot \dot{m}_{29} + h_{24} \cdot \dot{m}_{24} \quad (AIV \ xvi) \]

15.1.9 Energy outtake

The theoretical estimations/calculations in the MATLAB-model are based on the equations below.

15.1.9.1 Enthalpy change

Every energy outtake in the steam cycle can be explained as an enthalpy outtake change compared to the total enthalpy input change.

\[ \text{Outtake in node 5} = O_5 = \frac{(h_4 - h_5) + (h_1 - h_3)}{(h_1 - h_{18}) + (h_4 - h_3)} \quad (AIV \ xviii) \]

\[ O_6 = \frac{(h_4 - h_6) + (h_1 - h_3)}{(h_1 - h_{18}) + (h_4 - h_3)} \quad (AIV \ xviii) \]

\[ O_7 = \frac{(h_4 - h_7) + (h_1 - h_3)}{(h_1 - h_{18}) + (h_4 - h_3)} \quad (AIV \ xix) \]

\[ O_{42} = \frac{h_{11} - h_{12}}{(h_1 - h_{18}) + (h_4 - h_3)} \quad (AIV \ xx) \]
\[ O_{13} = \frac{(h_7 - h_{13})}{(h_1 - h_{18}) + (h_4 - h_3)} \quad (AIV \ xxix) \]

**15.1.9.2 Outtake fraction**
The efficiency of every node depends on the energy outtake and the mass flow.

*Outtake fraction in node 5 = \( OF_5 = O_5 \cdot \dot{m}_5 \) (AIV xxii)*

\[ OF_6 = O_6 \cdot \dot{m}_6 \quad (AIV \ xxiii) \]

\[ OF_7 = O_7 \cdot \dot{m}_7 \quad (AIV \ xxiv) \]

\[ OF_{12} = O_{12} \cdot \dot{m}_{12} \quad (AIV \ xxv) \]

\[ OF_{13} = O_{13} \cdot \dot{m}_{13} \quad (AIV \ xxvi) \]

**15.1.9.3 Electrical and thermal efficiency**
The electrical and thermal efficiency’s are determined by the total outtake fraction.

*Electrical efficiency = \( n_{el} = \frac{(OF_5 + OF_6 + OF_7)}{m_1} \) (AIV xxvii)*

*Thermal efficiency = \( n_{thermal} = \frac{(OF_{12} + OF_{13})}{m_1} \) (AIV xxvii)*

**15.1.10 Complete MATLAB code**
See Appendix VII
16 Appendix V – Results MATLAB-model

16.1 Node characteristic

The node characteristics are based on the new *nice* numbers configuration that is displayed in the report and not in the MATLAB-model.

![Diagram of node configuration, winter month](image)

*Figure 24 - Node configuration, winter month*
### Table 38 - Node configuration winter month

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>400.00</td>
<td>40.00</td>
<td>3214.37</td>
<td>1.00</td>
<td>6.77</td>
</tr>
<tr>
<td>2</td>
<td>203.14</td>
<td>6.18</td>
<td>2856.59</td>
<td>1.00</td>
<td>6.97</td>
</tr>
<tr>
<td>3</td>
<td>400.00</td>
<td>6.18</td>
<td>3270.43</td>
<td>1.00</td>
<td>7.70</td>
</tr>
<tr>
<td>4</td>
<td>277.37</td>
<td>2.57</td>
<td>3024.76</td>
<td>0.05</td>
<td>7.70</td>
</tr>
<tr>
<td>5</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.48</td>
<td>7.70</td>
</tr>
<tr>
<td>6</td>
<td>100.00</td>
<td>0.50</td>
<td>2682.40</td>
<td>0.47</td>
<td>7.70</td>
</tr>
<tr>
<td>7</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.01</td>
<td>7.70</td>
</tr>
<tr>
<td>8</td>
<td>85.00</td>
<td>1.02</td>
<td>356.00</td>
<td>0.01</td>
<td>0.99</td>
</tr>
<tr>
<td>9</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.47</td>
<td>7.70</td>
</tr>
<tr>
<td>10</td>
<td>100.00</td>
<td>1.02</td>
<td>419.10</td>
<td>0.47</td>
<td>1.31</td>
</tr>
<tr>
<td>11</td>
<td>70.00</td>
<td>0.32</td>
<td>293.02</td>
<td>0.47</td>
<td>0.96</td>
</tr>
<tr>
<td>12</td>
<td>70.00</td>
<td>1.02</td>
<td>293.08</td>
<td>0.47</td>
<td>0.96</td>
</tr>
<tr>
<td>13</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
</tr>
<tr>
<td>14</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
</tr>
<tr>
<td>15</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
<td>NaN</td>
</tr>
<tr>
<td>16</td>
<td>85.00</td>
<td>1.02</td>
<td>356.00</td>
<td>0.95</td>
<td>0.99</td>
</tr>
<tr>
<td>17</td>
<td>85.00</td>
<td>7.80</td>
<td>356.53</td>
<td>0.95</td>
<td>0.99</td>
</tr>
<tr>
<td>18</td>
<td>92.98</td>
<td>7.80</td>
<td>390.04</td>
<td>0.95</td>
<td>1.45</td>
</tr>
<tr>
<td>19</td>
<td>92.98</td>
<td>7.80</td>
<td>390.04</td>
<td>0.95</td>
<td>1.45</td>
</tr>
<tr>
<td>20</td>
<td>123.08</td>
<td>7.80</td>
<td>517.23</td>
<td>0.95</td>
<td>1.81</td>
</tr>
<tr>
<td>21</td>
<td>123.17</td>
<td>2.57</td>
<td>517.23</td>
<td>0.05</td>
<td>1.62</td>
</tr>
<tr>
<td>22</td>
<td>123.17</td>
<td>7.80</td>
<td>517.64</td>
<td>0.05</td>
<td>1.62</td>
</tr>
<tr>
<td>23</td>
<td>123.09</td>
<td>7.80</td>
<td>517.25</td>
<td>1.00</td>
<td>1.80</td>
</tr>
<tr>
<td>24</td>
<td>123.09</td>
<td>40.00</td>
<td>519.54</td>
<td>1.00</td>
<td>1.80</td>
</tr>
<tr>
<td>25</td>
<td>250.00</td>
<td>40.00</td>
<td>1085.69</td>
<td>1.00</td>
<td>2.79</td>
</tr>
<tr>
<td>26</td>
<td>70.00</td>
<td>2.50</td>
<td>293.20</td>
<td>NaN</td>
<td>0.95</td>
</tr>
<tr>
<td>27</td>
<td>70.00</td>
<td>11.33</td>
<td>293.92</td>
<td>NaN</td>
<td>0.95</td>
</tr>
<tr>
<td>28</td>
<td>100.00</td>
<td>11.33</td>
<td>419.87</td>
<td>NaN</td>
<td>1.31</td>
</tr>
<tr>
<td>29</td>
<td>130.00</td>
<td>11.33</td>
<td>546.97</td>
<td>NaN</td>
<td>1.63</td>
</tr>
<tr>
<td>------</td>
<td>------------------</td>
<td>---------------</td>
<td>------------------</td>
<td>----------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>1</td>
<td>400.00</td>
<td>40.00</td>
<td>3214.37</td>
<td>1.00</td>
<td>6.77</td>
</tr>
<tr>
<td>2</td>
<td>203.14</td>
<td>6.18</td>
<td>2856.59</td>
<td>1.00</td>
<td>6.97</td>
</tr>
<tr>
<td>3</td>
<td>400.00</td>
<td>6.18</td>
<td>3270.43</td>
<td>1.00</td>
<td>7.70</td>
</tr>
<tr>
<td>4</td>
<td>400.00</td>
<td>6.18</td>
<td>3270.43</td>
<td>0.06</td>
<td>7.70</td>
</tr>
<tr>
<td>5</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.47</td>
<td>7.70</td>
</tr>
<tr>
<td>6</td>
<td>100.00</td>
<td>0.50</td>
<td>2682.40</td>
<td>0.41</td>
<td>7.70</td>
</tr>
<tr>
<td>7</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.07</td>
<td>7.70</td>
</tr>
<tr>
<td>8</td>
<td>82.21</td>
<td>1.02</td>
<td>344.25</td>
<td>0.07</td>
<td>0.95</td>
</tr>
<tr>
<td>9</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.41</td>
<td>7.70</td>
</tr>
<tr>
<td>10</td>
<td>100.00</td>
<td>1.02</td>
<td>419.10</td>
<td>0.41</td>
<td>0.96</td>
</tr>
<tr>
<td>11</td>
<td>70.00</td>
<td>0.32</td>
<td>293.02</td>
<td>0.41</td>
<td>0.96</td>
</tr>
<tr>
<td>12</td>
<td>70.00</td>
<td>1.02</td>
<td>293.08</td>
<td>0.41</td>
<td>0.96</td>
</tr>
<tr>
<td>13</td>
<td>49.51</td>
<td>0.12</td>
<td>2465.15</td>
<td>0.07</td>
<td>8.09</td>
</tr>
<tr>
<td>14</td>
<td>47.51</td>
<td>0.12</td>
<td>198.91</td>
<td>0.07</td>
<td>0.67</td>
</tr>
<tr>
<td>15</td>
<td>47.51</td>
<td>1.02</td>
<td>198.99</td>
<td>0.07</td>
<td>0.67</td>
</tr>
<tr>
<td>16</td>
<td>82.21</td>
<td>1.02</td>
<td>344.25</td>
<td>0.94</td>
<td>0.95</td>
</tr>
<tr>
<td>17</td>
<td>82.21</td>
<td>7.80</td>
<td>344.78</td>
<td>0.94</td>
<td>0.95</td>
</tr>
<tr>
<td>18</td>
<td>122.58</td>
<td>7.80</td>
<td>515.09</td>
<td>0.94</td>
<td>1.42</td>
</tr>
<tr>
<td>19</td>
<td>122.58</td>
<td>7.80</td>
<td>515.09</td>
<td>0.94</td>
<td>1.42</td>
</tr>
<tr>
<td>20</td>
<td>158.58</td>
<td>7.80</td>
<td>669.40</td>
<td>0.94</td>
<td>1.81</td>
</tr>
<tr>
<td>21</td>
<td>158.60</td>
<td>6.18</td>
<td>669.40</td>
<td>0.06</td>
<td>1.81</td>
</tr>
<tr>
<td>22</td>
<td>158.60</td>
<td>7.80</td>
<td>669.60</td>
<td>0.06</td>
<td>1.81</td>
</tr>
<tr>
<td>23</td>
<td>158.58</td>
<td>7.80</td>
<td>669.41</td>
<td>1.00</td>
<td>1.81</td>
</tr>
<tr>
<td>24</td>
<td>158.58</td>
<td>40.00</td>
<td>671.42</td>
<td>1.00</td>
<td>1.80</td>
</tr>
<tr>
<td>25</td>
<td>250.00</td>
<td>40.00</td>
<td>1085.69</td>
<td>1.00</td>
<td>2.79</td>
</tr>
<tr>
<td>26</td>
<td>70.00</td>
<td>2.50</td>
<td>293.20</td>
<td>NaN</td>
<td>0.95</td>
</tr>
<tr>
<td>27</td>
<td>70.00</td>
<td>11.33</td>
<td>293.92</td>
<td>NaN</td>
<td>0.95</td>
</tr>
<tr>
<td>28</td>
<td>100.00</td>
<td>11.33</td>
<td>419.87</td>
<td>NaN</td>
<td>1.31</td>
</tr>
<tr>
<td>29</td>
<td>130.00</td>
<td>11.33</td>
<td>546.97</td>
<td>NaN</td>
<td>1.63</td>
</tr>
<tr>
<td>------</td>
<td>------------------</td>
<td>---------------</td>
<td>-----------------</td>
<td>---------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>1</td>
<td>400.00</td>
<td>40.00</td>
<td>3214.37</td>
<td>1.00</td>
<td>6.77</td>
</tr>
<tr>
<td>2</td>
<td>203.14</td>
<td>6.18</td>
<td>2856.59</td>
<td>1.00</td>
<td>6.97</td>
</tr>
<tr>
<td>3</td>
<td>400.00</td>
<td>6.18</td>
<td>3270.43</td>
<td>1.00</td>
<td>7.70</td>
</tr>
<tr>
<td>4</td>
<td>357.50</td>
<td>4.63</td>
<td>3184.33</td>
<td>0.06</td>
<td>7.70</td>
</tr>
<tr>
<td>5</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.32</td>
<td>7.70</td>
</tr>
<tr>
<td>6</td>
<td>100.00</td>
<td>0.50</td>
<td>2682.40</td>
<td>0.26</td>
<td>7.70</td>
</tr>
<tr>
<td>7</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.06</td>
<td>7.70</td>
</tr>
<tr>
<td>8</td>
<td>69.67</td>
<td>1.02</td>
<td>291.67</td>
<td>0.06</td>
<td>0.95</td>
</tr>
<tr>
<td>9</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.26</td>
<td>7.70</td>
</tr>
<tr>
<td>10</td>
<td>100.00</td>
<td>1.02</td>
<td>419.10</td>
<td>0.26</td>
<td>1.31</td>
</tr>
<tr>
<td>11</td>
<td>70.00</td>
<td>0.32</td>
<td>293.02</td>
<td>0.26</td>
<td>0.95</td>
</tr>
<tr>
<td>12</td>
<td>70.00</td>
<td>1.02</td>
<td>293.08</td>
<td>0.26</td>
<td>0.95</td>
</tr>
<tr>
<td>13</td>
<td>49.51</td>
<td>0.12</td>
<td>2465.15</td>
<td>0.36</td>
<td>8.09</td>
</tr>
<tr>
<td>14</td>
<td>47.51</td>
<td>0.12</td>
<td>198.91</td>
<td>0.36</td>
<td>0.67</td>
</tr>
<tr>
<td>15</td>
<td>47.51</td>
<td>1.02</td>
<td>198.99</td>
<td>0.36</td>
<td>0.67</td>
</tr>
<tr>
<td>16</td>
<td>69.67</td>
<td>1.02</td>
<td>291.67</td>
<td>0.94</td>
<td>0.95</td>
</tr>
<tr>
<td>17</td>
<td>69.67</td>
<td>7.80</td>
<td>292.23</td>
<td>0.94</td>
<td>0.95</td>
</tr>
<tr>
<td>18</td>
<td>110.42</td>
<td>7.80</td>
<td>463.57</td>
<td>0.94</td>
<td>1.42</td>
</tr>
<tr>
<td>19</td>
<td>110.42</td>
<td>7.80</td>
<td>463.57</td>
<td>0.94</td>
<td>1.42</td>
</tr>
<tr>
<td>20</td>
<td>146.58</td>
<td>7.80</td>
<td>617.64</td>
<td>0.94</td>
<td>1.81</td>
</tr>
<tr>
<td>21</td>
<td>146.63</td>
<td>4.63</td>
<td>617.64</td>
<td>0.06</td>
<td>1.81</td>
</tr>
<tr>
<td>22</td>
<td>146.63</td>
<td>7.80</td>
<td>617.93</td>
<td>0.06</td>
<td>1.81</td>
</tr>
<tr>
<td>23</td>
<td>146.59</td>
<td>7.80</td>
<td>617.66</td>
<td>1.00</td>
<td>1.81</td>
</tr>
<tr>
<td>24</td>
<td>146.59</td>
<td>40.00</td>
<td>619.78</td>
<td>1.00</td>
<td>1.80</td>
</tr>
<tr>
<td>25</td>
<td>250.00</td>
<td>40.00</td>
<td>1085.69</td>
<td>1.00</td>
<td>2.79</td>
</tr>
<tr>
<td>26</td>
<td>70.00</td>
<td>2.50</td>
<td>293.20</td>
<td>NaN</td>
<td>0.95</td>
</tr>
<tr>
<td>27</td>
<td>70.00</td>
<td>11.33</td>
<td>293.92</td>
<td>NaN</td>
<td>0.95</td>
</tr>
<tr>
<td>28</td>
<td>100.00</td>
<td>11.33</td>
<td>419.87</td>
<td>NaN</td>
<td>1.31</td>
</tr>
<tr>
<td>29</td>
<td>130.00</td>
<td>11.33</td>
<td>546.97</td>
<td>NaN</td>
<td>1.63</td>
</tr>
<tr>
<td>------</td>
<td>------------------</td>
<td>----------------</td>
<td>------------------</td>
<td>----------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>1</td>
<td>400.00</td>
<td>40.00</td>
<td>3214.37</td>
<td>1.00</td>
<td>6.77</td>
</tr>
<tr>
<td>2</td>
<td>203.14</td>
<td>6.18</td>
<td>2856.59</td>
<td>1.00</td>
<td>6.97</td>
</tr>
<tr>
<td>3</td>
<td>400.00</td>
<td>6.18</td>
<td>3270.43</td>
<td>1.00</td>
<td>7.70</td>
</tr>
<tr>
<td>4</td>
<td>340.73</td>
<td>4.12</td>
<td>3150.64</td>
<td>0.06</td>
<td>7.70</td>
</tr>
<tr>
<td>5</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.27</td>
<td>7.70</td>
</tr>
<tr>
<td>6</td>
<td>100.00</td>
<td>0.50</td>
<td>2682.40</td>
<td>0.20</td>
<td>7.70</td>
</tr>
<tr>
<td>7</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.06</td>
<td>7.70</td>
</tr>
<tr>
<td>8</td>
<td>64.96</td>
<td>1.02</td>
<td>271.98</td>
<td>0.06</td>
<td>0.89</td>
</tr>
<tr>
<td>9</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.20</td>
<td>7.70</td>
</tr>
<tr>
<td>10</td>
<td>100.00</td>
<td>1.02</td>
<td>419.10</td>
<td>0.20</td>
<td>1.31</td>
</tr>
<tr>
<td>11</td>
<td>70.00</td>
<td>0.32</td>
<td>293.08</td>
<td>0.20</td>
<td>0.95</td>
</tr>
<tr>
<td>12</td>
<td>70.00</td>
<td>1.02</td>
<td>293.08</td>
<td>0.20</td>
<td>0.95</td>
</tr>
<tr>
<td>13</td>
<td>49.51</td>
<td>0.12</td>
<td>2465.15</td>
<td>0.47</td>
<td>8.09</td>
</tr>
<tr>
<td>14</td>
<td>47.51</td>
<td>0.12</td>
<td>198.91</td>
<td>0.47</td>
<td>0.67</td>
</tr>
<tr>
<td>15</td>
<td>47.51</td>
<td>1.02</td>
<td>198.99</td>
<td>0.47</td>
<td>0.67</td>
</tr>
<tr>
<td>16</td>
<td>64.96</td>
<td>1.02</td>
<td>271.98</td>
<td>0.94</td>
<td>0.89</td>
</tr>
<tr>
<td>17</td>
<td>64.96</td>
<td>7.80</td>
<td>272.56</td>
<td>0.94</td>
<td>0.89</td>
</tr>
<tr>
<td>18</td>
<td>105.83</td>
<td>7.80</td>
<td>444.21</td>
<td>0.94</td>
<td>1.37</td>
</tr>
<tr>
<td>19</td>
<td>105.83</td>
<td>7.80</td>
<td>444.21</td>
<td>0.94</td>
<td>1.37</td>
</tr>
<tr>
<td>20</td>
<td>142.04</td>
<td>7.80</td>
<td>598.14</td>
<td>0.94</td>
<td>1.76</td>
</tr>
<tr>
<td>21</td>
<td>142.10</td>
<td>4.12</td>
<td>598.14</td>
<td>0.06</td>
<td>1.76</td>
</tr>
<tr>
<td>22</td>
<td>142.10</td>
<td>7.80</td>
<td>598.47</td>
<td>0.06</td>
<td>1.76</td>
</tr>
<tr>
<td>23</td>
<td>142.05</td>
<td>7.80</td>
<td>598.16</td>
<td>1.00</td>
<td>1.76</td>
</tr>
<tr>
<td>24</td>
<td>142.05</td>
<td>40.00</td>
<td>600.32</td>
<td>1.00</td>
<td>1.76</td>
</tr>
<tr>
<td>25</td>
<td>250.00</td>
<td>40.00</td>
<td>1085.69</td>
<td>1.00</td>
<td>2.79</td>
</tr>
<tr>
<td>26</td>
<td>70.00</td>
<td>2.50</td>
<td>293.20</td>
<td>NaN</td>
<td>0.95</td>
</tr>
<tr>
<td>27</td>
<td>70.00</td>
<td>11.33</td>
<td>293.92</td>
<td>NaN</td>
<td>0.95</td>
</tr>
<tr>
<td>28</td>
<td>100.00</td>
<td>11.33</td>
<td>419.87</td>
<td>NaN</td>
<td>1.31</td>
</tr>
<tr>
<td>29</td>
<td>130.00</td>
<td>11.33</td>
<td>546.97</td>
<td>NaN</td>
<td>1.63</td>
</tr>
</tbody>
</table>
### Table 42 - Node configuration September

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>400.00</td>
<td>40.00</td>
<td>3214.37</td>
<td>1.00</td>
<td>6.77</td>
</tr>
<tr>
<td>2</td>
<td>203.14</td>
<td>6.18</td>
<td>2856.59</td>
<td>1.00</td>
<td>6.97</td>
</tr>
<tr>
<td>3</td>
<td>400.00</td>
<td>6.18</td>
<td>3270.43</td>
<td>1.00</td>
<td>7.70</td>
</tr>
<tr>
<td>4</td>
<td>372.81</td>
<td>5.15</td>
<td>3215.22</td>
<td>0.06</td>
<td>7.70</td>
</tr>
<tr>
<td>5</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.37</td>
<td>7.70</td>
</tr>
<tr>
<td>6</td>
<td>100.00</td>
<td>0.50</td>
<td>2682.40</td>
<td>0.31</td>
<td>7.70</td>
</tr>
<tr>
<td>7</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.06</td>
<td>7.70</td>
</tr>
<tr>
<td>8</td>
<td>73.89</td>
<td>1.02</td>
<td>309.36</td>
<td>0.06</td>
<td>1.00</td>
</tr>
<tr>
<td>9</td>
<td>169.36</td>
<td>1.02</td>
<td>2814.83</td>
<td>0.31</td>
<td>7.70</td>
</tr>
<tr>
<td>10</td>
<td>100.00</td>
<td>1.02</td>
<td>419.10</td>
<td>0.31</td>
<td>1.31</td>
</tr>
<tr>
<td>11</td>
<td>70.00</td>
<td>0.32</td>
<td>293.02</td>
<td>0.31</td>
<td>0.95</td>
</tr>
<tr>
<td>12</td>
<td>70.00</td>
<td>1.02</td>
<td>293.08</td>
<td>0.31</td>
<td>0.95</td>
</tr>
<tr>
<td>13</td>
<td>49.51</td>
<td>0.12</td>
<td>2465.15</td>
<td>0.26</td>
<td>8.09</td>
</tr>
<tr>
<td>14</td>
<td>47.51</td>
<td>0.12</td>
<td>198.91</td>
<td>0.26</td>
<td>0.67</td>
</tr>
<tr>
<td>15</td>
<td>47.51</td>
<td>1.02</td>
<td>198.99</td>
<td>0.26</td>
<td>0.67</td>
</tr>
<tr>
<td>16</td>
<td>73.89</td>
<td>1.02</td>
<td>309.36</td>
<td>0.94</td>
<td>1.00</td>
</tr>
<tr>
<td>17</td>
<td>73.89</td>
<td>7.80</td>
<td>309.90</td>
<td>0.94</td>
<td>1.00</td>
</tr>
<tr>
<td>18</td>
<td>114.53</td>
<td>7.80</td>
<td>480.96</td>
<td>0.94</td>
<td>1.47</td>
</tr>
<tr>
<td>19</td>
<td>114.53</td>
<td>7.80</td>
<td>480.96</td>
<td>0.94</td>
<td>1.47</td>
</tr>
<tr>
<td>20</td>
<td>150.65</td>
<td>7.80</td>
<td>635.17</td>
<td>0.94</td>
<td>1.85</td>
</tr>
<tr>
<td>21</td>
<td>150.69</td>
<td>5.15</td>
<td>635.17</td>
<td>0.06</td>
<td>1.85</td>
</tr>
<tr>
<td>22</td>
<td>150.69</td>
<td>7.80</td>
<td>635.43</td>
<td>0.06</td>
<td>1.85</td>
</tr>
<tr>
<td>23</td>
<td>150.66</td>
<td>7.80</td>
<td>635.18</td>
<td>1.00</td>
<td>1.85</td>
</tr>
<tr>
<td>24</td>
<td>150.66</td>
<td>40.00</td>
<td>637.26</td>
<td>1.00</td>
<td>1.84</td>
</tr>
<tr>
<td>25</td>
<td>250.00</td>
<td>40.00</td>
<td>1085.69</td>
<td>1.00</td>
<td>2.79</td>
</tr>
<tr>
<td>26</td>
<td>70.00</td>
<td>2.50</td>
<td>293.20</td>
<td>NaN</td>
<td>0.95</td>
</tr>
<tr>
<td>27</td>
<td>70.00</td>
<td>11.33</td>
<td>293.92</td>
<td>NaN</td>
<td>0.95</td>
</tr>
<tr>
<td>28</td>
<td>100.00</td>
<td>11.33</td>
<td>419.87</td>
<td>NaN</td>
<td>1.31</td>
</tr>
<tr>
<td>29</td>
<td>130.00</td>
<td>11.33</td>
<td>546.97</td>
<td>NaN</td>
<td>1.63</td>
</tr>
</tbody>
</table>
### 16.2 Monthly production result

**Table 43 - Monthly production**

<table>
<thead>
<tr>
<th></th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>Produced heat [GWh]</td>
<td>59.55</td>
<td>53.85</td>
<td>59.82</td>
<td>58.21</td>
<td>55.00</td>
<td>33.48</td>
</tr>
<tr>
<td>Produced el [GWh]</td>
<td>22.95</td>
<td>20.75</td>
<td>23.05</td>
<td>22.43</td>
<td>24.50</td>
<td>23.89</td>
</tr>
<tr>
<td>Heat demand [GWh]</td>
<td>450.44</td>
<td>388.79</td>
<td>312.04</td>
<td>91.52</td>
<td>55.00</td>
<td>33.48</td>
</tr>
<tr>
<td>Profit [M Lei]</td>
<td>74.54</td>
<td>67.40</td>
<td>74.88</td>
<td>72.87</td>
<td>73.71</td>
<td>58.12</td>
</tr>
<tr>
<td>Profit [M €]</td>
<td>4.80</td>
<td>4.34</td>
<td>4.82</td>
<td>4.69</td>
<td>4.75</td>
<td>3.74</td>
</tr>
<tr>
<td>Profit from heat [M MDL]</td>
<td>40.68</td>
<td>36.79</td>
<td>40.87</td>
<td>39.77</td>
<td>37.58</td>
<td>22.88</td>
</tr>
<tr>
<td>Profit from heat [M €]</td>
<td>2.62</td>
<td>2.37</td>
<td>2.63</td>
<td>2.56</td>
<td>2.42</td>
<td>1.47</td>
</tr>
<tr>
<td>Profit from el [M MDL]</td>
<td>33.85</td>
<td>30.61</td>
<td>34.01</td>
<td>33.09</td>
<td>36.14</td>
<td>35.24</td>
</tr>
<tr>
<td>Profit from el [M €]</td>
<td>2.18</td>
<td>1.97</td>
<td>2.19</td>
<td>2.13</td>
<td>2.33</td>
<td>2.27</td>
</tr>
<tr>
<td>Heat power [MW]</td>
<td>80.04</td>
<td>80.13</td>
<td>80.40</td>
<td>80.85</td>
<td>73.92</td>
<td>46.51</td>
</tr>
<tr>
<td>El power [MW]</td>
<td>30.84</td>
<td>30.88</td>
<td>30.98</td>
<td>31.16</td>
<td>32.92</td>
<td>33.18</td>
</tr>
<tr>
<td>Heat power demand [MW]</td>
<td>605.43</td>
<td>578.55</td>
<td>419.42</td>
<td>127.11</td>
<td>73.92</td>
<td>46.50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>Produced heat [GWh]</td>
<td>0</td>
<td>26.45</td>
<td>39.95</td>
<td>60.14</td>
<td>57.95</td>
<td>59.68</td>
</tr>
<tr>
<td>Produced el [GWh]</td>
<td>0</td>
<td>26.99</td>
<td>25.13</td>
<td>23.18</td>
<td>22.33</td>
<td>23.00</td>
</tr>
<tr>
<td>Heat demand [GWh]</td>
<td>22.85</td>
<td>26.45</td>
<td>39.95</td>
<td>100.78</td>
<td>243.59</td>
<td>410.54</td>
</tr>
<tr>
<td>Profit [M MDL]</td>
<td>0</td>
<td>57.89</td>
<td>64.36</td>
<td>75.28</td>
<td>72.54</td>
<td>74.70</td>
</tr>
<tr>
<td>Profit [M €]</td>
<td>0</td>
<td>3.73</td>
<td>4.14</td>
<td>4.85</td>
<td>4.67</td>
<td>4.81</td>
</tr>
<tr>
<td>Profit from heat [M MDL]</td>
<td>0</td>
<td>18.07</td>
<td>27.30</td>
<td>41.09</td>
<td>39.59</td>
<td>40.77</td>
</tr>
<tr>
<td>Profit from heat [M €]</td>
<td>0</td>
<td>1.16</td>
<td>1.76</td>
<td>2.65</td>
<td>2.55</td>
<td>2.62</td>
</tr>
<tr>
<td>Profit from el [M MDL]</td>
<td>0</td>
<td>39.82</td>
<td>37.07</td>
<td>34.19</td>
<td>32.95</td>
<td>33.92</td>
</tr>
<tr>
<td>Profit from el [M €]</td>
<td>0</td>
<td>2.56</td>
<td>2.39</td>
<td>2.20</td>
<td>2.12</td>
<td>2.18</td>
</tr>
<tr>
<td>Heat power [MW]</td>
<td>0</td>
<td>36.34</td>
<td>55.49</td>
<td>80.84</td>
<td>80.49</td>
<td>80.21</td>
</tr>
<tr>
<td>El power [MW]</td>
<td>0</td>
<td>37.08</td>
<td>34.90</td>
<td>31.15</td>
<td>31.02</td>
<td>30.91</td>
</tr>
<tr>
<td>Heat power demand [MW]</td>
<td>30.71</td>
<td>35.55</td>
<td>55.49</td>
<td>135.46</td>
<td>338.32</td>
<td>551.81</td>
</tr>
</tbody>
</table>

87
17 Appendix VI – Results Investment calculations

17.1 Cash flow calculations

17.1.1 Chemical usage
The chemical usage and cost are displayed in Table 44. The chemical usage is based on the Avfall Sverige model and the price estimations are made by Rolf Hunt at Alstom Power Sweden.

Table 44 – Chemical usage and Price (25)

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>Price [€/tonne]</th>
<th>Usage [tonnes]</th>
<th>Cost [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime</td>
<td>111</td>
<td>1600</td>
<td>177 777</td>
</tr>
<tr>
<td>Activated carbon</td>
<td>889</td>
<td>400</td>
<td>355 555</td>
</tr>
<tr>
<td>Ammonium</td>
<td>189</td>
<td>2323</td>
<td>438 969</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>972 302</td>
</tr>
</tbody>
</table>

17.1.2 Cost of landfilling residues from the incineration
The cost for landfilling the residue from incineration is displayed in Table 45. The amount of produced ash comes from the Combustion model. The amount of used lime and used activated carbon comes from Table 44. The landfilling cost estimation is made by Simon Jansson at Ragn Sells Miljökonsult.

Table 45 – Landfilling cost and amount (23)

<table>
<thead>
<tr>
<th>Landfill</th>
<th>Amount [tonnes]</th>
<th>[€/tonne]</th>
<th>[€/ year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash</td>
<td>61151</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>Used Activated carbon</td>
<td>400</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>Used Lime</td>
<td>1600</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>Total cost</td>
<td>63151</td>
<td></td>
<td>7 016 782</td>
</tr>
</tbody>
</table>

17.1.3 Worker salaries
The salaries for the employees working on the power plant are displayed in Table 46.

Table 46 – Employees and salaries (35) (36)

<table>
<thead>
<tr>
<th>Salaries</th>
<th>Amount</th>
<th>Wage/ employee Month [MDL]</th>
<th>Wages / Month [€]</th>
<th>Wages / Year [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workers</td>
<td>35</td>
<td>4994</td>
<td>10981</td>
<td></td>
</tr>
<tr>
<td>Directors</td>
<td>2</td>
<td>6744</td>
<td>847</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>11 828</td>
<td>141 938</td>
</tr>
</tbody>
</table>
17.1.4 Carbon dioxide tax
The carbon tax is estimated to be the same as in Sweden. The result is displayed in Table 47.

Table 47 – Carbon dioxide tax (32)

<table>
<thead>
<tr>
<th>CO2 Tax</th>
<th>tonnes/year</th>
<th>SEK/tonne</th>
<th>MDL/tonne</th>
<th>MDL/year</th>
<th>€/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil CO2</td>
<td>51 499</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO2 tax</td>
<td>315</td>
<td>565</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Tax</td>
<td></td>
<td></td>
<td></td>
<td>29 102 267</td>
<td>1 834 633</td>
</tr>
</tbody>
</table>

Comments
The Swedish condition is assumed because it is a likely assumption to get true if a carbon dioxide tax is establish.

17.1.5 Support fuel
In order to maintain a constant incineration support fuel is needed. The support fuel is natural gas and the total energy content of the gas is estimated to 3% of the total energy content in the waste.

Table 48 - Usage and cost of support fuel (37)

<table>
<thead>
<tr>
<th></th>
<th>Cost [MDL/1000 m³]</th>
<th>Cost [€/1000m³]</th>
<th>Amount [1000m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>5 537</td>
<td>357</td>
<td></td>
</tr>
<tr>
<td>Usage</td>
<td></td>
<td></td>
<td>3 272</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>1 170 000</td>
</tr>
</tbody>
</table>

17.2 Net present value NPV
The impact of the sensitivity scenarios on the NPV result is displayed in the tables below. The accumulated profit is the profit accumulated during the economic lifetime of 20 years. The scenario with zero accumulated profit corresponds to the scenario there the discount rate is the internal rate of return.

Table 49 – Accumulated profit without taxes, 10% higher cost

<table>
<thead>
<tr>
<th>10% higher costs</th>
<th>Without Taxes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accumulated profit</td>
<td></td>
</tr>
<tr>
<td>Interest rate [%]</td>
<td>Discount rate [%]</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>19.32</td>
</tr>
<tr>
<td>Accumulated profit</td>
<td></td>
</tr>
<tr>
<td>Interest rate [%]</td>
<td>Discount rate [%]</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>18.33</td>
</tr>
<tr>
<td>Interest rate [%]</td>
<td>Discount rate [%]</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>17.29</td>
</tr>
</tbody>
</table>

Table 50 - Accumulated profit without taxes, 10 % higher investment cost

<table>
<thead>
<tr>
<th>10 % higher investment</th>
<th>Without Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accumulated profit</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Interest rate [%]</strong></td>
<td><strong>Discount rate [%]</strong></td>
</tr>
<tr>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>16.96</td>
</tr>
<tr>
<td><strong>Accumulated profit</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Interest rate [%]</strong></td>
<td><strong>Discount rate [%]</strong></td>
</tr>
<tr>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>15.94</td>
</tr>
<tr>
<td><strong>Accumulated profit</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Interest rate [%]</strong></td>
<td><strong>Discount rate [%]</strong></td>
</tr>
<tr>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>14.83</td>
</tr>
</tbody>
</table>
Table 51 - Accumulated profit without taxes, 10 % less yearly profit

<table>
<thead>
<tr>
<th>10 % less yearly profit</th>
<th>Without Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accumulated profit</strong></td>
<td></td>
</tr>
<tr>
<td>Interest rate [%]</td>
<td>Discount rate [%]</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>15.96</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>10 % less yearly profit</th>
<th>Without Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accumulated profit</strong></td>
<td></td>
</tr>
<tr>
<td>Interest rate [%]</td>
<td>Discount rate [%]</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>14.90</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>10 % less yearly profit</th>
<th>Without Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accumulated profit</strong></td>
<td></td>
</tr>
<tr>
<td>Interest rate [%]</td>
<td>Discount rate [%]</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>13.76</td>
</tr>
</tbody>
</table>

Table 52 – Accumulated profit with taxes, 10 % higher cost

<table>
<thead>
<tr>
<th>10 % higher costs</th>
<th>With tax</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accumulated profit</strong></td>
<td></td>
</tr>
<tr>
<td>Interest rate [%]</td>
<td>Discount rate [%]</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>14.36</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>10 % higher costs</th>
<th>With tax</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accumulated profit</strong></td>
<td></td>
</tr>
<tr>
<td>Interest rate [%]</td>
<td>Discount rate [%]</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>13.28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>10 % higher costs</th>
<th>With tax</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accumulated profit</strong></td>
<td></td>
</tr>
<tr>
<td>Interest rate [%]</td>
<td>Discount rate [%]</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>12.06</td>
</tr>
</tbody>
</table>
### Table 53 – Accumulated profit with taxes, 10% higher investment cost

<table>
<thead>
<tr>
<th>Interest rate [%]</th>
<th>Discount rate [%]</th>
<th>M€</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>8</td>
<td>75.61</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>42.74</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>16.55</td>
</tr>
<tr>
<td>4</td>
<td>13.55</td>
<td>0.00</td>
</tr>
</tbody>
</table>

### Table 54 – Accumulated profit with taxes, 10% less yearly profit

<table>
<thead>
<tr>
<th>Interest rate [%]</th>
<th>Discount rate [%]</th>
<th>M€</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>8</td>
<td>50.24</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>22.77</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>0.91</td>
</tr>
<tr>
<td>4</td>
<td>12.09</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interest rate [%]</th>
<th>Discount rate [%]</th>
<th>M€</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>8</td>
<td>36.76</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>10.17</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>-10.90</td>
</tr>
<tr>
<td>6</td>
<td>10.91</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interest rate [%]</th>
<th>Discount rate [%]</th>
<th>M€</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>8</td>
<td>20.03</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>-5.28</td>
</tr>
<tr>
<td>8</td>
<td>12</td>
<td>-25.22</td>
</tr>
<tr>
<td>8</td>
<td>9.54</td>
<td>0.00</td>
</tr>
</tbody>
</table>
18 Appendix 6

Authors
Linus Karlsson (LK) & Tomas Linderholm Jönsson (TLJ)

Abstract
Sammanfattning
Acknowledgements
Abbreviations
Table of contents
1 Purpose
2 Goals
3 Limitations
4 Background
4.1 The Republic of Moldova
4.1.1 Climate
4.1.2 Energy situation Moldova
4.1.3 The municipality of Chisinau
4.2 The development of Waste to Energy technology in Sweden
4.3 EU Regulations - Incineration Directive 2000 76
4.3.1 Operating conditions
4.3.2 Emissions
5 Theory
5.1 Waste incineration
5.1.1 Furnaces
5.1.2 Moving grate
5.1.3 Fluidized bed
5.2 Flue gas cleaning
5.2.1 Particles filters
5.2.2 Cyclones
5.2.3 Electrostatic precipitator
5.2.4 Electro venturi filter
5.2.5 Fabric filters
5.2.6 Wet scrubbers
5.3 Flue gas treatment
5.3.1 Dry treatment
5.3.2 Semi-dry treatment
5.3.3 Wet treatment
5.3.4 NOx reduction, DeNOx
5.4 Steam production
5.4.1 Steam boiler
5.4.2 Steam cycle
5.4.3 Rankine cycle
5.5 Cooling tower
6 Method
6.1 Chemical Combustion
6.2 Flue Gas Composition
6.3 Steam cycle model in MATLAB
6.3.1 Optimization or finding the best profit with given test limitations
6.3.2 Cooling demand
6.3.3 Total energy production and profit
6.4 Investment calculations
6.4.1 Payback time
6.4.2 Net present value and internal rate of return
6.5 Environmental comparison
6.5.1 Waste to energy vs gas turbines & landfills
6.5.2 WTE emissions
6.5.3 Gas Turbine emissions
6.5.4 Landfill emissions
6.5.5 Comparison
7 Conditions for design
7.1.1 Operating time
7.1.2 Waste accumulation
7.1.3 Waste composition
7.1.4 Environmental regulations
7.1.5 Fitting the solution into the Chisinau energy system
7.1.6 Location & water supply
7.1.7 Cooling demand
7.1.8 Economy
7.1.9 Staff and maintenance
8 Design
8.1 Operation
8.2 Waste supply
8.3 District heating system
8.4 Incineration grate
8.5 Steam cycle components
8.5.1 Steam Boiler [SB]
8.5.2 Turbines T[HP] & T[LP] and Generator [G]
8.5.3 Cooling Tower [CT]
8.5.4 Flue gas treatment and particle separation
8.5.5 SNCR DeNOx
8.6 Location
8.7 Flue gas chimney height
9 Results
9.1 Waste composition
9.2 Elemental composition
9.3 Combustion – Heat Generation
9.4 Flue gases
9.4.1 Generated flue gas flow
9.4.2 Flue gas composition
9.4.3 Energy output
9.5 Steam cycle model in MATLAB
9.5.1 Most profitable steam cycle parameter combination
9.5.2 Production, heat and electricity
9.5.3 Duration chart
9.6 Investment calculations
9.6.1 Investment cost
9.6.2 Yearly cash flow
9.6.3 Payback time
9.6.4 Net present value, NPV
9.7 Environmental Comparison
10 Conclusions
11 Potential for this WTE solution in Chisinau
12 Discussion
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Author(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.1</td>
<td>Potential sources of uncertainty</td>
<td>LK &amp; TLJ</td>
</tr>
<tr>
<td>12.1.1</td>
<td>Waste composition, heat generation and flue gas</td>
<td>TU</td>
</tr>
<tr>
<td>12.1.2</td>
<td>Steam cycle model</td>
<td>LK</td>
</tr>
<tr>
<td>12.1.3</td>
<td>District heating</td>
<td>TU</td>
</tr>
<tr>
<td>12.1.4</td>
<td>Economy</td>
<td>LK</td>
</tr>
<tr>
<td>12.1.5</td>
<td>Environmental Comparison</td>
<td>TU</td>
</tr>
<tr>
<td>12.2</td>
<td>Further studies</td>
<td>LK &amp; TLJ</td>
</tr>
<tr>
<td>13</td>
<td>References</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Appendix I – Waste composition simulation software</td>
<td>TLJ</td>
</tr>
<tr>
<td>15</td>
<td>Appendix II - Heat generation &amp; Flue gas composition</td>
<td>TLJ</td>
</tr>
<tr>
<td>15.1</td>
<td>Determining the elemental composition of the fuel</td>
<td></td>
</tr>
<tr>
<td>15.2</td>
<td>Calculating the necessary combustion air supply</td>
<td></td>
</tr>
<tr>
<td>15.3</td>
<td>Using fuel and air data to calculate heat generation</td>
<td></td>
</tr>
<tr>
<td>15.4</td>
<td>Determining the flue gas composition</td>
<td>TLJ</td>
</tr>
<tr>
<td>15.4.1</td>
<td>Air surplus, lò</td>
<td></td>
</tr>
<tr>
<td>15.4.2</td>
<td>Theoretical flue gas flow, gt</td>
<td></td>
</tr>
<tr>
<td>15.4.3</td>
<td>Real flue gas flow, gv</td>
<td></td>
</tr>
<tr>
<td>15.5</td>
<td>Flue gas flow summary</td>
<td></td>
</tr>
<tr>
<td>15.6</td>
<td>Flue gas heat capacity</td>
<td></td>
</tr>
<tr>
<td>15.7</td>
<td>Heat exchange and losses</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Appendix III - Environmental Comparison</td>
<td>TLJ</td>
</tr>
<tr>
<td>16.1</td>
<td>Landfill emissions</td>
<td></td>
</tr>
<tr>
<td>16.2</td>
<td>Gas turbine emissions</td>
<td></td>
</tr>
<tr>
<td>16.3</td>
<td>WTE Emissions</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Appendix IV- Method MATLAB model</td>
<td>LK</td>
</tr>
<tr>
<td>17.1</td>
<td>Main theory behind the MATLAB model</td>
<td></td>
</tr>
<tr>
<td>17.1.1</td>
<td>Pre heating of combustion air</td>
<td></td>
</tr>
<tr>
<td>17.1.2</td>
<td>Finding the best characteristics and corresponding profit</td>
<td></td>
</tr>
<tr>
<td>17.1.3</td>
<td>Isentropic efficiency</td>
<td></td>
</tr>
<tr>
<td>17.1.4</td>
<td>Feed water tank</td>
<td></td>
</tr>
<tr>
<td>17.1.5</td>
<td>Two stage DH heat exchanger</td>
<td></td>
</tr>
<tr>
<td>17.1.6</td>
<td>Condensate tank</td>
<td></td>
</tr>
<tr>
<td>17.1.7</td>
<td>Pre heating of feed water</td>
<td></td>
</tr>
<tr>
<td>17.1.8</td>
<td>Energy and mass balance or conservation</td>
<td></td>
</tr>
<tr>
<td>17.1.9</td>
<td>Energy outtake</td>
<td></td>
</tr>
<tr>
<td>17.1.10</td>
<td>Complete MATLAB code</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Appendix V – Results MATLAB-model</td>
<td>LK</td>
</tr>
<tr>
<td>18.1</td>
<td>Node characteristic</td>
<td></td>
</tr>
<tr>
<td>18.2</td>
<td>Monthly production result</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Appendix VI – Results Investment calculations</td>
<td>LK</td>
</tr>
<tr>
<td>19.1</td>
<td>Cash flow calculations</td>
<td></td>
</tr>
<tr>
<td>19.1.1</td>
<td>Chemical usage</td>
<td></td>
</tr>
<tr>
<td>19.1.2</td>
<td>Cost of landfilling residues from the incineration</td>
<td></td>
</tr>
<tr>
<td>19.1.3</td>
<td>Worker salaries</td>
<td></td>
</tr>
<tr>
<td>19.1.4</td>
<td>Carbon dioxide tax</td>
<td></td>
</tr>
<tr>
<td>19.1.5</td>
<td>Support fuel</td>
<td></td>
</tr>
<tr>
<td>19.2</td>
<td>Net present value NPV</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Appendix 6 Authors</td>
<td></td>
</tr>
</tbody>
</table>
1 MATLAB model code

1.1 Main program

clear
clc

% Kylning kyltornet, test= samplingsfrekvensen för flödet
TillKylning(1,12)=0;
test=0.00001; %0.001 ;%0.0001; %kan ökas för en snabbare men ej noga
körning för kyltorns-inställning
testar=10;

%Data för året
Sekunder = [744,672,744,720,744,720,0,728,720,744,720,744]*3600;
DriftTimmar = [744,672,744,720,744,720,0,728,720,744,720,744]; %tot 8000
DriftTimmar . inga DriftTimmar i Juli och 16timmar mindre i Augusti
Timmar = [744,672,744,720,744,720,744,720,744,720,744,720,744];
%Drifttid
DriftTid = 8000 ; %Drifttid 8000 timmar per år

% Försäljningspris % http://anre.md/rate/index.php?vers=1&sm=159 .CET 2

elkWhPriceBani = 158.63;
heatGcalPriceLei = 587.87;

eLMWhPriceLei =elkWhPriceBani*1000/100 ;
heatMWhPriceLei =heatGcalPriceLei*1.1622  ;

ekJJs = elkJs/(60*60*1000);
heatkJJs = heatkJJs/heatMWhPriceLei/(60*60*1000);
% elkMWhPriceLei = 1292.9;
% heatMWhPriceLei = 429;

%Intern elanvändning inklusive pumpar
IntEl=0.93; % Intern elanvändning

%Önskad fjärrvärme MWh , kJs
ForlöstInatet=0.79; % Förlusten i nuvarande fjärrvärmenät
DHperMonthMWh =([450441.1423,388785.4727,312044.9177,91520.73433,54998.65767,33481.607,22851.787,26450.109,39949.43767,100780.1527,243589.9623,410544.4273]; %MWh
DHperMonthkJJs =([450441.1423,388785.4727,312044.9177,91520.73433,54998.65767,33481.607,22851.787,26450.109,39949.43767,100780.1527,243589.9623,410544.4273]*1000*3600 ; %kJJs

%KlimatData
MedelTemp =[-3.2 , -1.7 , 2.8, 10.3, 16.1, 19.4, 20.9, 20.5, 16.2, 10.2, 4.4, -0.3]; %http://www.climate-charts.com/Locations/m/MD33815.php
FuktRelativ = [ 86,82,71,63,62,61,58,57,61,73,84,87]/100; % i procent
http://www.climatetemp.info/romania/
FuktAbsolutTotkgm3 = [3.76, 4.24, 5.87, 9.59, 13.71, 16.69, 18.21, 17.79, 13.80, 9.53, 6.54, 4.74]/1000; %kg/m³

Luftdenskgm3 = 1.25; %kg/m³ Uppskattad till samma hela året annars,

FuktAbsolutkgm3=FuktRelativ.*FuktAbsolutTotkgm3;

Angkvot = FuktAbsolutkgm3./Luftdenskgm3;

cpluft = 1.0; %kj/kg K
r0=2500; %kj/kg
cpanga =1.86 ;%kj/kgK
Luftdens = 1.25 ;%kg/m³

% %Bränsledata
bransle=13.88888889; %[kg/s] 50ton/h

%Energin som finns Boiler power från ånguttagsberäkningar
BoilerPower = 118.81*1000; %kW

% Luftdata och Rökgasdata
Luftmangd = 6.13; %kg luft/kg bränsle 9.26;%n=1,55.
6.88; % Från emisionsjämförelse.xls
RokGasmangd = 6.887; % kg rökgas /kg bränsle 9.89;%
%kg/kg
Diff =RokGasmangd-Luftmangd;

LuftFlode =Luftmangd*bransle; %kg
TotRokgas = RokGasmangd*bransle ; % kg

%Rökgas-temperaturen i Grader Celsius
RokgasTempInnanPanna = 850 ; %Rökgastemperatur innan ångpanna. 850
sämsta möjliga fallet
RokgasTempEfterRening = 130 ; %Rökgastemperatur efter rening
RokgasTempFinal = 70 ; %Rökgastemperatur innan skorsten

%Rökgas-entalpier kJ/kg
%Beräkna i Fluegascomposition.xls
RokGasEntalpiInnanPanna = 1020.431;
RokGasEntalpiEfterRening = 138.265 ;
RokGasEntalpiFinal = 74.45 ;
DeltaRokGasEntalpi = RokGasEntalpiEfterRening-RokGasEntalpiFinal; % Det som
kan återvinnas för luftförvärming

%RokGasDens = ; %För Skorstensberäkningar
%Energin som kan återvinnas ut ut rökgaserna innan de släpps ut
%RokGasEnergiTillVarmning = TotRokgas*DeltaRokGasEntalpi ; % ((kj/kg)*kg)
=kJ

% Temperatur på primär och sekundärluft
Luftvarme1 = 115 ;%60% om samma som i BE temp på luft som sprutas in
Luftvarme2 = 50 ; % 40%
Luftvarme3 = 850;

%Beräknar data för luften och kostnaden för att värma upp den
for i=1:12  %tolv månader
hluft(1,i)=
  (cpluft*MedelTemp(1,i))+(Angkvot(1,i)*(r0+(cpanga*MedelTemp(1,i))));

hluftOnsk1(1,i)=
  (cpluft*Luftvarme1)+Angkvot(1,i)*(r0+(cpanga*Luftvarme1));

hluftOnsk2(1,i)=
  (cpluft*Luftvarme2)+Angkvot(1,i)*(r0+(cpanga*Luftvarme2));

hluftOnsk3(1,i)=
  (cpluft*Luftvarme3)+Angkvot(1,i)*(r0+(cpanga*Luftvarme3));

Luftvarmeforlost(1,i) = (0.6*LuftFlode*(hluftOnsk1(1,i)-
  hluft(1,i)))+(0.4*LuftFlode*(hluftOnsk2(1,i)-hluft(1,i)));

%kvarvarande energi coh Effekt efter luftförvärmingen
EnergiAngakW(1,i) = BoilerPower -Luftvarmeforlost(1,i); % kW EffektAnga
EnergiAnga(1,i)=EnergiAngakW(1,i)/1000; %MW EffektAnga

end

%----------------------------------------------------------------
% Beräknar fram den bästa verkningsgraden/förhållandet mellan El och värme
% Månads looparna returnerar två stycken effekter som anläggningen
% levererar.

LoopVinterFinal % Vintermånadernas data. Vintermånad= månad som har
        % högre effektbehov än vad som kan levereras från WTE

LoopMajFinal  %Kör Maj
LoopJuniFinal %Kör Juni
%LoopJulifinal  %Juli är revisionsmånad , Ingen energi levereras
LoopAugFinal  %Kör Aug
LoopSepFinal  %Kör Sep

%----------------------------------------------------------------
%Beräknar vad el och värme har sålts för varje månad i Moldaviska Lei

Fortjanst(1,:) = EnergiFV*heatMWhPriceLei ; %Fortjänst från Försäljning av
värme
Fortjanst(2,:) = EnergiEl*elMWhPriceLei*IntEl;%Fortjänst från Försäljning
av el. 7% intern använd el
Fortjanst(3,:) = Fortjanst(1,:) + Fortjanst(2,:); % Total Fortjänst

EffektFV = EnergiFV./DriftTimmar; % värme-effekt
EffektEl = EnergiEl./DriftTimmar; % el-effekt

EffektDHperMonthMW=DHperMonthMWh./Timmar; %effekt i nätet
EffektDHperMonthMWmedForlust =EffektDHperMonthMW/ForlostInatet;
EffektFVenLinje=EffektFV/2;
month=(1:12);

% sparar resultat i TOTALEN skriver sedan ut den som en xls-fil
TOTALEN(1,:)=month;
TOTALEN(2,:)=EnergiFV; % levererad värme MWh
TOTALEN(3,:)=EnergiEl; % levererad el MWh
TOTALEN(4,:)=DHperMonthMWh; % energibehov i nätet
TOTALEN(5,:)=Fortjanst(3,:); % Förtjänst från försäljning

TOTALEN(7,:)=Fortjanst(1,:); %heat
TOTALEN(8,:)=Fortjanst(2,:); %el
TOTALEN(9,:)=EffektFV; % värme-effekt
TOTALEN(10,:)=EffektEl; % el-effekt
TOTALEN(11,:)=EffektDHperMonthMW; %effekt i nätet

TOTALEN(13,:)=EffektDHperMonthMWmedForlust; %EffektDHperMonthMWmedForlust

xlswrite('SlutgiltigtResultat.XLS', TOTALEN)

% skriver ut varje nods/components data för varje månad
xlswrite('NodData', Components)

%efficiencies
Efficiencies(1,:) = Elverknm(1,:);
Efficiencies(2,:) = Heatverknm(1,:);
xlswrite('Efficiencies.XLS', Efficiencies)
The program optimizes the steam cycle to get the most profit from the sale of electricity and district heating (DH).

The program varies four parameters:

- The mass flow to the cooling tower in case of a summer month
- The pressure drop after the high pressure turbine, node 3,
- The mass flow to the “district heating grid heaters”, node 6 and 11,
- The pressure in node 5 and the following characteristics for that point.

Beräknar fram den bästa verkningsgraden/förhållandet mellan El och värme räknar ut verkningsgraden el, värme. gånger med energin och respektive försäljningspris

```matlab
clc

% test matrisen som byggs upp
n=testar+1;
nn=n*n;
nnn=nn*n;
nnnn=nnn*n;
B=nnn+1;

% varierar trycket i som högturbinaren går ner till
pmin =6.18479;
pmax =6.1848;  % 6.1848; %maximalt värde 40

% Varierar olika massflöden till Fjärrvärmeverväxlararna värmeväxlarerna 44.2
minm = 0.47;
maxm =0.48;

%Varierar trycken som avlänkningen 5 använder
p5max=pmin;
p5min=1.0172 ; % samma som p(1,6);

a=31;  % antal noder/punkter i steam cycle

%p skapar testmatrisen
p=zeros(B,a);  %tryck
T=zeros(B,a);  %Temperatur
m=zeros(B,a);  %Massflöde
h=zeros(B,a);  %Entalpi
ss=0.003;  %Litet värde som används för att komma ovanför eller under saturations-punkten

%Beskriver initialvärdena
m(1:B,1)=1;
m(1:B,19) = m(1:B,1);
m(1:B,18) = m(1:B,1);

T(1:B,19) = 250;
p(1:B,19) = 40;

p(1:B,20) = 2.5; T(1:B,20)= 70;
p(1:B,21) = 11.33; T(1:B,21) = T(1:B,20);
p(1:B,22) =p(1:B,21); T(1:B,22) = 100 ;
```
\[ p(1:B,23) = p(1:B,21); T(1:B,23) = 130; \]
\[ p(1:B,1) = 40; T(1:B,1) = 400; \]
\[ T(1:B,12) = T(1:B,22); \]
\[ T(1:B,13) = T(1:B,13); \]
\[ T(1:B,4) = 400; \]
\[ T(1:B,6) = 130; \]
\[ T(1:B,7) = 100; \]

% Måste loopa värden som räknas ut med xsteam

\begin{verbatim}
for b=1:B
    % går över värdet för att bibehålla ånga och att ej xsteam kan beräkna
    % värden som ligger på saturations-kurvan
    p(b,6) = xsteam('psat_T',T(b,12))+ss;
    p(b,7) = 0.5; xsteam('psat_T',T(b,7))+ss;

    p(b,12) = xsteam('psat_T', T(1,12))+ss;
    p(b,13) = xsteam('psat_T', T(1,13))+ss;
end
\end{verbatim}

% de beräknade värdena fortplantar sig i "steam cycle"
\[ p(1:B,9) = p(1:B,6); \]
\[ p(1:B,10) = p(1:B,9); \]
\[ p(1:B,9) = p(1:B,6); \]
\[ p(1:B,11) = p(1:B,6); \]
\[ p(1:B,15) = p(1:B,12); \]
\[ p(1:B,14) = p(1:B,12); \]
\[ p(1:B,18) = p(1:B,19); \]

% Räknar ut de h som kan beräknas med initialvärdena
\begin{verbatim}
for i = 1:a
    for b=1:B
        h(b,i)=XSteam('h_pt',p(b,i),T(b,i));
    end
end
\end{verbatim}

% indexvärden
i=1; % Beräkningsindex
k=1; % Beräkningsindex
o=1; % Beräkningsindex

% minska värdet för pmin i nod 3 beräknas enligt följande
\[ s_{max} = xsteam('s_{pt}',p(1,7),T(1,7)); \]
\[ p_{min} = xsteam('p_{sT}',s_{max},T(1,4)); \]
sl=xsteam('s_pt',p(1,1),T(1,1));  %entropi för första noden

for j = pmin:(pmax-pmin)/testar:pmax %varierar trycket , går ner isentropiskt
    p(i,3) = j;
p(i,4) = p(i,3);
T(i,3) =xsteam('T_ps',j,sl);
his(i,3) =xsteam('h_pt',j,T(i,3));
    %beräknar det nya h med en isentropisk verkningsgrad på 0.8. 
    h(i,3) = -(0.8*(h(i,1)-his(i,3))-h(i,1));
T(i,3) = xsteam('T_ph',p(i,3),h(i,3));% ansätter det nya värdet för nod 3.

    % Ger testmatrisen sina värden , skapar talföjder för vad dessa % premisser gäller. Samma värde var nn´te
    p(i:(i+nn),3) = p(i,3);
p(i:(i+nn),4) = p(i,3);
T(i:(i+nn),3) = T(i,3);
T(i:(i+nn),3) = T(i,3);
h(i:(i+nn),3) = h(i,3);
h(i:(i+nn),4) = xsteam('h_pt',p(i,4),T(i,4));
s(i:(i+nn),4) = xsteam('s_pt', p(i,4),T(i,4));

    his(i:(i+nn),7) = xsteam('h_ps', p(i,7),s(i,4)); % det isentropiska h
    nisLT(i:(i+nn),7) = (h(i,4)-his(i,7))/(h(i,4)-his(i,7)); % Den isentropiska verkningsgraden räknas ut, används sedan för all avlänkningar ur LågTryckaren

    his(i:(i+nn),6) = xsteam('h_ps', p(i,6),s(i,4));
h(i:(i+nn),6)= -(nisLT(i,7)*h(i,4)-his(i,6))-h(i,4));
T(i:(i+nn),6) = xsteam('T_ph',p(i,6),h(i,6));
T(i:(i+nn),11) = T(i,6);
h(i:(i+nn),11) = h(i,6);

    % Skillnad mellan 12 och 13---> skillnaden mellan m11 m7
    % Skillnaden mellan att värma upp Fjärrvärmevattnet i de två % värmeväxlarna
    h1112=h(i,11)-h(i,12);
h713=h(i,7)-h(i,13);
till14faktor(i:(i+nn),1)=h713/h1112;

T(i:(i+nn),9) = T(i,6);

h(i:(i+nn),9) = xsteam('h_pt',p(i,9),T(i,9));

i=i+nn;

for f =minn:(maxm-minm)/testar:maxm
    m(k:(k+n),7) =f*m(1,1);
m(k:(k+n),11) =m(k,7)*till14faktor(k,1);
m(k:(k+n),12)=m(k:(k+n),11);

\( m(k:(k+n),13) = m(k:(k+n),7); \)
\( m(k:(k+n),15) = m(k:(k+n),13); \)

%Det som blir över för noderna 5 och 9 som är de två 
%förvärmningstegen
\( m95(k:(k+n),1) = m(1,1) - (m(k,11) + m(k,7)); \)

\( k = k + n; \)

%varierar trycket för avlänkningen 5. trycket på femman bestämmer 
%skillnaden mellan flödena i 5 och 9

\textbf{for} P= p5min:(p5max-p5min)/testar:p5max \%

\( p(o,5) = P; \)
\( p(o,17) = 7.8; \quad \% \quad 7.8; \quad \% \text{MAVATANK} \)
\( p(o,16) = p(o,17); \)

\( \text{his}(o,5) = \text{xsteam('h_ps', p(o,5), s(o,4));} \)
\( h(o,5) = -(\text{nisLT}(o,7)*(h(o,4)-\text{his}(o,5))-h(o,4)); \)
\( T(o,5) = \text{xsteam('T_ph', p(o,5), h(o,5));} \)

\% De två förvärmningstergen ska bidra med lika mycket energi 
% vardera vilket medför att för ett givet tryck i nod 5 kan 
% massflödet bestämmas för denna med hjälp av egenskaperna för 
% nod 9. 
% Ett högre tryck medför ett högre energiinnehåll som leder 
% till ett större massflöde

%energin i femman ska vara två gånger mer än energin i nian
\( m(o,5) = 4*(m95(o,1)*h(o,9))/(h(o,5)+4*h(o,9)); \)
\( \%m(o,5) = (m95(o,1)*h(o,9))/(h(o,5)+h(o,9)); \)
\( \%m(o,5) = (m95(o,1)*h(o,9))/(h(o,5)+h(o,9)); \)
\( m(o,9) = m95(o,1)-m(o,5); \)

\( m(o,6) = m(o,11)+m(o,9); \)
\( m(o,10)= m(o,9); \)
\( m(o,14) = m(o,12)+m(o,15)+m(o,10); \quad \%\text{Flödet till kondenstanken} \)
\( m(o,16) = m(o,14); \)
\( m(o,28) = m(o,16); \)
\( m(o,29) = m(o,28); \)
\( m(o,24) = m(o,29); \)

\( m(o,30) = m(o,5); \)

\( m(o,31) = m(o,30); \)
\( m(o,17) = m(o,24)+m(o,31); \)
% Kondenstanken
h(0,14) = (h(0,12)*m(0,12)+h(0,15)*m(0,15))/(m(0,12)+m(0,15));
h(0,10) = h(0,14);
T(0,14) = xsteam('T_ph',p(0,14),h(0,14));
T(0,10) = T(0,14);
T(0,16) = T(0,14);

h(0,16) = xsteam('h_pt',p(0,16),T(0,16));

% energikonservation och mass-konservation leder till att node 28 kan beräknas med
% hjälp av att det som kommer in ska vara med det som åker ut
h(0,28) = (h(0,9)*m(0,9)-h(0,10)*m(0,10)+h(0,16)*m(0,16))/m(0,28);
p(0,28)=p(0,16);
p(0,29)=p(0,28);
T(0,28) = xsteam('T_ph',p(0,28),h(0,28));
T(0,29) = T(0,28);
h(0,29) = h(0,28);
p(0,29) = p(0,29);
p(0,24) = p(0,29);

% energikonservation och mass-konservation leder till att node 30 kan beräknas med
% hjälp av att det som kommer in ska vara med det som åker ut
det som vi har kört med hela tiden
h(0,30) = (m(0,5)*h(0,5)+m(0,29)*h(0,29))/(m(0,5)+m(0,24)); % blir blandad ånga 13% inte bra måste ha högre tryck

h(0,30)=(h(0,29)*m(0,29)+h(0,5)*m(0,5) -
h(0,24)*m(0,24))/m(0,5);

h(0,24) = h(0,30);
p(0,30) = p(0,5);
T(0,30) = xsteam('T_ph',p(0,30),h(0,30));
T(0,24) = xsteam('T_ph',p(0,24),h(0,24));
T(0,31) = T(0,30);
p(0,31) = p(0,17);
m(0,31) = m(0,30);
h(0,31) = xsteam('h_pt',p(0,31),T(0,31));

%pump3031(o,1) = xsteam('h_pT',p(0,31),T(0,31))-xsteam('h_pT',p(0,30),T(0,30));
%h(0,31) = (m(0,30)*h(0,30)-pump3031)/m(0,31);
%h(0,31) =

% energikonservation och mass-konservation leder till att node 17 kan beräknas med
% hjälp av att det som kommer in ska vara med det som åker ut
h(o,17) = (m(o,31)*h(o,31)+m(o,24)*h(o,24))/(m(o,30)+m(o,24));

T(o,17) = xsteam('T_ph',p(o,17),h(o,17));

p(o,29) = p(o,24);

T(o,18) = T(o,17);
h(o,18) = xsteam('h_pt',p(o,18),T(o,18));

% Beroende var 5an avlankas kommer flödena bli olika
if p(o,3) < p(o,5)
    m(o,3) = m(o,1)-m(o,5);
else
    m(o,3) = m(o,1);
end

m(o,4) = m(o,3);

%kontroll att det ej är ånga där det ej får/ska vara det
% ejsteam = [12,13,15,10,16,28,29,30,31,17,18,24,14,26,27 ];
% steam = [1,3,4,5,6,7,9];
% for es=ejsteam
%    steamFrac(o,es) = xsteam('vx_ph',p(o,es),h(o,es));
% end
% for js =steam
%    steamFrac(o,js) = xsteam('vx_ph',p(o,js),h(o,js));
% end
% for es = ejsteam
%    if steamFrac(o,ejsteam) >0
%       m(o,es)=0 ;
%    end
% end
% for js =steam
%    if steamFrac(o,js) < 1
%       m(o,js)=0 ;
%    end
% end

steamFrac(o,30) = xsteam('vx_ph',p(o,30),h(o,30));
steamFrac(o,28) = xsteam('vx_ph',p(o,28),h(o,28));
steamFrac(o,17) = xsteam('vx_ph',p(o,17),h(o,17));
%pumpar
pumpar(o,1) = (h(o,16)-h(o,14))+(h(o,31)-h(o,30))+(h(o,18)-h(o,17))+(h(o,15)-h(o,13))+(h(o,21)-h(o,20));
\[
\text{input}(o,1) = (h(o,1) - h(o,18)) + (h(o,4) - h(o,3)) + \text{pumpar}(o,1);
\]

\[
\text{verkn}(o,5) = \frac{(h(o,4) - h(o,5) + h(o,1) - h(o,3))}{\text{input}(o,1)}; \quad \% \text{ el ur 5}
\]

\[
\text{verkn}(o,6) = \frac{(h(o,4) - h(o,6) + h(o,1) - h(o,3))}{\text{input}(o,1)}; \quad \% \text{ el ur 6}
\]

\[
\text{verkn}(o,7) = \frac{(h(o,4) - h(o,7) + h(o,1) - h(o,3))}{\text{input}(o,1)}; \quad \% \text{ el ur 7}
\]

\[
\text{verkn}(o,12) = \frac{(h(o,11) - h(o,12))}{\text{input}(o,1)};
\]

\[
\text{verkn}(o,13) = \frac{(h(o,7) - h(o,13))}{\text{input}(o,1)};
\]

% tar bort orimliga verkningsgrader om sådana produceras samt %att fall med felaktiga ångförhållanden tas bort

\[
\text{for } r=1:13 \quad \text{if } \text{verkn}(o,r) < 0 \quad \text{|| } \text{verkn}(o,r) > 1 \quad \text{verkn}(o,r) = 0;
\]

\[
\text{elseif } \text{steamFrac}(o,30) > 0 \quad \text{verkn}(o,r) = 0;
\]

\[
\text{elseif } \text{steamFrac}(o,28) > 0 \quad \text{verkn}(o,r) = 0;
\]

\[
\text{end}
\]

\[
\text{elseif } \text{steamFrac}(o,17) > 0 \quad \text{verkn}(o,r) = 0;
\]

\[
\text{end}
\]

% Energi-fraktion av det totala flödet. el

\[
\text{verkn}(o,5) = \text{verkn}(o,5) \ast \text{m}(o,5);
\]

\[
\text{verkn}(o,6) = \text{verkn}(o,6) \ast \text{m}(o,6);
\]

\[
\text{verkn}(o,7) = \text{verkn}(o,7) \ast \text{m}(o,7);
\]

% Energi-fraktion av det totala flödet. värme/termisk

\[
\text{verkn}(o,12) = \text{verkn}(o,12) \ast \text{m}(o,12);
\]

\[
\text{verkn}(o,13) = \text{verkn}(o,13) \ast \text{m}(o,13);
\]

\[
\text{totverkn}(o,1) = \frac{(\text{verkn}(o,5) + \text{verkn}(o,6) + \text{verkn}(o,7))}{\text{m}(o,1)};
\]

% Elektrisk verkningsgrad

\[
\text{totverkn}(o,2) = \frac{(\text{verkn}(o,12) + \text{verkn}(o,13))}{\text{m}(o,1)};
\]

% Värme verkningsgrad

% total försäljningsintäkt

\[
\text{totverkn}(o,3) = \{\text{elMWhPriceLei} \ast \text{totverkn}(o,1) + \text{heatMWhPriceLei} \ast \text{totverkn}(o,2)\};
\]

\[
\text{totverkn}(o,3) = \{\text{elkJs} \ast \text{totverkn}(o,1) + \text{heatkJJs} \ast \text{totverkn}(o,2)\}; \quad \% \text{total}
\]

försäljningsintäkt
o=o+1;
end
end

delan in flow

Y=(1:a);
RESULTATvinter(1,:)=Y;

totverknm(1,a) = 0;
max(totverknm(:,3));
[qV,z]=find(totverknm==max(totverknm(:,3)));  \% tar ut det bästa resultatet
och sparar det som qV
% %disp('p')
% RESULTATvinter(2,:)=p(qV,:);
% disp('T')
% RESULTATvinter(3,:)=T(qV,:);
% disp('m')
% RESULTATvinter(4,:)=m(qV,:);
% disp('h')
% RESULTATvinter(5,:)=h(qV,:);
% RESULTATvinter(6,:)= totverknm(qV,:);
% disp('Profit')
% RESULTATvinter(7,:)= qV;
%xlswrite('RESULTATtors.xls', RESULTAT)
BastaElVinter =totverknm(qV,1);
BastaVarmeVinter =totverknm(qV,2);

vinter =[1,2,3,4,10,11,12];  \%Vintermånaderna
%a =(1:12);
for i = vinter
  EnergiFV(1,i) = EnergiAnga(1,i)*BastaVarmeVinter*DriftTimmar(1,i);  \%MW*DriftTimmar = energin på en månad i Mwh
  EnergiEl(1,i) = EnergiAnga(1,i)*BastaElVinter*DriftTimmar(1,i) ;  \%MW*DriftTimmar = energin på en månad i Mwh
  Elverknm(1,i) = BastaElVinter;
  Heatverknm(1,i) = BastaVarmeVinter;
end

totverknm(qV,3);
p(qV,17);

%Måste loopa s värden som räknas ut med xsteam
for i=1:a
  sV(i,1) = xsteam('s_pT',p(qV,i),T(qV,i));
end

Components(:,1)=T(qV,:);
Components(:,2)=p(qV,:);
Components(:,3)=h(qV,:);
Components(:,4)=m(qV,:);
Components(:,5)=sV(:,1);
1.1.3 May

clc
%The program optimizes the steam cycle to get the most profit
%from the sale of electricity and district heating (DH).
%The program varies four parameters
%• The mass flow to the cooling tower in case of a summer month
%• The pressure drop after the high pressure turbine, point 3,
%• The mass flow to the “district heating grid heaters”, point 6 and 11,
%• The pressure in point 5 and the following characteristics for that
%point.
%Beräknar fram den bästa verkningsgraden/förhållandet mellan El och värme

n=11;
nn=n*n;
nnn=nn*n;
nnnn=nnn*n;
a=31; % antal noder/punkter i ångcykeln
B=nnn+1;

%Skapar arayer för punkterna
p=zeros(B,a); %Tryck, bar
T=zeros(B,a); %Temperatur, C
m=zeros(B,a); %massflöde. Maximala flödet =1. Andel av det maximala
massflödet
h=zeros(B,a); % entalpi
ss=0.003; % för att komma bort från instablia områden för programmet
Xsteam kring mättnadskurvan

DHperMonthMWh
=[450441.1423,388785.4727,312044.9177,91520.7343,3,54998.65767,33481.607,228
51.787,26450.109,39949.43767,100780.1527,243589.9623,410544.4273];
test=0.00001;
EnergiFV(1,5)=0;
% Kyltronsslingan
TillKylning(1,5) = 0.0658; %startvärde

while DHperMonthMWh(1,5) > EnergiFV(1,5)
    TillKylning(1,5) = TillKylning(1,5)-test; %miskar från startvärde
% varierar trycket i som högturbinaren går ner till

% minsa värdet för pmin i nod 3 beräknas enligt följande
%pmax= xsteam('s_pt',p(1,7),T(1,7));
%pmin = xsteam('p_sT',smax,T(1,4)); %denna funktion finns ej men tagit
ur

    pmin = 6.18479;
    pmax = 6.1848; % 6.1848; %maximalt värde 40
% Varierar olika massflöden till Fjärrvärmeväxlarna värmeväxlarna 44.2
minm = (1-TillKylning(1,5))/2-0.06;
maxm = (1-TillKylning(1,5))/2-0.04;
%Varierar trycken som avlännkningen 5 använder

p5max=pmin;
p5min=1.0172 ; % samma som p(1,6);

%Kyltorn
p(1:B,25) = xsteam('psat_t',50)-ss;
m(1:B,25) = TillKylning(1,5);

T(1:B,26) = (xsteam('Tsat_p',p(1,25)))-2;
p(1:B,26) = p(:,25);
m(1:B,26) = m(:,25);
T(1:B,27) = T(1:B,26);
m(1:B,27) = m(:,26);

%deklerering av initialvärden
m(1:B,1)=1;
p(1:B,1) = 40 ;
T(1:B,1) = 400 ;
T(1:B,4) = 400;
T(1:B,6) = 130;
T(1:B,7) = 100;
m(1:B,19) = m(1:B,1);
m(1:B,18) = m(1:B,1);
T(1:B,19) = 250;
p(1:B,19) = 40;
p(1:B,20) = 2.5;
T(1:B,20) = 70;
p(1:B,21) = 11.33;
T(1:B,21) = T(1:B,20);
p(1:B,22) = p(1:B,21);
T(1:B,22) = 100 ;
p(1:B,23) = p(1:B,21);
T(1:B,23) = 130;

T(1:B,12) = T(1:B,22);
T(1:B,13) = T(1:B,21);
T(1:B,15) = T(1:B,13);

%Måste loopa värden som räknas ut med xsteam
for b=1:B
%går över värdet för att bibehålla ånga och att ej xsteam kan
beräkna
%värden som ligger på saturations-kurvan
p(b,6) = xsteam('psat_T',T(b,12))+ss;
p(b,7) = 0.5; %xsteam('psat_T',T(b,7))+ss;
p(b,12) = xsteam('psat_T', T(1,12))+ss;
p(b,13) = xsteam('psat_T', T(1,13))+ss;
end

%de beräknade värdena fortplantar sig i "steam cycle"
p(1:B,9) = p(1:B,6);
p(1:B,10) = p(1:B,9);
p(1:B,9) = p(1:B,6);
p(1:B,11) = p(1:B,6);
p(1:B,15) = p(1:B,12);
p(1:B,14) = p(1:B,12);
p(1:B,27) = p(1:B,12);
p(1:B,18) = p(1:B,19);

% Räknar ut de h som är bestämda från början
for i = 1:a
    for b=1:B
        h(b,i)=XSteam('h_pt',p(b,i),T(b,i));
    end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%xsteam('p_st',smax,T(1,4));
smax= xsteam('s_pt',p(1,7),T(1,7));
%variera trean skapar 100 likadana för att variera 10 m å tio mava.

i=1; %Beräkningsindex
k=1; %Beräkningsindex
o=1; %Beräkningsindex
s40400=xsteam('s_pt',40,400); %entropi för första noden

for j = pmin:(pmax-pmin)/10:pmax %varierar trycket , går ner isentropiskt
    p(i,3) = j;
p(i,4) = p(i,3);
    T(i,3) =xsteam('T_ps',j,s40400);
    his(i,3) =xsteam('h_pt',j,T(i,3)); % Isentropiskt h för punkt tre

    h(i,3) = -(0.8*(h(i,1)-his(i,3))-h(i,1)); %beräknas med hjälp av den antagna isentropiska verkningsgraden på 0,8.
    T(i,3) = xsteam('T_ph',p(i,3),h(i,3));

    % Ger testmatrisen sina värden , skapar talföjder för vad dessa % premisser gäller. Samma värde var nn´te
    p(i:(i+nn),3) = p(i,3);
p(i:(i+nn),4) = p(i,3);
    T(i:(i+nn),3) = T(i,3);
\begin{verbatim}
T(i:(i+nn),3) = T(i,3); 
h(i:(i+nn),3) = h(i,3); 
h(i:(i+nn),4) = xsteam('h_pt', p(i,4), T(i,4)); 
s(i:(i+nn),4) = xsteam('s_pt', p(i,4), T(i,4)); 

his(i:(i+nn),7) = xsteam('h_ps', p(i,7), s(i,4)); \% det isentropiska h för 7an 
nisLT(i:(i+nn),7) = (h(i,4)-h(i,7))/(h(i,4)-his(i,7)); \% Den isentropiska verkningsgraden räknas ut, används sedan för all avlänkningar ur LågTryckaren 

his(i:(i+nn),6) = xsteam('h_ps', p(i,6), s(i,4)); 
h(i:(i+nn),6) = -(nisLT(i,7)*(h(i,4)-his(i,6))-h(i,4)); 
T(i:(i+nn),6) = xsteam('T_ph', p(i,6), h(i,6)); 

his(i:(i+nn),25) = xsteam('h_ps', p(i,25), s(i,4)); 
h(i:(i+nn),25) = -(nisLT(i,7)*(h(i,4)-his(i,25))-h(i,4)); 
T(i:(i+nn),25) = xsteam('T_ph', p(i,25), h(i,25)); 

\% Skillnad mellan 12 och 13--> skillnaden mellan m11 m7 
\% Skillnaden mellan att värma upp Fjärrvärmevattnet i de två 
\% värmeväxlanerna 
h1112 = h(i,11) - h(i,12); 
h713 = h(i,7) - h(i,13); 
till14faktor(i:(i+nn),1) = h713/h1112; \% skillnaden mellan de två flödena som levereras till kondensattanken punkt 14 

h(i:(i+nn),9) = xsteam('h_pt', p(i,9), T(i,9)); 

i=i+nn;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%testar olika flöden i 7an om leder till ett flöde i 6an --> ett visst 
%flöde kvar för 9an och 5an

for f = minm:(maxm-minm)/10:maxm 
  m(k:(k+n),7) = f*m(1,1); 
  m(k:(k+n),11) = m(k,7)*till14faktor(k,1); 
  m(k:(k+n),12) = m(k:(k+n),11); 
  m(k:(k+n),13) = m(k:(k+n),7); 
  m(k:(k+n),15) = m(k:(k+n),13); 

  m95(k:(k+n),1) = m(1,1)-(m(k,11)+m(k,7)+TillKylning(1,5));

  k=k+n;
\end{verbatim}
%varierar trycket för avlänkningen 5. trycket på femman
bestämmer
%skillnaden mellan flödena i 5 och 9

for P= p5min:(p5max-p5min)/testar:p5max %

    p(o,5) = P;
    p(o,17) = 7.8; % 7.8; % MAVATANK
    p(o,16) = p(o,17);

    his(o,5) = xsteam('h_ps', p(o,5), s(o,4));
    h(o,5) = -(nisLT(o,7)*(h(o,4)-his(o,5))-h(o,4));
    T(o,5) = xsteam('T_ph', p(o,5), h(o,5));

% De två förvärmningstergen ska bidra med lika mycket
energi
% vardera vilket medför att för ett givet tryck i nod 5 kan
% massflödet bestämmas för denna med hjälp av egenskaperna
för
% nod 9.
% Ett högre tryck medför ett högre energinnehåll som
leder
% till ett större massflöde

% energin i femman ska vara två gånger mer än energin i nian
% m(o,5) = 2*(m95(o,1)*h(o,9))/(h(o,5)+2*h(o,9));
    m(o,5) = (m95(o,1)*h(o,9))/(h(o,5)+h(o,9));
    m(o,9) = m95(o,1)-m(o,5);

    m(o,6) = m(o,11)+m(o,9);
    m(o,10) = m(o,9);
    m(o,14) = m(o,12)+m(o,15)+m(o,10)+m(o,27); %Flödet till
kondenstanken

    m(o,16) = m(o,14);
    m(o,28) = m(o,16);
    m(o,29) = m(o,28);
    m(o,24) = m(o,29);

    m(o,30) = m(o,5);

    m(o,31) = m(o,30);
    m(o,17) = m(o,24)+m(o,31);

    % % Kondenstanken
    h(o,14) = 
              (h(o,15)*m(o,15)+h(o,12)*m(o,12)+h(o,27)*m(o,27))/(m(o,14)-m(o,10));
    h(o,10) = h(o,14);
    T(o,14) = xsteam('T_ph', p(o,14), h(o,14));
\[ T(o,10) = T(o,14); \]
\[ T(o,16) = T(o,14); \]
\[ h(o,16) = xsteam('h_pt',p(o,16),T(o,16)); \]

\% energikonservation och mass-konservation leder till att
node 28 kan beräknas med
\% hjälp av att det som kommer in ska vara med det som åker ut
\[ h(o,28) = (h(o,9)*m(o,9) - \]
\[ h(o,10)*m(o,10) + h(o,16)*m(o,16))/m(o,28); \]
\[ p(o,28)=p(o,16); \]
\[ p(o,29)=p(o,28); \]
\[ T(o,28) = xsteam('T_ph',p(o,28),h(o,28)); \]
\[ T(o,29) = T(o,28); \]
\[ h(o,29) = h(o,28); \]
\[ p(o,29) = p(o,17); \]
\[ p(o,24) = p(o,29); \]

\% energikonservation och mass-konservation leder till att
node 30 kan beräknas med
\% hjälp av att det som kommer in ska vara med det som åker ut
\% det som vi har kört med hela tiden
\[ h(o,30) = (m(o,5)*h(o,5)+m(o,29)*h(o,29))/(m(o,5)+m(o,24)); \]
\% blir blandad ånga 13\% inte bra måste ha högre tryck
\[ h(o,30) = (h(o,29)*m(o,29)+h(o,5)*m(o,5) - \]
\[ h(o,24)*m(o,24))/m(o,5); \]
\[ h(o,24) = h(o,30); \]
\[ p(o,30) = p(o,5); \]
\[ T(o,30) = xsteam('T_ph',p(o,30),h(o,30)); \]
\[ T(o,24) = xsteam('T_ph',p(o,24),h(o,24)); \]
\[ T(o,31) = T(o,30); \]
\[ p(o,31) = p(o,17); \]
\[ m(o,31) = m(o,30); \]
\[ h(o,31) = xsteam('h_pt',p(o,31),T(o,31)); \]

\% energikonservation och mass-konservation leder till att
node 17 kan beräknas med
\% hjälp av att det som kommer in ska vara med det som åker ut
\[ h(o,17) = \]
\[ (m(o,31)*h(o,31)+m(o,24)*h(o,24))/m(o,30)+m(o,24)); \]
\[ T(o,17) = xsteam('T_ph',p(o,17),h(o,17)); \]
\[ p(o,29) = p(o,24); \]
\[ T(o,18) = T(o,17); \]
\[ h(o,18) = xsteam('h_pt', p(o,18), T(o,18)); \]

% Beroende var 5an avlänkas kommer flödena bli olika

\textbf{if} p(o,3) < p(o,5)
\[ m(o,3) = m(o,1) - m(o,5); \]
\textbf{else}
\[ m(o,3) = m(o,1); \]
\textbf{end}

\[ m(o,4) = m(o,3); \]

% kontrol att det ej är ånga där det ej får/ska vara det
% ejsteam
\[ =\{12,13,15,10,16,28,29,30,31,17,18,24,14,26,27\}; \]
% steam = \{1,3,4,5,6,7,9\};
%
% for es=ejsteam
% steamFrac(o,es) =
% xsteam('vx_ph', p(o,es), h(o,es));
% end
%
% for js =steam
% steamFrac(o,js) =
% xsteam('vx_ph', p(o,js), h(o,js));
% end
%
% for es = ejsteam
% % if steamFrac(o,es) >0
% % m(o,es)=0 ;
% % end
%
% for js =steam
% % if steamFrac(o,js) < 1
% % m(o,js)=0 ;
% % end
%
steamFrac(o,30) = xsteam('vx_ph', p(o,30), h(o,30));
steamFrac(o,28) = xsteam('vx_ph', p(o,28), h(o,28));
% pumpar
pumpar(o,1) = (h(o,16) - h(o,14)) + (h(o,31) - h(o,30)) + (h(o,18) - h(o,17)) + (h(o,15) - h(o,13)) + (h(o,21) - h(o,20)) + (h(o,27) - h(o,26));

% ENERGI-UTTAG
% energi ur turbinerna / totla tillförda energin. gången sedan
% med andel av totala m.

input(o,1) = ((h(o,1) - h(o,18)) + (h(o,4) - h(o,3)) + pumpar(o,1));
verkn(o,5) = (h(o,4)-h(o,5)+h(o,1)-h(o,3))/input(o,1); % el
verkn(o,6) = (h(o,4)-h(o,6)+h(o,1)-h(o,3))/input(o,1); % el
verkn(o,7) = (h(o,4)-h(o,7)+h(o,1)-h(o,3))/input(o,1); % el
verkn(o,25) = (h(o,4)-h(o,25)+h(o,1)-h(o,3))/input(o,1); %

% energi ur fjärrvärmeväxlarer / totla tillförda energin
verkn(o,12) = (h(o,11)-h(o,12))/input(o,1);
verkn(o,13) = (h(o,7)-h(o,13))/input(o,1);

% tar bort orimliga verkningsgrader om sådana produceras samt
% att fall med felaktiga ångförhållanden tas bort
for r=1:13
    if verkn(o,r) < 0 || verkn(o,r) > 1
        verkn(o,r) = 0;
    elseif steamFrac(o,30) > 0
        verkn(o,r) = 0;
    elseif steamFrac(o,28) > 0
        verkn(o,r) = 0;
    end
end

% Energi-fraktion av det totala flödet. el
verknm(o,5) = verkn(o,5)*m(o,5);
verknm(o,6) = verkn(o,6)*m(o,6);
verknm(o,7) = verkn(o,7)*m(o,7);
verknm(o,25) = verkn(o,25)*m(o,25);

% Energi-fraktion av det totala flödet. värme/termisk
verknm(o,12) = verkn(o,12)*m(o,12);
verknm(o,13) = verkn(o,13)*m(o,13);

totverknm(o,1) = (verknm(o,5)+verknm(o,6)+verknm(o,7)+verknm(o,25))/m(o,1); % Elektrisk verkningsgrad
totverknm(o,2) = (verknm(o,12)+verknm(o,13))/m(o,1); % Värme verkningsgrad
% total försäljningsintäkt
% total försäljningsintäkt
% total försäljningsintäkt

o=o+1;
Y=(1:a);
RESULTATjuni(1,:) = Y;

totverknm(1,a) = 0;
max(totverknm(:,3));
[q5,z]=find(totverknm==max(totverknm(:,1))); % tar ut det bästa resultatet och sparar det som q5
% disp('p')
RESULTATjuni(2,:) = p(q5,:);
% disp('T')
RESULTATjuni(3,:) = T(q5,:);
% disp('m')
RESULTATjuni(4,:) = m(q5,:);
% disp('h')
RESULTATjuni(5,:) = h(q5,:);
RESULTATjuni(6,:) = totverknm(q5,:);
% disp('Profit')
% disp('q5')
RESULTATjuni(7,:) = q5;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Beräknar hur mycket energi som har levererats DHperMonthMWh(1,5)
EnergiFV(1,5) = EnergiAnga(1,5)*totverknm(q5,2)*DriftTimmar(1,5);
EnergiFV(1,5)
EnergiEl(1,5) = EnergiAnga(1,5)*totverknm(q5,1)*DriftTimmar(1,5) ;
EnergiFV(1,5);

c for i=1:a

    s5(i,1) = xsteam('s_pT',p(q5,i),T(q5,i));

c end

Components(:,6) = T(q5,:);
Components(:,7) = p(q5,:);
Components(:,8) = h(q5,:);
Components(:,9) = m(q5,:);
Components(:,10) = s5(q5);
xlswrite('RESULTATmaj.XLS', RESULTAT)
1.14 June
clc
% The program optimizes the steam cycle to get the most profit
% from the sale of electricity and district heating (DH).
% The program varies four parameters
% • The pressure drop after the high pressure turbine, point 3,
% • The mass flow to the “district heating grid heaters”, point 6 and 11,
% • The pressure in point 5 and the following characteristics for that
% point.
% • The mass flow to the cooling tower in case of a summer month
% Beräknar fram den bästa verkningsgraden/förhållandet mellan El och värme

n=11;
nn=n*n;
nnn=nn*n;
nnnn=nnn*n;

a=31; % antal noder/punkter i ångcykeln
B=nnn+1;

%Skapar arayer för punkterna
p=zeros(B,a); % Tryck, bar
T=zeros(B,a); % Temperatur, C
m=zeros(B,a); % Massflöde. Maximala flödet =1. Andel av det maximala
massflödet
h=zeros(B,a); % Entalpi
ss=0.003; % för att komma bort från instablia områden för programmet
Xsteam kring mättnadskurvan

DHperMonthMWh
=(450441.1423,388785.4727,312044.9177,91520.73433,54998.65767,33481.607,228
178,26450.109,39949.43767,100780.1527,243589.9623,410544.4273);
test=0.00001;
EnergiFV(1,6)=0;
% Kyltronsslingan
TillKylning(1,6) = 0.3603;

while DHperMonthMWh(1,6) > EnergiFV(1,6)
    TillKylning(1,6) = TillKylning(1,6) - test;
    % varierar trycket i som högturbinaren går ner till
    % minska värden för pmin i nod 3 beräknas enligt följande
    % smax= xsteam('s_pt',p(1,7),T(1,7));
    %pmin = xsteam('p_st',smax,T(1,4)); %denna funktion finns ej men tagit
    % ur

    pmin = 6.18479;
    pmax = 6.1848; % 6.1848; % maximalt värde 40
% Varierar olika massflöden till Fjärrvärmeväxlarna värmeväxlarna 44.2
minm = ((1-TillKylning(1,6))/2)-0.06;
maxm = ((1-TillKylning(1,6))/2)-0.02;

%Varierar trycken som avlänkningen 5 använder
p5max=pmin;  
p5min=1.0172;  % samma som p(1,6);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
p(1:B,25) = xsteam('psat_t',50)-ss;
m(1:B,25) = TillKylning(1,6);

T(1:B,26) = xsteam('Tsat_p',p(1,25))-2;
p(1:B,26) = p(:,25);
m(1:B,26) = m(:,25);
T(1:B,27) = T(1:B,26);
m(1:B,27) = m(:,26);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%deklarering av initialvärden
m(1:B,1)=1;
p(1:B,1) = 40 ;
T(1:B,1) = 400 ;
T(1:B,4) = 400;
T(1:B,6) = 130;
T(1:B,7) = 100;
m(1:B,19) = m(1:B,1);
m(1:B,18) = m(1:B,1);

T(1:B,19) = 250;
p(1:B,19) = 40;
p(1:B,20) = 2.5;
T(1:B,20)= 70;
p(1:B,21) = 11.33;
T(1:B,21) = T(1:B,20);
p(1:B,22) =p(1:B,21);
T(1:B,22) = 100 ;
p(1:B,23) = p(1:B,21);
T(1:B,23) = 130;

T(1:B,12) = T(1:B,22);
T(1:B,13) = T(1:B,21);
T(1:B,15) = T(1:B,13);

%Måste loopa värden som räknas ut med xsteam
for b=1:B  
   %går ner under kurvan för att bibehålla ånga  
   p(b,6) = xsteam('psat_T',T(b,12))+ss;
   p(b,7) = 0.5;  %xsteam('psat_T',T(b,7))+ss;
   p(b,12) = xsteam('psat_T', T(b,12))+ss;
   p(b,13) = xsteam('psat_T', T(b,13))+ss;
end

p(1:B,9) = p(1:B,6);
\[
p(1:B,10) = p(1:B,9); 
p(1:B,9) = p(1:B,6); 
p(1:B,11) = p(1:B,6); 
p(1:B,15) = p(1:B,12); 
p(1:B,14) = p(1:B,12); 
p(1:B,27) = p(1:B,12); 
p(1:B,18) = p(1:B,19); 
\]

% Räknar ut de h som är bestämda från början

\[
\text{for } i = 1:a \\
\text{for } b=1:B \\
\quad h(b,i)=\text{XSteam('h_pt',}p(b,i),T(b,i)); \\
\text{end} \\
\text{end}
\]

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
\text{xsteam('p_st',smax,T(1,4));} 
\text{smax= xsteam('s_pt',}p(1,7),T(1,7));
\text{%variera trean skapar 100 likadana för att variera 10 m å tio mava.}
\text{pmin = 6.18479; %tabellvärde för det lägsta trycket som är möjligt i}
\text{punkt 3. Måste titta på diagram}
\text{pmax = 6.23; %Maximalt värde som testas}

\text{i=1; %Beräkningsindex}
\text{k=1; %Beräkningsindex}
\text{o=1; %Beräkningsindex}
\text{s40400=xsteam('s_pt',40,400);} 
\text{for } j = pmin:(pmax-pmin)/10:pmax \text{ %varierar trycket , går ner}
\text{isentropiskt}

\[
p(i,3) = j; 
p(i,4) = p(i,3); 
T(i,3) = xsteam('T_ps',j,s40400); 
h(i,3) = xsteam('h_pt',j,T(i,3)); \text{% Isentropiskt h för punkt tre}
\]

\[
h(i,3)= -(0.8*(h(i,1)-his(i,3))-h(i,1)); \text{%beräknas med hjälp av den}
\text{antagna isentropiska verkningsgraden på 0,8.}
\]

\[
T(i,3) = xsteam('T_ph',p(i,3),h(i,3)); 
\text{% Skapar talföjder för vad dessa premisser gäller. Samma värde var}
\text{nn`te}
\]

\[
p(i:(i+nn),3) = p(i,3); 
p(i:(i+nn),4) = p(i,3); 
T(i:(i+nn),3) = T(i,3); 
T(i:(i+nn),3) = T(i,3); 
h(i:(i+nn),3) = h(i,3); 
h(i:(i+nn),4) = xsteam('h_pt',p(i,4),T(i,4)); 
s(i:(i+nn),4) = xsteam('s_pt', p(i,4),T(i,4));
\]
his(i:(i+nn),7) = xsteam('h_ps', p(i,7),s(i,4)); % det isentropiska h för 7an
nisLT(i:(i+nn),7) = (h(i,4)-h(i,7))/(h(i,4)-his(i,7)); % Den isentropiska verkningsgraden räknas ut, används sedan för all avlänkningar ur LågTryckaren

his(i:(i+nn),6) = xsteam('h_ps', p(i,6),s(i,4));
h(i:(i+nn),6)= -(nisLT(i,7)*(h(i,4)-his(i,6))-h(i,4));
T(i:(i+nn),6) = xsteam('T_ph',p(i,6),h(i,6));
T(i:(i+nn),9) = T(i,6);
h(i:(i+nn),9) = h(i,6);
h(i:(i+nn),11) = h(i,11);
T(i:(i+nn),11) = T(i,11);
h(i:(i+nn),12) = h(i,12);
T(i:(i+nn),25) = xsteam('T_ph',p(i,25),h(i,25));

% Skillnad i h mellan punkt 12 och punkt 13--> skillnaden mellan dess % masflöden
h1112=h(i,11)-h(i,12);
h713=h(i,7)-h(i,13);
till14 faktor(i:(i+nn),1)=h713/h1112; % skillnaden mellan de två flödena som levereras till kondensattanken punkt 14

h(i:(i+nn),9) = xsteam('h_pt',p(i,9),T(i,9));

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%testar olika flöden i 7an om leder till ett flöde i 6an --> ett visst %flöde kvar för 9an och 5an
for f =minm:(maxm-minm)/10:maxm
m(k:(k+n),7) =f*m(1,1);
m(k:(k+n),11) =m(k,7)*till14faktor(k,1);
m(k:(k+n),12)=m(k:(k+n),11);
m(k:(k+n),13)=m(k:(k+n),7);
m(k:(k+n),15)=m(k:(k+n),13);

%Det som blir över för noderna 5 och 9 som är de två %förvärmningstegen
m95(k:(k+n),1)=m(1,1)-(m(k,11)+m(k,7)+TillKylning(1,6));

k=k+n;

%varierar trycket för avlänkningen 5. trycket på femman bestämmer %skillnaden mellan flödena i 5 och 9
for P= p5min:(p5max-p5min)/testar:p5max 

\[
p(o,5) = P;
\]

\[
p(o,17) = 7.8; \% 7.8; \% MAVATANK
p(o,16) = p(o,17);
\]

\[
his(o,5) = xsteam('h_ps', p(o,5), s(o,4));
\]

\[
h(o,5) = -(nisLT(o,7)*(h(o,4)-his(o,5))-h(o,4));
\]

\[
T(o,5) = xsteam('T_ph', p(o,5), h(o,5));
\]

% De två förvärmningstergen ska bidra med lika mycket 

% Del av formeln att för ett givet tryck i nod 5 kan 
% massflödet bestämmas med denna med hjälp av egenskaperna 

% för 

% nod 9. 

% Ett högre tryck medför ett högre energiinnehåll som 

% till ett större massflöde 

% energin i femman ska vara två gånger mer än energin i nian 
% m(o,5) = 2*(m95(o,1)*h(o,9))/(h(o,5)+2*h(o,9));
% m(o,5) = (m95(o,1)*h(o,9))/(h(o,5)+h(o,9));
% m(o,9) = m95(o,1)-m(o,5);
% m(o,5) = (m95(o,1)*h(o,9))/(h(o,5)+h(o,9));
% m(o,9) = m95(o,1)-m(o,5);

\[
\begin{align*}
m(o,6) &= m(o,11)+m(o,9); \\
m(o,10) &= m(o,9); \\
m(o,14) &= m(o,12)+m(o,15)+m(o,10)+m(o,27); \% Flödet till kondenstanke
\end{align*}
\]

% kondenstanken
\[
\begin{align*}
m(o,16) &= m(o,14); \\
m(o,29) &= m(o,16); \\
m(o,29) &= m(o,28); \\
m(o,24) &= m(o,29); \\
m(o,30) &= m(o,5); \\
m(o,31) &= m(o,30); \\
m(o,17) &= m(o,24)+m(o,31); \\
\end{align*}
\]

% % Kondenstanken 
\[
\begin{align*}
h(o,14) &= (h(o,15)*m(o,15)+h(o,12)*m(o,12)+h(o,27)*m(o,27))/(m(o,14)-m(o,10)); \\
h(o,10) &= h(o,14); \\
T(o,14) &= xsteam('T_ph', p(o,14), h(o,14)); \\
T(o,10) &= T(o,14); \\
T(o,16) &= T(o,14); \\
h(o,16) &= xsteam('h_pt', p(o,16), T(o,16)); \\
\end{align*}
\]
% energikonservation och mass-konservation leder till att node 28 kan beräknas med
% hjälp av att det som kommer in ska vara med det som åker ut
h(o,28) = (h(o,9)*m(o,9)-
h(o,10)*m(o,10)+h(o,16)*m(o,16))/m(o,28);
p(o,28)=p(o,16);
p(o,29)=p(o,28);
T(o,28) = xsteam('T_ph',p(o,28),h(o,28));
T(o,29) = T(o,28);
h(o,29) = h(o,28);
p(o,29) = p(o,17);
p(o,24) = p(o,29);

% energikonservation och mass-konservation leder till att node 30 kan beräknas med
% hjälp av att det som kommer in ska vara med det som åker ut
% det som vi har kört med hela tiden
h(o,30) = (m(o,5)*h(o,5)+m(o,29)*h(o,29))/(m(o,5)+m(o,24));
% blir blandad ånga 13% inte bra måste ha högre tryck
h(o,30)=(h(o,29)*m(o,29)+h(o,5)*m(o,5)-
h(o,24)*m(o,24))/m(o,5);
h(o,24) = h(o,30);
p(o,30) = p(o,5);
T(o,30) = xsteam('T_ph',p(o,30),h(o,30));
T(o,24) = xsteam('T_ph',p(o,24),h(o,24));
T(o,31) = T(o,30);
p(o,31) = p(o,17);
m(o,31) = m(o,30);
h(o,31) = xsteam('h_pt',p(o,31),T(o,31));

% energikonservation och mass-konservation leder till att node 17 kan beräknas med
% hjälp av att det som kommer in ska vara med det som åker ut
h(o,17) =
(m(o,31)*h(o,31)+m(o,24)*h(o,24))/(m(o,30)+m(o,24));
T(o,17) = xsteam('T_ph',p(o,17),h(o,17));
p(o,29) = p(o,24);
T(o,18) = T(o,17);
h(o,18) = xsteam('h_pt',p(o,18),T(o,18));
% Beroende var 5an avlänkas kommer flödena bli olika
if \( p(o,3) < p(o,5) \)
\[
m(o,3) = m(o,1) - m(o,5);
\]
else
\[
m(o,3) = m(o,1);
\]
end

\[
m(o,4) = m(o,3);
\]

%kontroll att det ej är ånga där det ej får/ska vara det
% ejsteam = [12,13,15,10,16,28,29,30,31,17,18,24,14,26,27 ];
% steam = [1,3,4,5,6,7,9];
% for es=ejsteam
% steamFrac(o,es) = xsteam('vx_ph',p(o,es),h(o,es));
% end
% for js =steam
% steamFrac(o/js) = xsteam('vx_ph',p(o,js),h(o,js));
% end
% for es = ejsteam
% if steamFrac(o,ejsteam) >0
% m(o,es) = 0;
% end
% end
% for js =steam
% if steamFrac(o,js) < 1
% m(o,js) = 0;
% end
% end

steamFrac(o,30) = xsteam('vx_ph',p(o,30),h(o,30));
steamFrac(o,28) = xsteam('vx_ph',p(o,28),h(o,28));

%pumpar
pumpar(o,1) = (h(o,16)-h(o,14))+(h(o,31)-h(o,30))+(h(o,18)-h(o,17))+(h(o,15)-h(o,13))+(h(o,21)-h(o,20))+(h(o,27)-h(o,26));

%ENERGI-UTTAG
% energi ur turbinerna / totla tillförda energin. gångra
% med andel av totala m.
input(o,1) = ((h(o,1)-h(o,18))+(h(o,4)-h(o,3))+pumpar(o,1));
verkn(o,5) = (h(o,4)-h(o,5)+h(o,1)-h(o,3))/input(o,1); % el ur 5
verkn(o,6) = (h(o,4) - h(o,6) + h(o,1) - h(o,3))/input(o,1); % el ur 6
verkn(o,7) = (h(o,4) - h(o,7) + h(o,1) - h(o,3))/input(o,1); % el ur 7
verkn(o,25) = (h(o,4) - h(o,25) + h(o,1) - h(o,3))/input(o,1); %
% energi ur fjärrvärmeväxlar / totla tillförda energin
verkn(o,12) = (h(o,11) - h(o,12))/input(o,1);
verkn(o,13) = (h(o,7) - h(o,13))/input(o,1);
% tar bort orimliga verkningsgrader om sådana produceras
% att fall med felaktiga ångförhållanden tas bort
for r=1:13
    if verkn(o,r) < 0 || verkn(o,r) > 1
        verkn(o,r)= 0;
    elseif steamFrac(o,30) >0
        verkn(o,r)= 0;
    elseif steamFrac(o,28) >0
        verkn(o,r)= 0;
    end
end
% Energi-fraktion av det totala flödet. el
verknm(o,5) = verkn(o,5)*m(o,5);
verknm(o,6) = verkn(o,6)*m(o,6);
verknm(o,7) = verkn(o,7)*m(o,7);
verknm(o,25) = verkn(o,25)*m(o,25);
% Energi-fraktion av det totala flödet .värme/termisk
verknm(o,12) = verkn(o,12)*m(o,12);
verknm(o,13) = verkn(o,13)*m(o,13);
totverknm(o,1) = (verknm(o,5)+verknm(o,6)+verknm(o,7)+verknm(o,25))/m(o,1); % Elektrisk verkningsgrad
totverknm(o,2) = (verknm(o,12)+verknm(o,13))/m(o,1);
% Värme verkningsgrad
% total försäljningsintäkt
totverknm(o,3) = (elMWhPriceLei*totverknm(o,1)+heatMWhPriceLei*totverknm(o,2));
%totverknm(o,3) = (elkJstotverknm(o,1)+heatkJstotverknm(o,2)); % total försäljningsintäkt

o=o+1;
end
end
end

Y=(1:a);
RESULTATjuni(1,:) = Y;
totverknm(1,a) = 0;
max(totverknm(:,1));
[q6,z]=find(totverknm==max(totverknm(:,1))); % tar ut det bästa resultatet

% disp('p')
RESULTATjuni(2,:)=p(q6,:);
% disp('T')
RESULTATjuni(3,:)=T(q6,:);
% disp('m')
RESULTATjuni(4,:)=m(q6,:);
% disp('h')
RESULTATjuni(5,:)=h(q6,:);
RESULTATjuni(6,:)= totverkm(q6,:);
% disp('Profit')
% disp('q')
RESULTATjuni(7,:)= q6;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Beräknar hur mycket energi som har levererats
DHperMonthMWh(1,6)
EnergiFV(1,6)=EnergiAnga(1,6)*totverknm(q6,2)*DriftTimmar(1,6);
EnergiFV(1,6)
EnergiEl(1,6) = EnergiAnga(1,6)*totverknm(q6,1)*DriftTimmar(1,6) ;
EnergiFV(1,6);
end
TillKylning(1,6)
Elverkmn(1,6) = totverkm(q6,1);
Heatverkmn(1,6) = totverkm(q6,2);

for i=1:a

    s6(i,1) = xsteam('s_pT',p(q6,i),T(q6,i));

end
Components(:,11)=T(q6,:);
Components(:,12)=p(q6,:);
Components(:,13)=h(q6,:);
Components(:,14)=m(q6,:);
Components(:,15)=s6(:,1);

%xlswrite('RESULTAT.XLS', RESULTAT)
1.1.5 August
clc

% börjar med att dópa allt i första raden. och ger de som har initialvärden
% det rätta värdet
% varierar den första avlänkningen från HT till LT först. sparar det i en
% array. sedan måste alla dessa körningar köras med olika m på 6 å sju.
% sedan variera tempen på mavatanken.
% räknar ut verkningssgraden el, vårme. gångrar med energin och respektive
% försäljningspris

n=11;
nn=n*n;
nnn=nn*n;
nnnn=nnn*n;
a=31; % antal noder/punkter
B=nnn+1;
p=zeros(B,a);
T=zeros(B,a);
m=zeros(B,a);
h=zeros(B,a);

% Andel av ånga som går till kyltorn under den näst varmaste månaden.
% räknar på omkring 100MW konstant effekt. behov i FV-nät 35MW, så 100-35
% måste kylas ----> 65% av m går
% till kyltorn
DHperMonthMWh
={450441.1423,388785.4727,312044.9177,91520.73433,54998.65767,33481.607,228
1.787,26450.109,39949.43767,100780.1527,243589.9623,410544.4273};
test=0.00001;
EnergiFV(1,8)=0;
TillKylning(1,8) =0.47061; %0.58775;

while DHperMonthMWh(1,8) > EnergiFV(1,8)

TillKylning(1,8) = TillKylning(1,8)-test ;

% varierar trycket i som högturbinen går ner till
% minska värdet för pmin i nod 3 beräknas enligt följande
% smin= xsteam('s_pt',p(1,7),T(1,7));
% pmin = xsteam('p_sT',smax,T(1,4)); %denna funktion finns ej men tagit

pmin =6.18479;
pmax =6.1848; % 6.1848; %maximalt värde 40

% Varierar olika massflöden till Fjärrvärmeväxlarna värmeväxlarna 44.2
minm = ((1-TillKylning(1,8))/2)-0.06;
maxm =((1-TillKylning(1,8))/2)-0.04;
%Varierar trycken som avlänkningen 5 använder
pSmx=pmin;
p5min=1.0172 ; % samma som p(1,6);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
p(1:B,25) = xsteam('psat_t',50)-ss;
m(1:B,25) = TillKylning(1,8);
T(1:B,26) = xsteam('Tsat_p',p(1,25))-2;
p(1:B,26) = p(:,25);
m(1:B,26) = m(:,25);
T(1:B,27) = T(1:B,26);
m(1:B,27) = m(:,26);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% deklarering av initialvärden
m(1:B,1) = 1;
p(1:B,1) = 40;
T(1:B,1) = 400;
T(1:B,4) = 400;
T(1:B,6) = 130;
T(1:B,7) = 100;
m(1:B,19) = m(1:B,1);
m(1:B,18) = m(1:B,1);
T(1:B,19) = 250;
p(1:B,19) = 40;
p(1:B,20) = 2.5;
T(1:B,20) = 70;
p(1:B,21) = 11.33;
T(1:B,21) = T(1:B,20);
p(1:B,22) = p(1:B,21);
T(1:B,22) = 100;
p(1:B,23) = p(1:B,21);
T(1:B,23) = 130;
T(1:B,12) = T(1:B,22);
T(1:B,13) = T(1:B,21);
T(1:B,15) = T(1:B,13);

% Måste loopa värden som räknas ut med xsteam
for b=1:B
    % går ner under kurvan för att bibehålla ånga
    p(b,6) = xsteam('psat_T',T(b,12))+ss;
p(b,7) = 0.5;  % xsteam('psat_T',T(b,7))+ss;
    p(b,12) = xsteam('psat_T', T(b,12))+ss;
p(b,13) = xsteam('psat_T', T(b,13))+ss;
end

p(1:B,9) = p(1:B,6);
p(1:B,10) = p(1:B,9);
p(1:B,9) = p(1:B,6);
p(1:B,11) = p(1:B,6);
\[ p(1:B,15) = p(1:B,12); \]
\[ p(1:B,14) = p(1:B,12); \]
\[ p(1:B,27) = p(1:B,12); \]
\[ p(1:B,18) = p(1:B,19); \]

% Räknar ut de \( h \) som är bestämda från början

\[
\text{for } i = 1:a \\
\quad \text{for } b=1:B \\
\quad \quad h(b,i)=\text{xSteam('h\_pt',p(b,i),T(b,i))}; \\
\quad \text{end} \\
\text{end}
\]

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

\text{xsteam('p\_st',smax,T(1,4))}; \\
\text{smax= xsteam('s\_pt',p(1,7),T(1,7))}; \\
%variera trean skapar 100 likadana för att variera 10 m å tio mava.

\[
i=1; \quad \%\text{Beräkningsindex} \\
k=1; \quad \%\text{Beräkningsindex} \\
o=1; \quad \%\text{Beräkningsindex}
\]

\[
s40400=xsteam('s\_pt',40,400);
\]

\[
pmin = 6.18479; \quad \%\text{tabellvärde för det lägsta trycket som är möjligt i punkt 3. Måste titta på diagram} \\
pmax = 10; \quad \%\text{Maximalt värde som testas}
\]

\[
\text{for } j = pmin:(pmax-pmin)/10:pmax \quad \%\text{varierar trycket, går ner isentropiskt}
\]

\[
p(i,3) = j; \\
p(i,4) = p(i,3); \\
T(i,3) =\text{xSteam('T\_ps',j,s40400)}; \\
h(i,3) =\text{xSteam('h\_pt',j,T(i,3))}\% \text{Isentropiskt } h \text{ för punkt tre}
\]

\[
h(i,3) = -(0.8*(h(i,1)-h(i,3))-h(i,1)); \%\text{beräknas med hjälp av den antagna isentropiska verkningsgraden på 0.8.}
\]

\[
T(i,3) =\text{xsteam('T\_ph',p(i,3),h(i,3))}; \\
\% \text{Skapar talföjder för vad dessa premisser gäller. Samma värde var nn\'te}
\]

\[
p(i:(i+nn),3) = p(i,3); \\
p(i:(i+nn),4) = p(i,3); \\
T(i:(i+nn),3) = T(i,3); \\
T(i:(i+nn),3) = T(i,3); \\
h(i:(i+nn),3) = h(i,3); \\
h(i:(i+nn),4) = \text{xSteam('h\_pt',p(i,4),T(i,4))}; \\
s(i:(i+nn),4) = \text{xsteam('s\_pt', p(i,4),T(i,4))};
his(i:(i+nn),7) = xsteam('h_ps', p(i,7),s(i,4)); % det isentropiska h för 7an
nisLT(i:(i+nn),7) = (h(i,4)-h(i,7))/(h(i,4)-his(i,7)); % Den isentropiska verkningsgraden räknas ut, används sedan för all avlänkningar ur LågTryckaren
his(i:(i+nn),6) = xsteam('h_ps', p(i,6),s(i,4));
h(i:(i+nn),6)= -(nisLT(i,7)*(h(i,4)-his(i,6))-h(i,4));
T(i:(i+nn),6) = xsteam('T_ph',p(i,6),h(i,6));
T(i:(i+nn),11) = T(i,6);
h(i:(i+nn),11) = h(i,6);
T(i:(i+nn),9) = T(i,6);

his(i:(i+nn),25) = xsteam('h_ps', p(i,25),s(i,4));
h(i:(i+nn),25)= -(nisLT(i,7)*(h(i,4)-his(i,25))-h(i,4));
T(i:(i+nn),25) = xsteam('T_ph',p(i,25),h(i,25));

% Skillnad i h mellan punkt 12 och punkt 13--> skillnaden mellan dess
% masflöden
h1112=h(i,11)-h(i,12);
h713=h(i,7)-h(i,13);
till14faktor(i:(i+nn),1)=h713/h1112; % skillnaden mellan de två flödena som levereras till kondensattanken punkt 14

h(i:(i+nn),9) = xsteam('h_pt',p(i,9),T(i,9));
i=i+nn;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Testar olika flöden i 7an om leder till ett flöde i 6an --> ett visst
%flöde kvar för 9an och 5an
for f =minm:(maxm-minm)/10:maxm
    m(k:(k+n),7) =f*m(1,1);
    m(k:(k+n),11) =m(k,7)*till14faktor(k,1);
    m(k:(k+n),12) =m(k:(k+n),11);
    m(k:(k+n),13) =m(k:(k+n),7);
    m(k:(k+n),15) =m(k:(k+n),13);
end

% Det som blir över för noderna 5 och 9 som är de två %förvärmningstegen
m95(k:(k+n),1)=m(1,1)-(m(k,11)+m(k,7)+TillKylning(1,8));
k=k+n;

% Varierar trycket för avlänkningen 5. trycket på femman
bestämmer
% skillnaden mellan flödena i 5 och 9

for P= p5min:(p5max-p5min)/testar:p5max %
\( p(o,5) = P; \)
\( p(o,17) = 7.8; \quad % \ 7.8; \quad % \text{MAVATANK} \)
\( p(o,16) = p(o,17); \)

\( \text{his}(o,5) = \text{xsteam}(\text{'h_ps'}, p(o,5), s(o,4)); \)
\( h(o,5) = -(\text{nisLT}(o,7)*(h(o,4)-\text{his}(o,5))-h(o,4)); \)
\( T(o,5) = \text{xsteam}(\text{'T_ph'}, p(o,5), h(o,5)); \)

% De två förvarmningstergen ska bidra med lika mycket energi
% vardera vilket medför att för ett givet tryck i nod 5 kan % massflödet bestämmas för denna med hjälp av egenskaperna för % nod 9.
% Ett högre tryck medför ett högre energinnehåll som leder % till ett större massflöde

% energin i femman ska vara två gånger mer än energin i nian
% \( m(o,5) = 2*(m95(o,1)*h(o,9))/(h(o,5)+2*h(o,9)); \)
% \( m(o,9) = (m95(o,1)*h(o,9))/(h(o,5)+h(o,9)); \)
% \( m(o,9) = m95(o,1)-m(o,5); \)

\( m(o,6) = m(o,11)+m(o,9); \)
\( m(o,10) = m(o,9); \)
\( m(o,14) = m(o,12)+m(o,15)+m(o,10)+m(o,27); \quad \%\text{Flödet till kondenstanken} \)

\( m(o,16) = m(o,14); \)
\( m(o,29) = m(o,16); \)
\( m(o,29) = m(o,28); \)
\( m(o,24) = m(o,29); \)
\( m(o,30) = m(o,5); \)

\( m(o,31) = m(o,30); \)
\( m(o,17) = m(o,24)+m(o,31); \)

% % Kondenstanken
\( h(o,14) = \)
\( (h(o,15)*m(o,15)+h(o,12)*m(o,12)+h(o,27)*m(o,27))/(m(o,14)-m(o,10)); \)
\( h(o,10) = h(o,14); \)
\( T(o,14) = \text{xsteam}(\text{'T_ph'}, p(o,14), h(o,14)); \)
\( T(o,10) = T(o,14); \)
\( T(o,16) = T(o,14); \)
\( h(o,16) = \text{xsteam}(\text{'h_pt'}, p(o,16), T(o,16)); \)

% energikonservation och mass-konservation leder till att node 28 kan beräknas med
h\(o,29\) = \((h\(o,9\) \bullet m\(o,9\) - h\(o,10\) \bullet m\(o,10\) + h\(o,16\) \bullet m\(o,16\))/m\(o,28\));

\(p\(o,28\) = p\(o,16\);
\(p\(o,29\) = p\(o,28\);

\(T\(o,28\) = \text{xsteam}'T_ph', p\(o,28\), h\(o,28\)));

\(T\(o,29\) = T\(o,28\);
\(h\(o,29\) = h\(o,28\);
\(p\(o,29\) = p\(o,17\);
\(p\(o,24\) = p\(o,29\);

% energikonservation och mass-konservation leder till att node 30 kan beräknas med
% hjälp av att det som kommer in ska vara med det som åker ut

% det som vi har kört med hela tiden
\(h\(o,30\) = \((m\(o,5\) \bullet h\(o,5\) + m\(o,29\) \bullet h\(o,29\))/m\(o,5\)+m\(o,24\));
\% blir blandad ånga 13% inte bra måste ha högre tryck

\(h\(o,30\) = (h\(o,29\) \bullet m\(o,29\) + h\(o,5\) \bullet m\(o,5\) - h\(o,24\) \bullet m\(o,24\))/m\(o,5\);

\(h\(o,24\) = h\(o,30\);
\(p\(o,30\) = p\(o,5\);
\(T\(o,30\) = \text{xsteam}'T_ph', p\(o,30\), h\(o,30\));
\(T\(o,24\) = \text{xsteam}'T_ph', p\(o,24\), h\(o,24\));

\(T\(o,31\) = T\(o,30\);
\(p\(o,31\) = p\(o,17\);
\(m\(o,31\) = m\(o,30\);
\(h\(o,31\) = \text{xsteam}'h_pt', p\(o,31\), T\(o,31\));

% energikonservation och mass-konservation leder till att node 17 kan beräknas med
% hjälp av att det som kommer in ska vara med det som åker ut
\(h\(o,17\) = (m\(o,31\) \bullet h\(o,31\) + m\(o,24\) \bullet h\(o,24\))/m\(o,30\)+m\(o,24\));

\(T\(o,17\) = \text{xsteam}'T_ph', p\(o,17\), h\(o,17\));
\(p\(o,29\) = p\(o,24\);

\(T\(o,18\) = T\(o,17\);
\(h\(o,18\) = \text{xsteam}'h_pt', p\(o,18\), T\(o,18\));

% Beroende var 5an avlänkas kommer flödena bli olika
if \(p\(o,3\) < p\(o,5\)
\(m\(o,3\) = m\(o,1\)-m\(o,5\);
else
\[ m(o,3) = m(o,1); \]

\[ m(o,4) = m(o,3); \]

% kontroll att det ej är ånga där det ej får/ska vara det

\[ \text{ejsteam} = [12,13,15,10,16,28,29,30,31,17,18,24,14,26,27]; \]

\[ \text{steam} = [1,3,4,5,6,7,9]; \]

\[ \text{for es = ejsteam} \]

\[ \text{steamFrac}(o,es) = \text{xsteam('vx_ph',p(o,es),h(o,es))}; \]

\[ \text{for js = steam} \]

\[ \text{steamFrac}(o,js) = \text{xsteam('vx_ph',p(o,js),h(o,js))}; \]

\[ \text{for es = ejsteam} \]

\[ \text{if steamFrac}(o,es) > 0 \]

\[ m(o,es) = 0; \]

\[ \text{end} \]

\[ \text{end} \]

\[ \text{for js = steam} \]

\[ \text{if steamFrac}(o,js) < 1 \]

\[ m(o,js) = 0; \]

\[ \text{end} \]

\[ \text{end} \]

\[ \text{steamFrac}(o,30) = \text{xsteam('vx_ph',p(o,30),h(o,30))}; \]

\[ \text{steamFrac}(o,28) = \text{xsteam('vx_ph',p(o,28),h(o,28))}; \]

\[ \text{pumpar}(o,1) = (h(o,16)-h(o,14))+(h(o,31)-h(o,30))+(h(o,18)-h(o,17))+ (h(o,15)-h(o,13))+(h(o,21)-h(o,20))+(h(o,27)-h(o,26)); \]

\[ \text{ENERGI-UTTAG} \]

\[ \text{energi ur turbinerna / totla tillförda energin. gånga} \]

\[ \text{sedan} \]

\[ \text{med andel av totala m.} \]

\[ \text{input}(o,1) = ((h(o,1)-h(o,18))+(h(o,4)-h(o,3)) + \text{pumpar}(o,1)); \]

\[ \text{verkn}(o,5) = (h(o,4)-h(o,5)+h(o,1)-h(o,3))/\text{input}(o,1); \] \% el ur 5

\[ \text{verkn}(o,6) = (h(o,4)-h(o,6)+h(o,1)-h(o,3))/\text{input}(o,1); \] \% el ur 6

\[ \text{verkn}(o,7) = (h(o,4)-h(o,7)+h(o,1)-h(o,3))/\text{input}(o,1); \] \% el ur 7

\[ \text{verkn}(o,25) = (h(o,4)-h(o,25)+h(o,1)-h(o,3))/\text{input}(o,1); \] \% el ur 25
% energi ur fjärrvärmeväxlare / totla tillförda energin

verkn(o,12) = (h(o,11)-h(o,12))/input(o,1);
verkn(o,13) = (h(o,7)-h(o,13))/input(o,1);

% tar bort orimliga verkningsgrader om sådana produceras samt
% att fall med felaktiga ångförhållanden tas bort
for r=1:13
    if verkn(o,r) < 0 || verkn(o,r) > 1
        verkn(o,r) = 0;
    elseif steamFrac(o,30) >0
        verkn(o,r) = 0;
    elseif steamFrac(o,28) >0
        verkn(o,r) = 0;
    end
end

totverknm(o,1) = (verkn(o,5)+verkn(o,6)+verkn(o,7)+verkn(o,25))/m(o,1);  % Elektrisk verkningsgrad
totverknm(o,2) = (verkn(o,12)+verkn(o,13))/m(o,1);  % Värme verkningsgrad

% total försäljningsintäkt
totverknm(o,3) = (elMWhPriceLei*totverknm(o,1)+heatMWhPriceLei*totverknm(o,2));  % total försäljningsintäkt

o=o+1;
end
end

Y=(1:a);
RESULTATAug(1,:) = Y;
totverknm(1,a) = 0;
%max(totverknm(:,3));
[q8,z]=find(totverknm==max(totverknm(:,1))); % tar ut det bästa resultatet
RESULTATaug(2,:)=p(q8,:);
% disp('T')
RESULTATaug(3,:)=T(q8,:);
% disp('m')
RESULTATaug(4,:)=m(q8,:);
% disp('h')
RESULTATaug(5,:)=h(q8,:);
RESULTATaug(6,:)= totverknm(q8,:);
% disp('Profit')
% disp('q8')
RESULTATaug(7,:)= q8;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Beräknar hur mycket energi som har levererats
DHperMonthMWh(1,8)
EnergiFV(1,8)=EnergiAnga(1,8)*totverknm(q8,2)*DriftTimmar(1,8);
EnergiFV(1,8)
EnergiEl(1,8) = EnergiAnga(1,8)*totverknm(q8,1)*DriftTimmar(1,8) ;
end
TillKylning(1,8)
Elverknm(1,8) = totverknm(q8,1);
Heatverknm(1,8) = totverknm(q8,2);

for i=1:a

    s8(i,1) = xsteam('s_pT',p(q8,i),T(q8,i));

end
Components(:,16)=T(q8,:);
Components(:,17)=p(q8,:);
Components(:,18)=h(q8,:);
Components(:,19)=m(q8,:);
Components(:,20)=s8(:,1);

%xlswrite('RESULTATaug.XLS', RESULTAT)
1.1.6 September

clc
%clear
%
% börjar med att döpa allt i första raden. och ger de som har initialvärden
% det rätta värdet
% varierar den första avlänkningen från HT till LT först . sparar det i en
% array. sedan måste alla dessa körningar köras med olika m på 6 å sju.
% sedan variera tempen på mavatanken.
% räknar ut verkningsgraden el, värme. gångrar med energin och respektive

n=11;
nn=n*n;
nnn=nn*n;
nnnn=nnn*n;
a=31;  % antal noder/punkter
B=nnn+1;

p=zeros(B,a);
T=zeros(B,a);
m=zeros(B,a);
h=zeros(B,a);
ss=0.003;

EnergiFV(1,9)=0;
test=0.00001;
TillKylning(1,9) = 0.2612;

while DHperMonthMWh(1,9) > EnergiFV(1,9)

    TillKylning(1,9) = TillKylning(1,9)-test ;

    % minskar värdet för pmin i nod 3 beräknas enligt följande
    %smax= xsteam('s_pt',p(1,7),T(1,7));
    %pmin = xsteam('p_sT',smax,T(1,4)); %denna funktion finns ej men tagit
    %ur

    pmin =6.18479;
    pmax =6.1848;  % 6.1848; %maximalt värde 40

    % Varierar olika massflöden till Fjärrvärmeväxllarna värmeväxllarna 44.2
    minm = ((1-TillKylning(1,9))/2)-0.06;
    maxm =((1-TillKylning(1,9))/2)-0.02;
    %Varierar tryckten som avlänkningen 5 använder
    p5max=pmin;
    p5min=1.0172 ;  % samma som p(1,6);
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

    p(1:B,25) = xsteam('psat_t',50)-ss;
m(1:B,25) = TillKylning(1,9);

    T(1:B,26) = xsteam('Tsat_p',p(1,25))-2;
p(1:B,26) = p(:,25);
m(1:B,26) = m(:,25);
T(1:B,27) = T(1:B,26);
m(1:B,27) = m(:,26);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% deklarering av initialvärden
m(1:B,1) = 1;
p(1:B,1) = 40;
T(1:B,1) = 400;
T(1:B,4) = 400;
T(1:B,6) = 130;
T(1:B,7) = 100;
m(1:B,19) = m(1:B,1);
m(1:B,18) = m(1:B,1);
T(1:B,19) = 250;
p(1:B,19) = 40;
p(1:B,20) = 2.5;
T(1:B,20) = 70;
p(1:B,21) = 11.33;
T(1:B,21) = T(1:B,20);
p(1:B,22) = p(1:B,21);
T(1:B,22) = 100;
p(1:B,23) = p(1:B,21);
T(1:B,23) = 130;
T(1:B,12) = T(1:B,22);
T(1:B,13) = T(1:B,21);
T(1:B,15) = T(1:B,13);

% Måste loopa värden som räknas ut med xsteam
for b=1:B
    % går ner under kurvan för att bibehålla ånga
    p(b,6) = xsteam('psat_T',T(b,12))+ss;
p(b,7) = 0.5; % xsteam('psat_T',T(b,?))+ss;
p(b,12) = xsteam('psat_T', T(1,12))+ss;
p(b,13) = xsteam('psat_T', T(1,13))+ss;
end
p(1:B,9) = p(1:B,6);
p(1:B,10) = p(1:B,9);
p(1:B,9) = p(1:B,6);
p(1:B,11) = p(1:B,6);
p(1:B,15) = p(1:B,12);
p(1:B,14) = p(1:B,12);
p(1:B,27) = p(1:B,12);
p(1:B,18) = p(1:B,19);

% Räknar ut de h som är bestämda från början
for i = 1:a
    for b=1:B
h(b,i)=XSteam('h_pt',p(b,i),T(b,i));
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
xsteam('p_st',smax,T(1,4));
smax= xsteam('s_pt',p(1,7),T(1,7));
%variera trean skapar 100 likadana för att variera 10 m å tio mava.
pmin = 6.18479; %tabellvärde för det lägsta trycket som är möjligt i
punkt 3. Måste titta på diagram
pmax = 6.23; %Maximalt värde som testas
i=1; %Beräkningsindex
k=1; %Beräkningsindex
o=1; %Beräkningsindex
s40400=xsteam('s_pt',40,400);

for j = pmin:(pmax-pmin)/10:pmax %varierar trycket , går ner
isentropiskt
p(i,3) = j;
p(i,4) = p(i,3);
T(i,3) = xsteam('T_ps',j,s40400);
his(i,3) = xsteam('h_pt',j,T(i,3)); % Isentropiskt h för punkt tre

h(i,3)= -(0.8*(h(i,1)-his(i,3))-h(i,1)); %beräknas med hjälp av den
antagna isentropiska verkningsgraden på 0.8.
T(i,3) = xsteam('T_ph',p(i,3),h(i,3));

% Skapar talföjder för vad dessa premisser gäller. Samma värde var
nn`te
p(i:(i+nn),3) = p(i,3);
p(i:(i+nn),4) = p(i,3);
T(i:(i+nn),3) = T(i,3);
T(i:(i+nn),3) = T(i,3);
h(i:(i+nn),3) = h(i,3);
h(i:(i+nn),4) = xsteam('h_pt',p(i,4),T(i,4));
s(i:(i+nn),4) = xsteam('s_pt', p(i,4),T(i,4));

his(i:(i+nn),7) = xsteam('h_ps', p(i,7),s(i,4)); % det isentropiska
h för 7an
nisLT(i:(i+nn),7) = (h(i,4)-his(i,7))/(h(i,4)-his(i,7)); % Den
isentropiska verkningsgraden räknas ut, används sedan för all avlänkningar
ur LågTryckaren

his(i:(i+nn),6) = xsteam('h_ps', p(i,6),s(i,4));
h(i:(i+nn),6)= - (nisLT(i,7)*h(i,4)-his(i,6))-h(i,4);
T(i:(i+nn),6) = xsteam('T_ph',p(i,6),h(i,6));
T(i:(i+nn),11) = T(i,6);
h(i:(i+nn),11) = h(i,6);
T(i:(i+nn),9) = T(i,6);

his(i:(i+nn),25) = xsteam('h_ps', p(i,25),s(i,4));
h(i:(i+nn),25)= - (nisLT(i,7)*h(i,4)-his(i,25))-h(i,4));
\( T(i:(i+nn),25) = xsteam('T_{ph}',p(i,25),h(i,25)); \)

% Skillnad i h mellan punkt 12 och punkt 13 --> skillnaden mellan dess
% masflöden
\( h_{1112} = h(i,11) - h(i,12); \)
\( h_{713} = h(i,7) - h(i,13); \)
\( \text{till14faktor}(i:(i+nn),1) = h_{713}/h_{1112}; \) % skillnaden mellan de två
flödena som levereras till kondensattanken punkt 14

\( h(i:(i+nn),9) = xsteam('h_{pt}',p(i,9),T(i,9)); \)

\( i = i + nn; \)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%testar olika flöden i 7an om leder till ett flöde i 6an --> ett
%visst
%flöde kvar för 9an och 5an
for \( f = \text{minm}:(\text{maxm}-\text{minm})/10:\text{maxm} \)
\( m(k:(k+n),7) = f \cdot m(1,1); \)
\( m(k:(k+n),11) = m(k,7) \cdot \text{till14faktor}(k,1); \)
\( m(k:(k+n),12) = m(k:(k+n),11); \)
\( m(k:(k+n),13) = m(k:(k+n),7); \)
\( m(k:(k+n),15) = m(k:(k+n),13); \)

%Det som blir över för noderna 5 och 9 som är de två
%förvärmningstegen
\( m_{95}(k:(k+n),1) = m(1,1) - (m(k,11) + m(k,7) + \text{TillKylning}(1,9)); \)

\( k = k + n; \)

%varierar trycket för avlänkningen 5. trycket på femman
%skillnaden mellan flödena i 5 och 9
for \( P = \text{p5min}:(\text{p5max}-\text{p5min})/\text{testar}:\text{p5max} \) %

\( p(o,5) = P; \)
\( p(o,17) = 7.8; \) % 7.8; % MAVATANK
\( p(o,16) = p(o,17); \)

\( \text{his}(o,5) = xsteam('h_{ps}', p(o,5), s(o,4)); \)
\( h(o,5) = -(\text{nisLT}(o,7) \cdot (h(o,4) - \text{his}(o,5)) - h(o,4)); \)
\( T(o,5) = xsteam('T_{ph}', p(o,5), h(o,5)); \)
energi

% De två förvärmningstergen ska bidra med lika mycket

% vardera vilket medför att för ett givet tryck i nod 5 kan
% massflödet bestämmas för denna med hjälp av egenskaperna

%för
%
% nod 9.
% Ett högre tryck medför ett högre energinnehåll som

% leder
%
% till ett större massflöde
%

% energin i femman ska vara två gånger mer än energin i nian
% m(o,5) = 2*(m95(o,1)*h(o,9))/(h(o,5)+2*h(o,9));
%m(o,5) = (m95(o,1)*h(o,9))/(h(o,5)+h(o,9));
m(o,5) = (m95(o,1)*h(o,9))/(h(o,5)+h(o,9));
%m(o,9) = m95(o,1)-m(o,5);

m(o,6) = m(o,11)+m(o,9);
m(o,10)= m(o,9);
m(o,14) = m(o,12)+m(o,15)+m(o,10)+m(o,27); % Flödet till

kondenstanken

m(o,16) = m(o,14);
m(o,28) = m(o,16);
m(o,29) = m(o,28);
m(o,24) = m(o,29);

m(o,30) = m(o,5);

m(o,31) = m(o,30);
m(o,17) = m(o,24)+m(o,31);

% % Kondenstanken
h(o,14) = (h(o,15)*m(o,15)+h(o,12)*m(o,12)+h(o,27)*m(o,27))/(m(o,14)-m(o,10));
h(o,10) = h(o,14);
T(o,14) = xsteam('T_pt',p(o,14),h(o,14));
T(o,10) = T(o,14);
T(o,16) = T(o,14);

h(o,16) = xsteam('h_pt',p(o,16),T(o,16));

% energikonservation och mass-konservation leder till att
node 28 kan beräknas med
%
% hjälp av att det som kommer in ska vara med det som åker ut
h(o,28) = (h(o,9)*m(o,9)-
h(o,10)*m(o,10)+h(o,16)*m(o,16))/m(o,28);

p(o,28)=p(o,16);
p(o,29)=p(o,28);

T(o,28) = xsteam('T_ph',p(o,28),h(o,28));
T(o,29) = T(o,28);
h(o,29) = h(o,28);

p(o,29) = p(o,17);
p(o,24) = p(o,29);
% energikonservation och mass-konservation leder till att node 30 kan beräknas med
% hjälp av att det som kommer in ska vara med det som åker ut

h(o,30) = (m(o,5)*h(o,5)+m(o,29)*h(o,29))/(m(o,5)+m(o,24));

% det som vi har kört med hela tiden
%det blir blandad ånga 13% inte bra måste ha högre tryck

h(o,30)=(h(o,29)*m(o,29)+h(o,5)*m(o,5)-
h(o,24)*m(o,24))/m(o,5);

T(o,30) = xsteam('T_ph',p(o,30),h(o,30));

m(o,30) = m(o,5);

T(o,24) = xsteam('T_ph',p(o,24),h(o,24));

h(o,24) = h(o,30);
p(o,30) = p(o,5);

T(o,31) = T(o,30);
p(o,31) = p(o,17);
m(o,31) = m(o,30);
h(o,31) = xsteam('h_pt',p(o,31),T(o,31));

% energikonservation och mass-konservation leder till att node 17 kan beräknas med
% hjälp av att det som kommer in ska vara med det som åker ut

h(o,17) = (m(o,31)*h(o,31)+m(o,24)*h(o,24))/(m(o,30)+m(o,24));

T(o,17) = xsteam('T_ph',p(o,17),h(o,17));
p(o,29) = p(o,24);

T(o,18) = T(o,17);
h(o,18) = xsteam('h_pt',p(o,18),T(o,18));

% Beroende var 5an avlänkas kommer flödena bli olika
if p(o,3) < p(o,5)
    m(o,3) = m(o,1)-m(o,5);
else
    m(o,3) = m(o,1);
end

m(o,4) = m(o,3);

% kontroll att det ej är ånga där det ej får/ska vara det
% ejsteam = [12,13,15,10,16,28,29,30,31,17,18,24,14,26,27 ];
% steam = [1,3,4,5,6,7,9];
% for es=ejsteam
%    steamFrac(o,es) =
xsteam('vx_ph',p(o,es),h(o,es));
end
steamFrac(o,30) = xsteam('vx_ph',p(o,30),h(o,30));
steamFrac(o,28) = xsteam('vx_ph',p(o,28),h(o,28));
pumpar(o,1) = (h(o,16)-h(o,14))+(h(o,31)-h(o,30))+(h(o,18)-h(o,17))+
(h(o,15)-h(o,13))+(h(o,21)-h(o,20))+(h(o,27)-h(o,26));

verkn(o,5) =(h(o,4)-h(o,5)+h(o,1)-h(o,3))/input(o,1); % el ur 5
verkn(o,6) =(h(o,4)-h(o,6)+h(o,1)-h(o,3))/input(o,1); % el ur 6
verkn(o,7) =(h(o,4)-h(o,7)+h(o,1)-h(o,3))/input(o,1); % el ur 7
verkn(o,25) =(h(o,4)-h(o,25)+h(o,1)-h(o,3))/input(o,1); % el ur 25

verkn(o,12) = (h(o,11)-h(o,12))/input(o,1);
verkn(o,13) = (h(o,7)-h(o,13))/input(o,1);

if verkn(o,r) < 0 || verkn(o,r) > 1
  verkn(o,r)= 0;
elseif steamFrac(o,30) >0
  verkn(o,r)= 0;
% Energi-fraktion av det totala flödet. el
verknm(o,5) = verkn(o,5)*m(o,5);
verknm(o,6) = verkn(o,6)*m(o,6);
verknm(o,7) = verkn(o,7)*m(o,7);
verknm(o,25) = verkn(o,25)*m(o,25);
% Energi-fraktion av det totala flödet .värme/termisk
verknm(o,12) = verkn(o,12)*m(o,12);
verknm(o,13) = verkn(o,13)*m(o,13);

% Elektrisk verkningsgrad
[totverknm(o,1) = (verknm(o,5)+verknm(o,6)+verknm(o,7)+verknm(o,25))/m(o,1);]
% Värme verkningsgrad
% total försäljningsintäkt
[totverknm(o,3) = (elMWhPriceLei*totverknm(o,1)+heatMWhPriceLei*totverknm(o,2));]
% total försäljningsintäkt

o=o+1;
end
end
end

Y=(1:a);
RESULTATsep(1,:) = Y;

[totverknm(1,a) = 0;
max(totverknm(:,3));
[q9,z]=find(totverknm==max(totverknm(:,1))); % tar ut det bästa resultatet
RESULTATsep(2,:) = p(q9,:);
% disp('T')
RESULTATsep(3,:) = T(q9,:);
% disp('m')
RESULTATsep(4,:) = m(q9,:);
% disp('h')
RESULTATsep(5,:) = h(q9,:);
RESULTATsep(6,:) = totverkm(q9,:);
% disp('Profit')
% disp('q9')
RESULTATsep(7,:) = q9;

% Beräknar hur mycket energi som har levererats
DHperMonthMWh(1,9)
EnergiFV(1,9) = EnergiAnga(1,9)*totverknm(q9,2)*DriftTimmar(1,9);
EnergiEl(1,9) = EnergiAnga(1,9)*totverknm(q9,1)*DriftTimmar(1,9);
EnergiFV(1,9)
end
TillKylning(1,9)
Elverknm(1,9) = totverknm(q9,1);
Heatverknm(1,9) = totverknm(q9,2);
for i=1:a
    s9(i,1) = xsteam('s_pT',p(q9,i),T(q9,i));
end
Components(:,21)=T(q9,:);
Components(:,22)=p(q9,:);
Components(:,23)=h(q9,:);
Components(:,24)=m(q9,:);
Components(:,25)=s9(:,1);
%xlswrite('RESULTATsep.XLS', RESULTAT)