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Waste-to-Energy in Kutai Kartanegara, Indonesia

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Waste-to-Energy in Kutai Kartanegara, Indonesia

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Cover: Uncontrolled landfill in Muara Jawa, 2015. Photo: Jon Gezelius

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Abstract

The thesis outlined in this report is a pre-feasibility study of the potential to use waste-to-energy technology in the region Kutai Kartanegara, Borneo, Indonesia. The project is collaboration between the Kutai Kartanegara government, Uppsala University, the Swedish University of agricultural sciences and technology consultancy Sweco.

The current waste management system in Kutai Kartanegara consists of landfills in the cities and open burnings and dumping in the lesser developed sub-districts. This is a growing problem both environmentally and logistically. The electrification in the sub-districts is sometimes as low as 17 % and access to electricity is often limited to a couple of hours per day. The current electricity production in the region is mainly from fossil fuels.

Data was collected during a two month long field study in Tenggarong, the capital of Kutai Kartanegara. From the collected data, various waste-to-energy systems and collection areas were simulated in Matlab. Results from the simulations show that a system using both a waste incineration and biogas plant would be the best solution for the region.

The chosen system is designed to handle a total of 250,000 tons of waste annually, collected from Tenggarong and neighboring districts. The system will provide between 155 and 200 GWh electricity and between 207 and 314 GWh of excess heat energy annually. Some of this is used in a district heating system with an absorption-cooling machine. The system investment cost is around 42.5 MUSD and it is expected to generate an annual profit of 16 MUSD. The recommended solution will decrease the emissions of CO_2-equivalents compared to the current waste system and fossil electricity production with 50%. The results in the study clearly show that there are both economic and environmental potential for waste-to-energy technologies in the region. But the waste management and infrastructure has to be improved to be able to utilize these technologies.

By implementing waste-to-energy technologies, the supplied waste can be seen as a resource instead of a problem. This would give incentives for further actions and investments regarding waste management.

Populärvetenskaplig sammanfattning

Examensarbetet är en förstudie av potentialen för användande av waste-to-energy tekniker i regionen Kutai Kartanegara som ligger på Indonesiska Borneo. Projektet är ett sammarbete mellan den lokala regeringen i regionen, Uppsala universitet, Svenska lantbruksuniversitetet och teknik-konsultföretaget Sweco.

Det befintliga systemet för sophantering i Kutai Kartanegara utgörs av deponier i städerna och öppen förbränning och dumpning i de mindre utvecklade underdistrikten. El tillgången i underdistrikten är låg, i vissa fall så låg som 17 % och tillgången är ofta begränsad till några timmar varje kväll. Den el som produceras kommer från fossila källor.

Under en två månader lång fältstudie i Tenggarong, huvudstaden i Kutai Kartanegara, har data samlats in. Den insamlade datan har sedan använts för att kunna simulera olika waste-to-energy system och olika insamlingsområden. Resultaten från simuleringarna visar att ett system som utgörs av både en förbränningsdel samt en biogasdel är det bästa alternativet i regionen.

Det valda systemet är utformat för att kunna hantera 250 000 ton avfall årligen, insamlat från Tenggarong och närliggande distrikt. Systemet kommer då att leverera mellan 155 och 200 GWh elektricitet och mellan 207 och 314 GWh värme. Delar av spillvärmen kommer att användas i en absorptionskylmaskin och ett fjärrkylenät för att öka verkningsgraden och lönsamheten på verket. Investeringskostnaden för systemet är ca 42,5 MUSD och kommer att generera en årlig inkomst på 16 MUSD. Det rekommenderade systemet kommer att reducera klimatpåverkan från utsläpp av koldioxidekvivalenter till hälften jämfört med nuvarande elproduktion och deponier. Resultaten visar tydligt att det finns både ekonomisk och miljömässig lönsamhet i att implementera waste-to-energy tekniker i regionen. Men sophantering och infrastruktur i regionen kommer att behöva förbättras för att kunna utnyttja dessa tekniker.

Genom att implementera waste-to-energy tekniker så hoppas vi att synen på skräp kan förändras från bara ett problem till en nyttig resurs. Detta skulle kunna ge incitament för fortsatta investeringar och projekt relaterat till avfallsproblemet.

Executive summary

Based on the results in this pre-feasability study, the recommendation to the local government in Kutai Kartanegara region is to proceed with a more detailed study regarding waste to energy in the region. Results in this study show that there are both economical and environmental incentments to implement waste to energy technologies in the region.

The recommended system is designed to handle a total of 250,000 tons of waste annually, collected from Tenggarong and neighboring districts. The system will provide between 155 and 200 GWh electricity and between 207 and 314 GWh of excess heat energy annually. Some of this will be used in a district heating system with an absorption-cooling machine. The system investment cost is around 42.5 MUSD and it is expected to generate an annual profit of 16 MUSD. The recommended solution will decrease the emissions of CO_2-equivalents compared to the current waste system and fossil electricity production with 50%. However the research also shows that waste management and infrastructure has to be improved to be able to utilize this technologies.

By implementing waste-to-energy technologies, the supplied waste can be seen as a resource instead of a problem. This would give incentives for further actions and investments regarding waste management.

Forewords

In the fall of 2013 a delegation from Kutai Kartanegara, Indonesia, visited Falun and Borlänge in order to learn from the region's sustainable energy and waste management system. Due to waste- and energy problems in Kutai Kartanegara, the delegation was interested in implementing this sustainable technology to produce green energy and reduce greenhouse gas emissions.

Through Melviana Hedén, Falu Energi och Vatten and Ronny Arnberg, Borlänge Energi, Sweco and IVL were contacted about the project. Sweco and IVL were interested and tried to get funding for a pre-feasibility study where the potential of waste-to-energy would be investigated. Since no funds were available it was decided to be completed as a technical master thesis at University level.

This master thesis was assigned to us, Johan Torstensson and Jon Gezelius, and is the final part of our degree as Master of Science in engineering. Johan has been responsible for the, economical and environmental calculations, waste stream section and co-responsible for the incineration section. Johan will complete a degree in Socio-technical engineering, energy specialization at Uppsala Universitet.

Jon has been responsible for the, biogas section, transportation and waste handling calculations and co-responsible for the incineration section. Jon will complete a degree in Energy Systems at the Swedish Agricultural University and Uppsala University. Gunnar Larsson at the Swedish Agricultural University has been academic supervisor and Gunnar Bark at Sweco has been supervisor in this master thesis.

There have been many people involved in this study, and we would like to take the opportunity to express our gratitude to everyone that have helped along the way which made this study possible.

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Uppsala, October 2015

Johan Torstensson & Jon Gezelius

Nomenclature

BLH - Badan Lingkungan Hidup
BOD – Biochemical oxygen demand
CHP – Combined heat and power
CIPS – Chartered Institute of Procurement & Supply
CO – Carbon monoxide
CO_2 – Carbon dioxide
COD – Chemical oxygen demand
COP – Coefficient of performance
DDOC – Degraded degradable organic carbon
DH – District heating
DKP – Dinas Kebersihan Dan Pertamanan (Responsible for waste in Samarinda)
DOC – Degradable organic carbon
EIA – Energy information administration
EPM – Environmental protection management law
EU – European union
EUR – Euro
FOD – First order decay
GHG – Greenhouse gases
GWh – Gigawatt hour
GWP - Global-warming potential
HCl – Hydrogen chloride
HF – Hydrogen fluoride
IDR – Indonesian Rupiah
IEA – International energy agency
IPCC – Interngovernmental Panel on Climate Change
IPP – Independent power project
IRR – Internal rate of return
IUPTL – Electricity supply business permit
MEMR – Ministry of Energy and Mineral Resources
MoF – Ministry of Finance
MSW – Municipal solid waste
MWh – Mega Watt hour
NGO – Non-governmental Organization
NIP – National Industry Policy
NO_x – Nitric oxides
NPV – Net present value
PKKK – Pemerintah Kabupaten Kutai Kartanegara (Local government in Kutai Kartanegara)
PLN – Perusahaan Listrik Negara (State owned electricity company)
PPA – Power purchase agreement
PPP – Public-private partnerships
PPU – Private power utilities
PVC – Polyvinyl chloride
PwC – Price Waterhouse Coopers
REDD – reduce emissions from deforestation and degradation
RGDP – Regional gross domestic product
SCR – Selective catalytic reaction
SEK – Swedish crowns
SNCR – Selective non catalytic reaction
SO_x – Sulphuric oxides
TPA – Final waste dumping site

TPS – Temporary waste collection point
TS-content – Dry substance
USD – US dollar
VS-content – Volatile solids
WID – Waste Incineration Directives
WtE – Waste to energy

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1. Introduction

Current global municipal solid waste, MSW, generation is approximately 1.3 billion tons a year and is estimated to increase to 2.2 billion tons per year by 2025, waste that in many cases ends up in the wrong place (Hoornweg & Bhada-Tata, 2012).

Many of the developing countries do not have a functional waste management system and do not have the technology to take proper care of their waste. Data from the World Bank (2012) states that low income countries dump 13% of their waste on uncontrolled landfills and either burn or dump 27% of the waste (Hoornweg & Bhada-Tata, 2012).

Indonesia has a rapidly growing middle class and are now experiencing problems related to a more consuming lifestyle. These problems include an accelerated energy demand and an accelerating waste production. The government in Indonesia is beginning to address these problems, but have a shortage in knowledge of technologies (Rawlins, Beyer, Lampreia, & Tumiwa, 2014).

Sweden is right now one of the leading countries in the world when it comes to waste management and energy recovery from waste. This gives the opportunity to help developing countries to solve their problems.

The local government in Kutai Kartanegara regency, Indonesia on Borneo is well aware of their problems and as a step forward they have in cooperation with Sweco, Uppsala University and the Swedish University of Agricultural Sciences initiated this project.

This study addresses three of the larger problems in the world right now: the shortage of energy, the accumulation of waste and the emissions of greenhouse gasses (World Energy Council, 2013). The project aims to investigate waste as an energy resource in Kutai Kartanegara regency as well as estimate the potential environmental impacts of implementing waste-to-energy systems.

This project is a prefeasibility study of waste-to-energy in Kutai Kartanagare and also a piloting student exchange, with the potential to become a consultancy project and an on-going collaboration between regions in Sweden and Indonesia.

1.1. Formulate goal and milestones

The goal is to do a pre-feasibility study on the possibility to implement waste-to-energy plants in the Kutai Kartanegara region. The plants should be economically and environmentally sustainable.

1.1.1. Milestones

To accomplish this goal, the following milestones have to be considered:

- Map the present energy supply and demand of the Kutai Kartanegara region.
- Locate the available municipal solid waste supply in the Kutai Kartanegara region. Investigate the composition and energy potential of the waste.
- From available resources and energy demand simulate different kinds of CHP and biogas plants.
- Make a sensitivity analysis where different parameters in the model are varied. Examples on varied variables are: moisture in fuel, size of plant and supply of fuel.
- Create economical models that calculate the economic viability and payback time. Create a model that calculates the change in greenhouse gas emissions that an implementation would bring.
- Present a final proposal of waste-to-energy plant(s) in the region that will optimize the performance and work according to Indonesian laws. The plant(s) will be evaluated in terms of their ability to meet current demand with the available resources and how well they perform from an environmental, economic and technological perspective.

1.2. Limitations in the study

To be able to finish this study within the time frame, some limitations were needed. When locating the waste streams only the municipal solid waste was accounted for. Industrial waste and agricultural waste has not been investigated. The different technology solutions might need separation of the available waste. This study will not investigate how this separation can be performed.

In the economical calculations all investment costs have not been included, connection to the grid and pipe lines for district cooling are not included. Taxes and inflation are other parameters that are excluded from the economic models. In the environmental analysis only greenhouse gas emissions are considered. Toxins and pollutants are not investigated.

2. Background

Details about the region, Kutai Kartanegara and municipal solid waste in general are presented in this section.

2.1. Kutai Kartanegara

Kutai Kartanegara regency is an autonomous region located in East Kalimatan, Borneo, Indonesia, see Figure 2-1. The region is divided into 18 districts and 237 villages over an area of 27,263 km^2. In 2012 the total population was 674,464, a 3.6% increase from 2011. The population density in Kutai Kartanegara was 25 people/ km^2 in 2012. The 930 km long Mahakam River runs through the region (BPS-Statisitcs of Kutai Kartanegara regency, 2013).

Figure 2-1 Map over the Kutai Kartanegara region, showing the 18 different subdistricts (Gerbang Informasi Kabupaten Kutai Kartanegara, 2013)

The Kutai region is known for its rich natural resources, there are plenty of coal, oil, natural gas and tropical forest compared to other regions in East Kalimantan. The region is located along the equator as shown by the pointer in Figure 2-2, and has a tropical climate which means a stable temperature around 27 C^o with a humidity varying within the range 70-90%. There are two minor seasonal periods: one rainy season, November-May, and one dry, June – October. Average rainfall is around 200 mm a month, see Figure 2-3. The region has a unique wildlife with endangered species such as orangutan, siamese crocodile and fresh water dolphin (BPS-Statisitcs of Kutai Kartanegara regency, 2013).

Figure 2-2 Tenggarong location (Google maps, 2015)

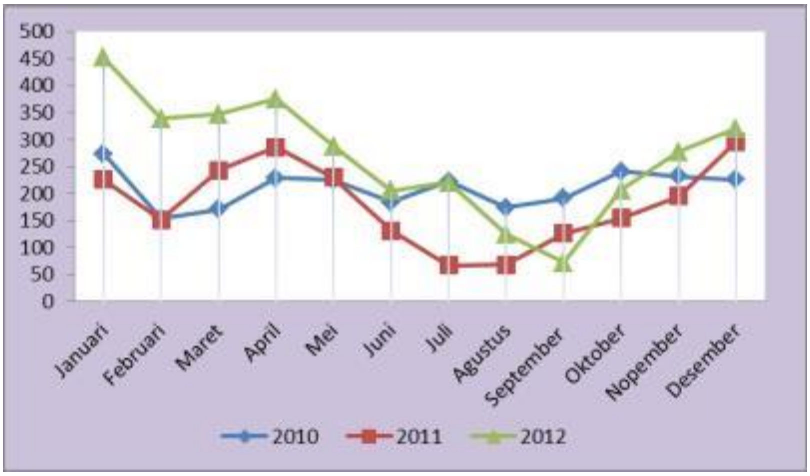

Figure 2-3 Rainfall by month, 2010-2102 (BPS-Statisitcs of Kutai Kartanegara regency, 2013)

The infrastructure in the region is not fully developed. The quality and availability of roads and bridges is a major problem. Currently villages in some sub-districts are dependent on the river to access other remote districts and villages. The length and conditions of the roads in Kutai Kartanegara is presented in Table 2-1. Most of the good roads are situated close to the Tenggarong district and between Tenggarong and major cities in neighbouring regions. Transportation in rural areas are costly due to high fuel prices and time consuming because of the insufficient infrastructure (BPS-Statisitcs of Kutai Kartanegara regency, 2013).

Table 2-1 Conditions of roads in Kutai Kartanegara regency

Condition of road	Good	Moderate	Damaged	Heavy damaged	Total
Length (km)	294	398	233	639	1564

(BPS-Statisitcs of Kutai Kartanegara regency, 2013)

The economy in Kutai Kartanegara is dominated by the coal mining, oil – natural gas and quarrying sector which stands for around 84 % of the regional gross domestic product, RGDP. Agriculture and forestry is the second biggest sector, it stands for 7% of the RGDP in the region (BPS-Statisitcs of Kutai Kartanegara regency, 2013). Figure 2-4 summarizes the different sectors and their contribution to the RGDP in percent. The RGDP per capita with current prices has increased steadily by around 3-4 % per year the last years (BPS-Statisitcs of Kutai Kartanegara regency, 2013).

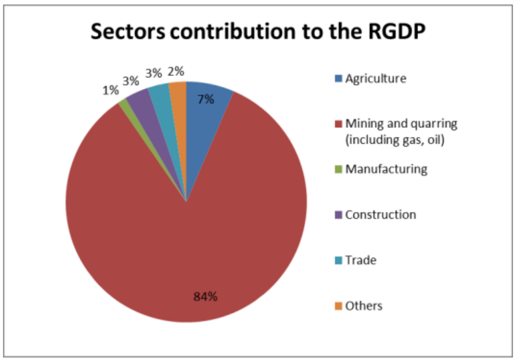

Figure 2-4 Diagram over the different sectors share of the Regional Gross Domestic Product (BPS-Statisitcs of Kutai Kartanegara regency, 2013)

2.1.1. Regions

Figure 2-5 is a map over Kutai Kartanegara regency and its neighbouring regions.

Figure 2-5 Map of Kutai Kartanegara and neighboring regions (BPS-Statisitcs of Kutai Kartanegara regency, 2013)

Tenggarong is the capital and most populous city in the Kutai Kartanegara region. In 2012 the city had 104,044 inhabitants. The city is located in the central part of Kutai Kartanegara, along the Mahakam River. Since Tenggarong is the capital, a lot of regional government buildings and company buildings are located in the city. Tenggarong also has a lot of civil service buildings, hotels and markets (BPS-Statisitcs of Kutai Kartanegara regency, 2013). At the moment a new shopping mall and bridge over the Mahakam river is under construction. The bridge will ease travelling to Samarinda.

Samarinda is a small region, 718 km^2, encircled by Kutai Kartanegara, see **Figure** 2-5. The region consists of 6 districts with 53 villages. In 2014 the region had 857,569 inhabitants and a population density of 1,194 inhabitants/km^2 (Head of DKPP Samarinda, 2015). The population growth is around 3 % a year (Samarinda Green Clean Health, 2014). The city of Samarinda, Borneo's largest city, is the capital of the East Kalimantan province; it is located 25 km east of Tenggarong, 45 km following the Mahakam river (BPS-Statisitcs of Kutai Kartanegara regency, 2013). Samarinda host many provincial institutions and is also a centre of commerce.

Balikpapan is a 503 km^2 region located 145 km south of Tenggarong. The region consist mainly of Balikpapan city which is divided into five districts. In 2014 the population was around 715,000, which gives an approximate population density of 1,421 inhabitants/km^2 (Head of Balikpapan Waste Management, 2015). The population growth is around 3 % a year (Abadi, 2014). Balikpapan's economy is based on the oil industry. The city has a large oil refinery and many international oil companies have their Kalimantan headquarter in the city. The presence of international companies has improved the infrastructure, and Balikpapan has an international airport as well as a large port (Head of Balikpapan Waste Management, 2015).

Bontang is a region 129 km north of Tenggarong. It occupies an area of 498 km^2 and had a population of 175,830 in 2012, resulting in a population density of 353 inhabitants/km^2. The population growth is around 4 % a year (Balitbangda, 2015). The region is dependent on LNG production, coal mining, ammonia and urea production and manufacturing. Most of these products are exported to Japan and South Korea (Balitbangda, 2015).

2.1.2. Energy in Indonesia

Indonesia is a country with rich energy resources. It has a large fossil reserve but also potential in geothermal energy and hydropower. Due to the large fossil resources the electricity generation is highly dependent on fossil fuels. In 2013, around 91 % of the electricity generation used fossil fuels (Aiman & Prawara, 2014), see Figure 2-6.

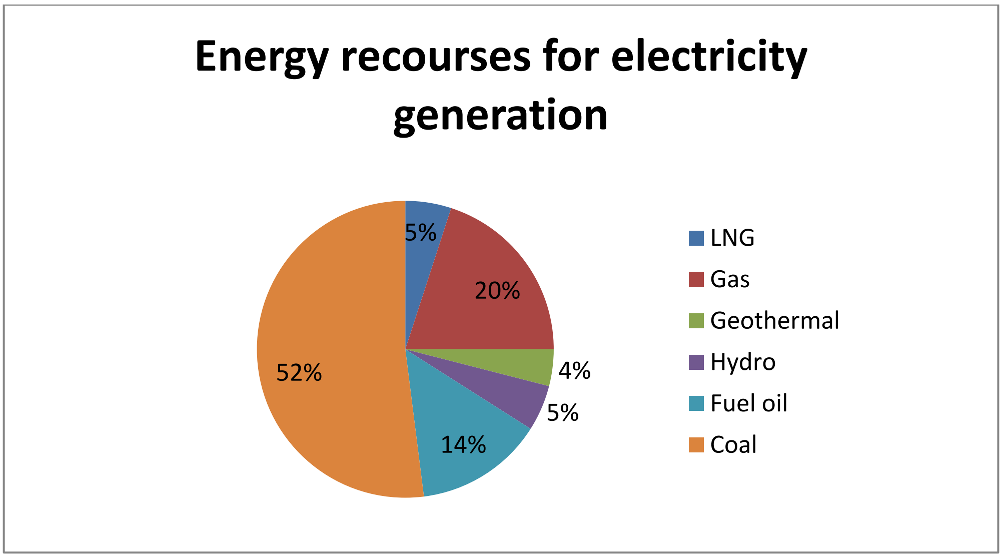

Figure 2-6 Energy resources for electricity production in Indonesia, 2013 (Aiman & Prawara, 2014)

In September 2013 the total installed capacity in Indonesia was 40,533 MW, consisting of 31,815 MW in Java-Bali and 8,718 MW in Sumatra and East Indonesia (PWC, 2013). The generation is spread out in separate grids due to natural geographical reasons. The electrification rate has grown from 62 % in 2008 to 76 % in 2012 (PWC, 2013). Compared to similar countries in the Southeast Asia this electrification rate is very low, see Table 2-2. In some regions the generation capacity is barely sufficient to meet the demands and the transmission grid is underdeveloped, which results in a low electricity availability (Kelistrikan Kabupaten Kutai Kartanegara, 2014).

Table 2-2 Electrification rate in Southeast Asian countries

Country	Electrification rate (%)	Population without electricity (million)
Indonesia	76	62,4
Philippines	89,7	9,5
Vietnam	97,3	2,1
Malaysia	99,4	0,2

(PWC, 2013)

2.1.3. Electricity in Kutai Kartanergara

The electricity provided in Tenggarong is generated and distributed in the 150 kV Mahakam power system. The Mahakam power system is the main system in the Kutai Kartanegara region and stretches from Balikpapan in the south to Bontang in the north (PT PLN, 2013), see Figure 2-7. In 2014 the total power generation of Mahakam system was 429 MW divided on 16 major power producers using 58 power units (Kelistrikan Kabupaten Kutai Kartanegara, 2014). These producers mainly use fossil fuels for power generation. In addition to the Mahakam power system four smaller systems with a total capacity of 115 MW provide the majority of electricity in East Kalimantan. The total installed power generation capacity in East Kalimantan is 544 MW (PT PLN, 2013).

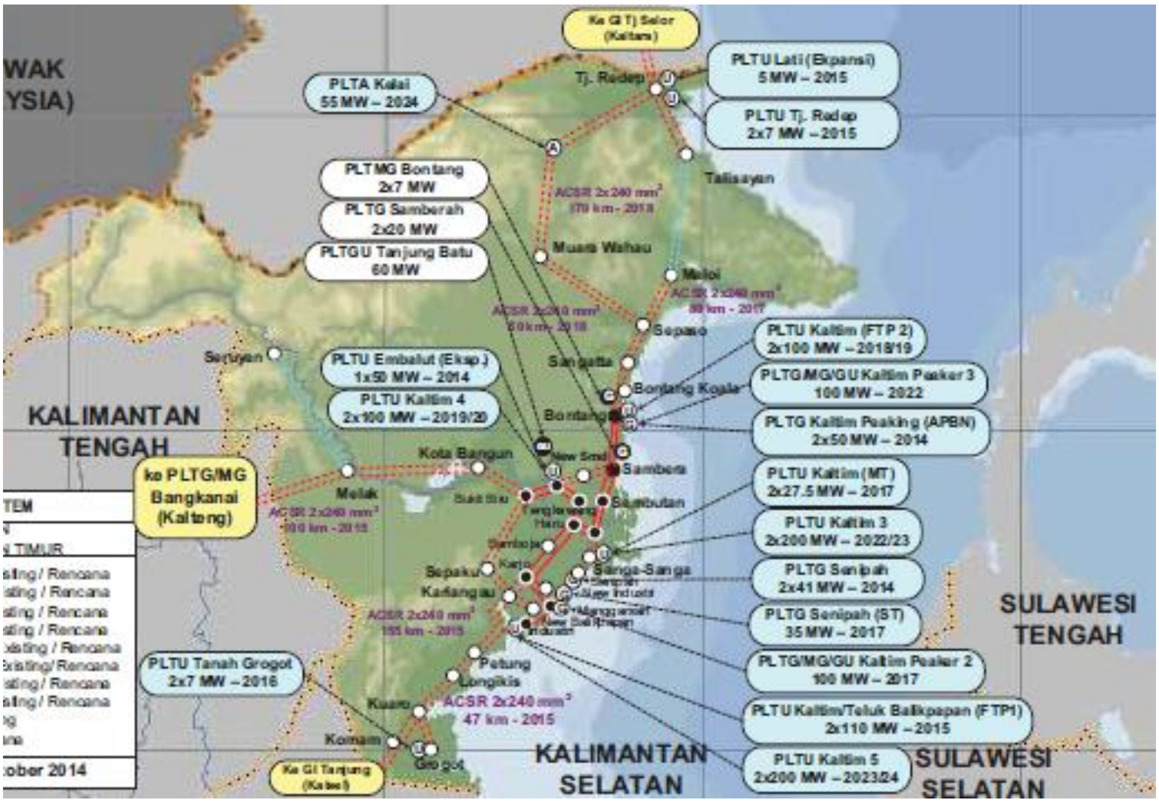

Figure 2-7 Overview of Mahakam power system (PT PLN, 2013)

Due to insufficient infrastructure, all districts in Kutai Kartanegara are not connected to the Mahakam system. In remote districts and villages small isolated systems are providing electricity (PT PLN, 2013). These isolated systems are using diesel generators and have a total capacity of 9 MW. One exception is the biogas power plant in Kembang Janggut, 8 MW, that supply parts of the Kembang Janggut district (Kelistrikan Kabupaten Kutai Kartanegara, 2014). The electrification rate of households in Kutai Kartanegara is 82 %, where Perusahaan Listrik Negara ,PLN, serve 78 % of the area (Kelistrikan Kabupaten Kutai Kartanegara, 2014), see Table 2-3. Even if a household is electrified it is not certain that power is available the whole day. Remote households connected to local grids usually only have access to electricity 6-8 hours per day (Head of Muara Kaman, 2015).

Table 2-3 Electrification rate Kutai Kartanegara

District	Number of households	Connected to an electricity grid	PLN share (%)	Total (%)
Anggana	12,129	10,349	81	85
Kota Bangun	9,211	6,765	71	73
Marang Kayu	7,894	2,361	30	30
Muara Kaman	10,623	10,272	94	97
Muara Muntai	5,406	5,377	74	99
Muara Wis	2,612	457	17	17
Kembang Janggut	7,148	3,729	10	52
Kenohan	3,333	559	16	17
Loa Janan	19,472	19,472	93	100
Muara Badak	11,554	5,936	51	51
Muara Jawa	9,667	7,079	73	73
Semboja	17,271	16,073	93	93
Sebulu	11,049	11,049	100	100
Tenggarong Seb	15,016	14,306	95	95
Loa Kulu	13,251	11,963	90	90
Tenggarong	24,594	22,679	89	92
Tabang	2,849	1,207	42	42
Sanga-sanga	5,634	5,634	98	100
Total	188,713	155,267	78	82

(Kelistrikan Kabupaten Kutai Kartanegara, 2014)

The household sector is the sector that demands most electricity in the region. In 2013 64 % of the generated electricity was used by households (Kelistrikan Kabupaten Kutai Kartanegara, 2014). The peak load was according to PLN around 400 MW in the Kutai Kartanegara region (PT PLN, 2013). Even if the supply is sufficient there are plenty of blackouts due to limited power reserves and an underdeveloped transmission grid (Kelistrikan Kabupaten Kutai Kartanegara, 2014). Many households are on a waiting list for electricity supply. Electricity consumption for each sector and customer in Kutai Kartanegara is shown in Table 2-4.

Table 2-4 Annual electricity usage per sector and customer in Kutai Kartanegara, 2013

Sector	Electricity consumption 2013 (MWh)	% of electricity consumption	Electricity consumption per customer/year (MWh)
Household	285,893	64	2
Social-Service	18,488	4	5,85
Business	84,218	19	15,5
Industry	27,565	7	574,3
Public-service	29,529	7	22,17
Total	445,694	100	2,83

(Kelistrikan Kabupaten Kutai Kartanegara, 2014)

According to PLN the electricity demand in Kutai Kartanegara will increase by approximately 9 % annually during the coming years (PT PLN, 2013). This will require large investments in power generation and transmission grid.

2.1.4. Stakeholders and laws on the Indonesian electricity market

The following section will briefly present the stakeholders and laws on the Indonesian electricity market.

2.1.4.1. Ministry of Energy and Mineral Resources, MEMR

The MEMR is the policy-making department for electricity. The MEMR is responsible for long term electricity plans as well as laws and regulation related to electricity. It is also responsible for tariff and subsidy policies as well as issuing of business licenses (Norton Rose, 2010).

2.1.4.2. PT Perusahaan Listrik Negara, PLN

PT Perusahaan Listrik Negara, PLN, is the state-owned electric utility company in Indonesia. PLN is responsible for the majority of the power generation in Indonesia, 77 %, and has exclusive rights for distribution, transmission and supply of electricity to the public (PWC, 2013). PLN is supervised by the MEMR, the Ministry of Finance, MoF and the Ministry of State Owned Enterprises.

PLN's income is retrieved from electricity tariffs, regulated by MEMR. Fuel cost stands for around 85 % of PLN's operation expenses and the tariffs are not high enough to cover the cost for electricity generation. Even if the MoF pays subsidy to the PLN it is not sufficient to provide for PLN's expenditure requirements. Due to increased subsidies from MoF PLN's financial situation has improved since 2011, but it is still not sufficient to fund the large investment needed. Even so, PLN is the major investor of new electricity generation projects in Indonesia (PWC, 2013).

2.1.4.3. Independent Power Projects, IPP

Independent Power Projects, IPP, are private independent actors on the Indonesian market that can generate electricity and sell it to PLN through Power Purchase Agreements, PPA, licensed by the central government. The price per kWh and duration of the agreement between PLN and IPP should be stated in the PPA. IPP stood for around 19 % of the total generating capacity in Indonesia in 2011 (PWC, 2013).

IPP's were from early 1990's seen as a good investment due to high forecasted returns; this resulted in a high uptake of investors in the early tendering process. However, when the Asian financial crisis struck in 1997, the PLN had problems to carry out the agreed PPA's, resulting in lower returns for the IPP's (DIFFER, 2012).

After the financial crisis few new IPP's were established due to low forecasted returns and high risks for investors. PLN’s monopoly also contributed to the low investing rate. To improve the conditions for IPP's new laws and regulations were stated in 2009 (PWC, 2013).

2.1.4.4. Electricity law 30

The 2009 Electricity Law 30 improves the conditions for IPP's on several points. The three key reforms of Law 30 are the following (Norton Rose, 2010):

- PLN will no longer have a monopoly on supply and distribution to end-customers
- Private business may provide electricity for public use, but PLN have a "right of first priority"
- Greater role for regional governments in future projects in terms of license granting and tariff costs.

These reforms are made to increase private participation in electricity generation and increase the regional autonomy. Even if this law ends PLN's monopoly role as electricity supplier, IPP's must sell generated electricity to PLN through negotiated PPA's. The "right of refusal" gives PLN priority to serve areas without an electricity grid. If PLN does not plan to serve an area with electricity IPP's can serve these areas. IPP's are always allowed to sell directly to end-customers if they have an IUPTL license (Electricity supply business permit) and their own transmission grid. This is, however, very rare due to high investment costs (Norton Rose, 2010).

The new rules also allows Public-Private Partnerships, PPP, that in a general sense is a collaboration between local or regional government and private partners to utilize private projects more efficiently, and to benefit the private and public sector. The law has increased autonomy for regional governments and is believed to increase rural electrification. Local and regional governments need an IUPTL license to be able to sell electricity to end-users (DIFFER, 2012).

Captive electricity generation in the form of Private Power Utilities, PPU, is power plants that generate electricity for their own use, for example industries. To be able to generate and distribute their own electricity they need a license. If possible, PPU's may sell excess electricity to PLN or end-customers if approved by local government. Generation from PPU’s to end-customers is only used in some remote areas where customers not are connected to a PLN grid (PWC, 2013).

In summary there are four ways for an IPP to sell generated electricity (DIFFER, 2012), see Figure 2-8:

- To PLN through PPAs
- To Regional governments through PPA or PPP (Regional government needs IUPTL)
- Direct to end-users with an IUPTL license and their own transmission grid
- Captive generation through granted Operation License

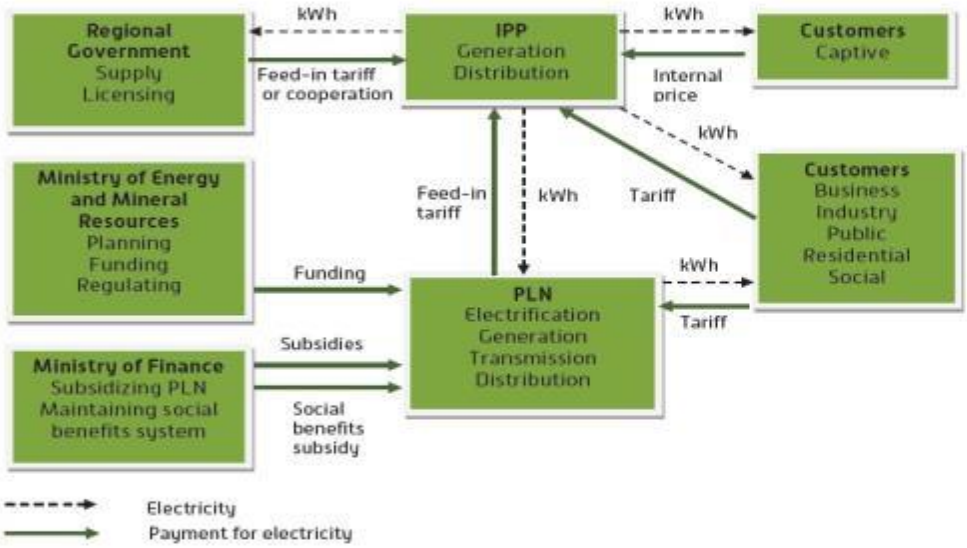

Figure 2-8 Organization of the Indonesian electricity sector (DIFFER, 2012)

2.2. Waste

Waste can be seen as unwanted materials, such as scrap material, or any surplus substance and article that are unwanted, because it is worn out, broken, contaminated or otherwise spoiled (CIPS, 2007). Waste mainly comes from three sectors: agriculture, the municipal sector and different industrial facilities (CIPS, 2007).

- Industrial waste - The industrial waste is produced from a wide range of industrial activities. Usually the waste is generated from the production of metals, beverage, wood and wood products and paper products. The waste may be liquid, solid or sludge.

- Agricultural waste - Agricultural waste is produced in agricultural operations such as harvesting and farming. This waste is mainly organic and is comprised of manure, harvest waste, compost and offal. Plastics and scrap machinery might also be found in the agricultural waste.

- Municipal waste - The municipal waste is the waste generated by households and enterprises such as commerce, offices and institutions. This waste is by definition supposed to be collected by the local municipality. Sometimes there are parts of industrial waste in the municipal waste.

The waste from these three sectors contains the following more detailed waste categories. The fraction of each category varies depending on the local conditions and waste sector (CIPS, 2007).

- Hazardous waste - The hazardous waste is waste that can be a potential threat to public health or the environment. A lot of businesses generate small amounts of hazardous waste, such as hospitals, automobile service shops and photo processing centres. The largest hazardous waste generators are heavy industries such as chemical industries, metal industries and oil refineries.

- E - Waste - This waste is comprised of a range of electrical and electronic items such as refrigerators, cell phones, televisions and other electronic tools. This waste originates from households, businesses and industries.

- Construction and demolition waste - This waste arises from the construction and demolition activities of new and old buildings and infrastructure. This waste category can be made up of numerous different materials including concrete, glass, wood, bricks etc. Many of these materials can be recycled.

- Organic waste - Organic or biodegradable waste is waste that can be broken down to its base compounds by micro-organisms. Examples of organic waste are food, fruit, harvest waste, manure and slaughter house waste. This waste usually constitutes a large part of municipal waste and agricultural waste.

- Mining waste - Mining waste arise from the mining industry, extracting, prospecting and treating storage of minerals. This is by weight the largest category of waste. It is all generated within the industrial sector.

- Packaging waste - Any material that has been used to contain, handle, deliver or present goods can be seen as packaging waste. The packaging items are usually made of glass, plastic, aluminium or paper. The packaging waste is usually generated in the industrial or municipal waste sector. Most of this waste can be recycled.

2.2.1. Municipal Solid Waste in the world today

Current global municipal solid waste, MSW, generation is approximately 1.3 billion ton a year and it is estimated to increase to 2.2 billion ton per year by 2025 (Hoornweg & Bhada-Tata, 2012). The MSW generation is influenced by economic development, level of industrialization, public habits and local climate; hence the waste generation vary considerably between countries and regions. Generally high urbanization and high living standards results in greater amount of MSW generation, see Figure 2-9. The vast majority of the total amount of MSW is generated in the cities. The increased generation depends on urbanization, economic growth and increased world population. Southeast Asia is one of the regions where MSW generation is predicted to increase the most (Hoornweg & Bhada-Tata, 2012).

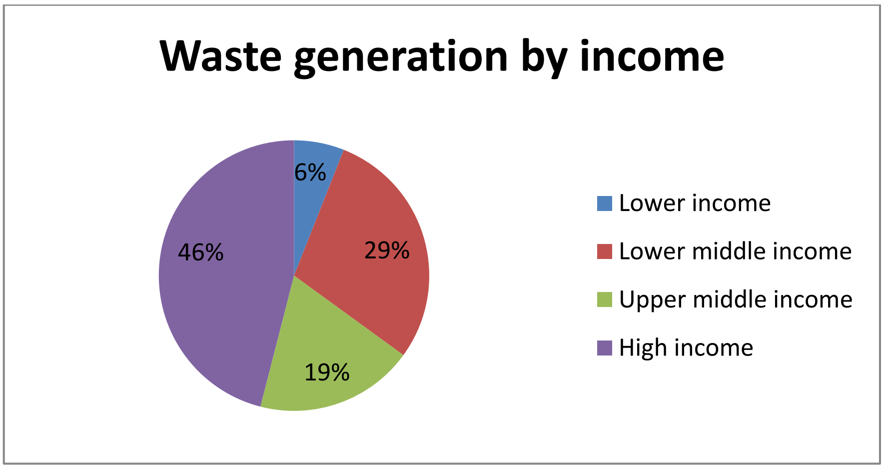

Figure 2-9 Waste generation by income (Hoornweg & Bhada-Tata, 2012)

The composition varies considerable from region to region; this is influenced by economic development, climate and culture. Low income regions have the highest fraction of organic waste, around 64 %, compared to high income regions where it is around 27 %. High-income regions have instead larger fractions of paper, metal and glass, which are smaller in low-income regions. The tendency is that when regions develop economically, the organic fraction of the MSW decreases (Hoornweg & Bhada-Tata, 2012).

Waste collection has an important role to play for public and environmental health. Local authorities' usually have the responsibility for waste collection. The total collection rate varies depending on the economic development and population density. High-income regions and cities have a collection rate of around 98 %, while low-income cities with low population density have collection rates around 40 %. In poor, remote, regions it is not certain that there is any waste collection at all. The separation of waste also varies depending on income. High-income areas have a better separation system, while low income areas rely on waste pickers since a separation system can be too costly (Hoornweg & Bhada-Tata, 2012).

There are no certain data on countries MSW disposal techniques, but according to data from the World Bank, the most common treatment is disposal at controlled landfills, 45 % of the total amount of waste is treated this way.

The treatment tends to vary considerably between different regions. In high income regions controlled landfills are most commonly used, 42 % of the cases. However, recycling (22 %) and energy recovery (21 %) are also common. Middle-income regions dump the majority of the waste on controlled landfills (60 %), but dumping on open uncontrolled dumpsites is also common (33 %). In the low-income regions dumping at landfills and open dumping is by far the most common disposal method (Hoornweg & Bhada-Tata, 2012). These regions also have a large share of unknown disposal. This share is according to World Data thrown on illegal dumpsites or burned openly. Figure 2-10 below shows the disposal method in low income countries to the left and upper-middle income countries to the right (Hoornweg & Bhada-Tata, 2012).

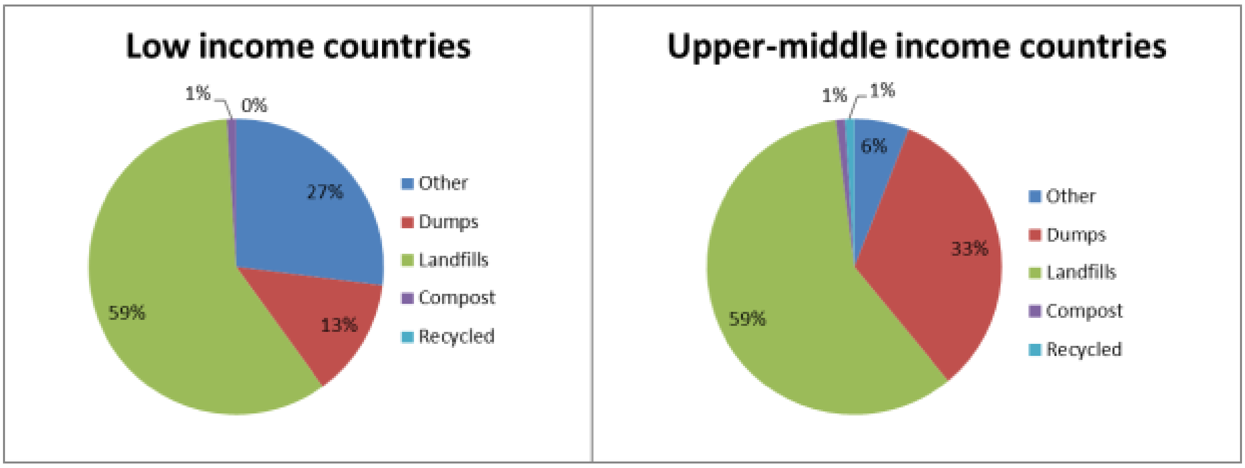

Figure 2-10 Disposal methods in low income countries and upper-middle income countries (Hoornweg & Bhada-Tata, 2012)

2.2.2. Environmental impact

Landfills, open burning and dumping are the least preferred treatments of municipal waste. The environmental impacts from these disposal techniques are briefly presented in the following text.

2.2.2.1. Emissions from landfills

Putting the waste on landfills will generate two types of emissions: gas emissions in form of landfill-gas and leachate water. The definition of leachate water is water that has been in contact with the waste. It is produced as a result of infiltrating water from precipitation surplus, penetration of groundwater or streams, surface water that enters the landfill area or water content in the waste that gets compressed. To get an estimation of the amounts of leachate you usually do a water balance over the area according to Equation 2-1 (Naturvårdsverket, 2008).

Equation 2-1

$$Leachate = precipitation - evaporation\ (+penetrating\ groundwater + moisture\ content\ in\ the\ waste)$$

An easy approximation would be to only look at the precipitation – evaporation, for more exact analysis the groundwater and the moisture content of the waste has to be accounted for (Avfall Sverige, 2012).

Examples of components in the leachate water from landfills are:

- Nutrients like nitrogen
- Oxygen-consumers (measured by BOD and COD)
- Metals like lead, iron, cadmium, copper, chromium, mercury, manganese, nickel and zinc.
- Organic environmental poisons like dioxins, bromic nonflamants and pesticides.
- Compounds from medication like antibiotics, nonflamants and hormones.

The composition of the leachate depends on the composition of the waste in the landfill. There is a risk that these compounds will have a harmful effect on soil, river streams and groundwater and the contents might be toxic to animals and plants. Some of it might also bio-accumulate and thus result in a large impact even if the concentrations are low (Naturvårdsverket, 2008).

To understand and prevent environmental effects from a specific landfill, it is important to run tests on the leachate water and have a cleaning process before emission. The amount of water leaking is also highly dependent on the preparatory work on the landfill (Avfall Sverige, 2012).

Gas emissions from landfills mainly consist of methane and carbon dioxide, which both are climate-affecting gasses. The composition of landfill gas is usually 40-60 % methane, 30-40 % carbon dioxide and 1-20 % nitrogen, though small fractions of other gasses also occur, see Table 2-5. As long as there are water and organic compounds in the landfill it will keep producing gas (Avfall Sverige, 2012).

Table 2-5 Compositions of typical landfill gas

Gas component	Value	Unit
Methane	30-60	Vol-%
Carbon dioxide	30-40	Vol-%
Nitrogen	1-20	Vol-%
Hydrogen	0-2	Vol%
Oxygen	0-2	Vol-%
Sulphuric hydrogen	10-1000	Ppm
Water	5-30	Mg/N m^3
Chlorine	250	Mg/N m^3
Di-chlorine-methane	400	Mg/N m^3
Tetrachloroethylene	233	Mg/N m^3
Freon 12	118	Mg/N m^3

(Avfall Sverige, 2012)

When the degradable organic compounds, DOC, are decomposed in the landfill they emit landfill gas. If the DOC fraction of the waste composition is known, the amount of emitted methane from a specific landfill can be estimated theoretically using an IPCC implemented model (Pipatti & Svardal, 2006).

2.2.2.2. *Open burning*

Households or villages sometimes burn their waste due to a lack of waste collection or poor information. Open burning is inefficient and the combustion temperature is usually around 250-700 °C. Because of the low temperature combustion will be incomplete and have higher environmental impact than controlled combustion would have (SASK Spills, 2010).

The smoke from open burning may contain aldehydes, acids, dioxins, nitrogen oxides, volatilized heavy metals and sulphur oxides. The ash from combustion can also contain toxics like dioxins, furans and heavy metals. Some of the ash will be carried into the atmosphere as fly ash and can travel thousands of kilometres before it descends and enter ecosystems. The majority of the ash will remain at the combustion site where the toxins contaminate the ground and water streams. The contaminations have severe negative health effects on humans and wildlife such as fishes (Aye & Widaya, 2005).

The environmental effect varies depending on the waste composition. Most toxins are released when plastics, electronic waste and hazardous waste are burned (SASK Spills, 2010).

2.2.2.3. *Dumping*

Water streams and backyards have historically been used as small scale dump sites due to practical reasons when no waste collection is available. Dumping plastic waste and electronics on the ground and in water streams will cause contamination of the environment (Aye & Widaya, 2005).

The plastic waste on the ground will eventually release environmental toxins which will contaminate the ground or water streams nearby. Usually waste follows the tidal and ends up in water streams. In water streams waste will spread toxins such as heavy metals and stable organic toxins, for example dioxins. These toxins will accumulate in wild life and can be accumulated by humans. Electronic and plastic waste will cause especially negative environmental consequences (Aye & Widaya, 2005).

2.2.3. Laws and regulation for waste management and renewable energy in Indonesia

The Indonesian government has a clear vision about how to reduce emissions of greenhouse gases. Development of technologies that enables opportunities to reduce GHG emissions and increase renewable energy generation is in line with their target. To pursue these targets the government has formed national policies in different sectors over the last decade (Rawlins, Beyer, Lampreia, & Tumiwa, 2014). Figure 2-11 shows some policies that directly influence waste management and WtE technology in Indonesia.

Figure 2-11 Laws and regulations towards GHG reduction (Rawlins, Beyer, Lampreia, & Tumiwa, 2014)

2.2.3.1. Municipal solid waste law

Until 2008 local regulations decided how the waste management was carried out since no national directive existed. But in May 2008, the Municipal Solid Waste law was enacted. This law states that the national government has responsibility to create waste strategies at a national level and develop cooperation with the local government. The local governments still have responsibility to form waste strategies at a local level to meet the national strategy as well as control and evaluate their progress (Damanhuri, Handoko, & Padma, 2013).

The MSW law also state that the local governments are obliged to plan for decommissioning of open landfills by 2013. New landfills must be equipped with processing stations that can handle waste sorting and recycling. The final disposal in new landfill sites must avoid methane emissions (Damanhuri, Handoko, & Padma, 2013).

2.2.3.2. National Industry policy and Environmental protection and management law

The National Industry Policy, NIP and the Environmental protection and management law, EPM were developed in combination to the MSW in 2008-2009 to improve the waste management in the industrial sector (Rawlins, Beyer, Lampreia, & Tumiwa, 2014).

The NIP aims to develop the industrial sector in Indonesia by removing tariff levels on pollution control and waste treatment equipment. The policy also enables soft loans and grants to acquire such equipment (Rawlins, Beyer, Lampreia, & Tumiwa, 2014).

The EPM is a stricter environmental law that regulates the waste management among industries. The law requires high pollutant industries to obtain permits which restrict their solid, liquid and gaseous emissions. If industries do not meet the restrictions, harsh penalties are carried out. These emission restrictions work as a legal hurdle for industries, but it also strengthens the case for modern WtE technology that can reduce industrial emission (Damanhuri, Handoko, & Padma, 2013).

New regulations are prepared by the Ministry of environment that imposes stricter control on handling industrial waste. The new regulation will oblige industries to require documents stating their abilities to treat hazardous waste before they can collect or manage it (Rawlins, Beyer, Lampreia, & Tumiwa, 2014).

2.2.3.3. Import duty and VAT exemption, Income tax reduction for renewable energy projects

To promote renewable technology such as WtE incineration solutions the Ministry of Finance enacted import duty exemptions on machinery and capital used for renewable technology in 2010. This fiscal policy also reduces the net income tax by 5 % of the investment value over six years, when investing in the renewable sector. Other fiscal incentives for renewable energy technology are: accelerated depreciation which will reduce income tax paid by investors, income tax reduction for foreign investors allowing them to pay only 10 % on dividends, and compensation for losses for foreign investors (Damuri & Atje, 2012).

2.2.3.4. National action plan for GHG emission reduction

In 2009, the Indonesian government committed to reduce the nations GHG emissions by 26 %, with national effort, and 41 %, with help from other countries, by 2020 compared to 2009 emission levels. To achieve this goal the National action plan for GHG emission reduction was formed. This plan defines targets for the renewable energy sector as well as for the waste sector to reduce GHG emissions. The targets states that renewables should generate 30.9 % of the nation's electricity by 2030, and at least rise its capacity by 10 GW to 2025. The waste sector has to reduce its GHG emissions by 78 Mt CO_2 to reach the 41 % GHG reduction target (Rawlins, Beyer, Lampreia, & Tumiwa, 2014).

2.2.3.5. Feed-In-Tariff for small and medium scale renewable energy, including WtE

To be able to meet the renewable energy targets the Ministry of Energy and Mineral Resources, MEMR stated a new regulation in 2012 to support decentralized renewable energy generation. The regulation works as an incentive by increasing the Feed-in-tariffs for renewable electricity. The regulation is only adapted for small and medium renewable energy plants, including WtE technology. The tariff levels vary depending on region, technology and voltage of the connecting grid (Rawlins, Beyer, Lampreia, & Tumiwa, 2014).

3. Waste-to-energy technology

Waste-to-energy, WtE technologies can convert the energy content in different kinds of waste into various form of valuable energy. Power can be generated and distributed through national and local grid systems. Heat or steam can be produced and transported through a district heating system or used in industries and for specific thermodynamic processes. Several kinds of biofuels can be extracted from organic waste, fuels that after refining can be sold on the market. Other benefits from WtE technologies are the reduction of waste volume, reduction of land used for landfills, and reduction of the environmental impact landfills have on the environment (World Energy Council, 2013).

Different WtE technologies produce different energy output and the feasibility of the technology depends on the waste composition and the waste flow. Every technology has its advantages and disadvantages. No technology will provide a universal solution that is always best suited for a local area. Each case has to be analysed with regards to the available waste as well as the demanded output and the social impact the technology has on the region (Rawlins, Beyer, Lampreia, & Tumiwa, 2014).

The WtE technologies can be divided into two categories, shown in Figure 3-1. These categories are chemical conversion technologies and thermal processing categories.

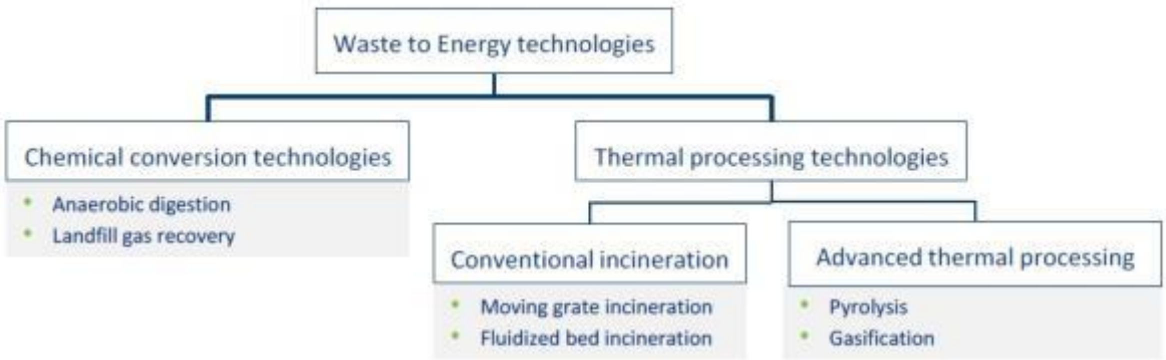

Figure 3-1 Waste-to-energy technologies (Rawlins, Beyer, Lampreia, & Tumiwa, 2014)

The chemical conversion technologies consist of bio-chemical decomposition of organic waste. This decomposition creates biogas which can be burned for direct heat and power use, or refined to biofuels. The main chemical conversion methods are anaerobic digestion and landfill gas recovery (Rawlins, Beyer, Lampreia, & Tumiwa, 2014).

Thermal processing technologies involve combustion of solid waste to generate energy. The combustion generates heat that can be used directly or converted into electrical energy. The most common technology of this kind is conventional incineration. More advanced technologies such as pyrolysis and gasification can produce a more versatile range of products such as syngas, liquid and solid fuels, heat and electricity. These advanced technologies are in the early stages of commercial development (Rawlins, Beyer, Lampreia, & Tumiwa, 2014).

In the sections below the anaerobic digestion and conventional incineration are explained more in detail since these are the technologies that are going to be investigated and modelled in the Kutai Kartanegara region.

3.1. **Waste incineration**

Waste incineration is the most established technology for waste-to-energy recovery. According to Coolsweep (2012) around 2,000 conventional incineration plants are in service today, and together they have a capacity to process 100 million tons of waste per year. The energy recovery process in an incineration plant is simple. Through combustion of waste heat is generated, which is used to produce steam. The steam can, depending on the local demand either be used to generate only electricity or heat. To increase the efficiency both heat and electricity can be generated in a combined heat and power plant, CHP. Depending on technology the net electrical efficiencies varies from 17 to 30%, while CHP plants have energy efficiencies as high as 80 % (Coolsweep, 2012).

The waste used in incineration is a combination of industrial, agricultural and municipal waste, where especially the organic part in agricultural and municipal waste has a lower calorific value due to its high moisture content (Bisaillon, Sahlin, Johansson, & Jones, 2014). Therefore the mixture of waste can have a range of calorific value from 5 MJ/kg to 15 MJ/kg, while for example coal has a calorific value of around 25 - 30 MJ/kg (Alvarez, 2006).

Figure 3-2 shows an overview of an incineration process in a CHP plant. The following sections will go through the main steps of this process in detail.

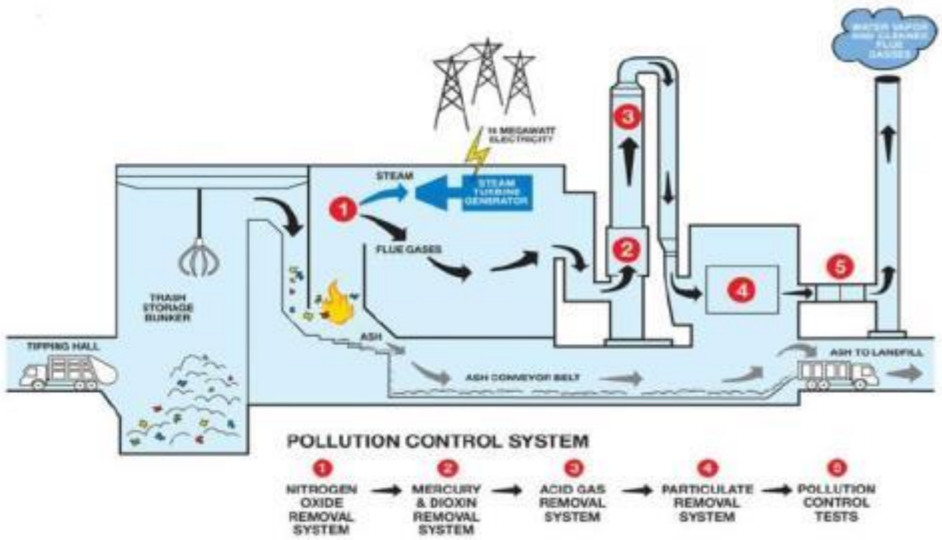

Figure 3-2 Overview over an incineration plant (Coolsweep, 2012)

3.1.1. Furnaces

There are two main types of furnaces in CHP plants where waste is the fuel. These are the moving grate incinerator and the fluidized bed.

3.1.1.1. Moving grate

The moving grate incinerator technology is the most used WtE technology thanks to its durability and ability to process a variation of waste composition.

A crane feeds waste to the moving grate from a storage bunker, where the waste has been mixed and stored. The grate consists of separate moving parts that slowly move the waste further into the incinerator. During the transportation on the moving grate the waste is evenly distributed and dried before combustion. When the dried waste reaches the incinerator combustion takes place (Coolsweep, 2012).

The combustion process is a chemical reaction between elements in the waste fuel and oxygen from the input air. During combustion flue gas is formed and heat is released. Dross is a residue from the combustion process that consists of non-combustible or unburned parts of the fuel (Alvarez, 2006). Disposal of dross and other residues is explained in Section 3.1.4. A simple figure of the combustion process is shown in Figure 3-3. Formulas for the chemical reactions are shown in Equation 3-1 and 3-2 (Alvarez, 2006)

Equation 3-1

$$C + O_2 = CO_2 + heat$$

Equation 3-2

$$2H_2 + O_2 = 2H_2O + heat$$

To get a full and efficient combustion it is vital to have a high temperature, sufficient access of oxygen and a steady circulation of the waste. It is also important to maintain a constant supply of fuel. If the combustion is incomplete it produces undesirable emissions like carbon monoxide and hydrocarbons, it also lowers the efficiency (Alvarez, 2006).

To get a close to complete combustion, air is supplied through the gate from below. This air supply has the purpose to oxygenate the waste as well as to cool down the grate. Secondary combustion air is also supplied straight to the incinerator through nozzles above the grate. This air is supplied to improve turbulence and give a surplus of oxygen to ensure a full combustion (Alvarez, 2006).

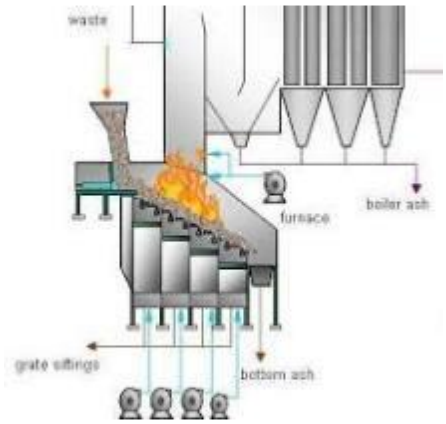

Figure 3-3 Combustion process in a moving grate (Lahl, 2012)

In order to ensure proper breakdown of toxic organic substances the flue gas has to be at least 850°C for at least two seconds (European Commission, 2006). According to Alvarez (2006) this temperature is reached when it is 1,300 °C in the furnace. There are auxiliary burners in the furnace that make sure that the temperature is reached if the calorific value of the waste is not high enough to maintain the desired temperature (Coolsweep, 2012).

The hot flue gas is cooled by the steam boiler, where the heat from the flue gas is exchanged for steam production. After the heat exchange the flue gas is passed to the flue gas cleaning system, before leaving the chimney. The produced ash and slag is transported on the moving grate until it is tipped out to the bottom ash container (Alvarez, 2006).

The capacity of moving grate plants can vary significantly both in terms of waste input and energy output, a typical capacity is around 30-40 ton/hour (Coolsweep, 2012). Moving grate plants have a lower investment cost, but also lower efficiency compared to other incineration technologies. The main advantages with the moving grate are the capacity to handle waste that has not been pre-treated and its ability to accommodate large variations in waste composition and calorific value (Rawlins, Beyer, Lampreia, & Tumiwa, 2014).

3.1.1.2. Fluidized bed

In a fluidized bed the incineration process is done in a bed of sand and waste. The waste is reduced into small particles that are used in the furnace. Combustion air is blowing through the bed from below to transform the bed into a liquid-like state, waste particles are added and mixed with the sand as it is combusted. The temperature in furnaces of this kind is usually around 900 ^{o}C. Bubbling fluidized bed and circulating fluidized bed are the two main types used for commercial use (Alvarez, 2006). A circulating fluidized bed boiler is shown in Figure 3-4.

For waste streams with a homogeneous calorific value the fluidized bed technology gives a higher efficiency compared to the moving grate technology. On the contrary the fluidized bed technology cannot process waste feedstock with a wide variety of quality or high moisture waste in an efficient manner. It also requires pre-sorting and shredding of the waste feedstock, which tend to increase the operating cost compared to the moving grate technology (Alvarez, 2006).

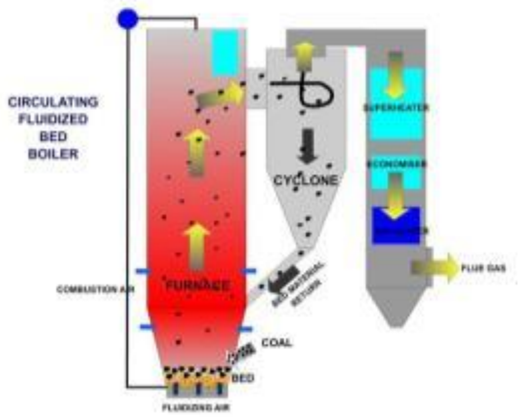

Figure 3-4 Fluidized bed (Bright hub engineering, 2009)

3.1.2. Steam

The main purpose of a CHP is to generate steam that can be converted into electricity and heat through a steam turbine or heat exchanger (Alvarez, 2006). The following sections will briefly explain the steam production process and the steam cycle in a CHP plant.

3.1.2.1. Steam Boiler

The steam is generated in the boiler where feed water is vaporized through heat exchange with the flue gas. The process can be explained through the following steps in Figure 3-5. (1) Feed water is pumped to an economizer where the water is preheated before the boiler during constant pressure. (2) The heated water is vaporized in the evaporator before the generated steam (3) increases its temperature in a super heater. When the over-heated steam has been used to generate electricity in a steam turbine it can be (4) reheated in an intermediate super-heater. By controlling the super heater and re-heater one can get desired steam properties. (5) The combustion air used in the incineration of waste is also pre-heated in the steam boiler to make the combustion process more effective. All of the energy that is used for vaporization of feed water and heating of combustion air comes from heat energy generated by waste incineration in the combustion process (Alvarez, 2006).

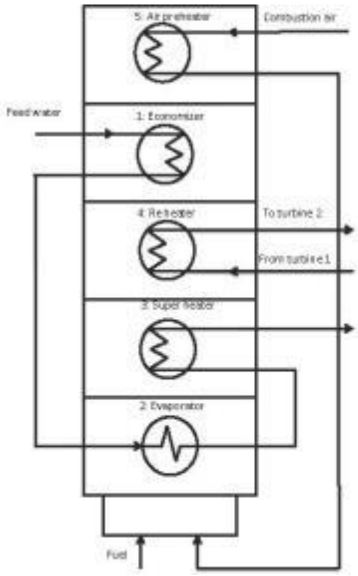

Figure 3-5 Steam Boiler

3.1.2.2. Steam Cycle

The steam generated in the steam boiler can be used in different ways to generate energy. In a CHP plant the steam is used to produce both electricity and heated water. The hot water could then be used to produce district cooling with absorption cooling technology (Alvarez, 2006).

Rankine Cycle

The Rankine cycle is a thermodynamic cycle describing one of the most common steam cycles. A thermodynamic cycle is when a system goes through a set of steps with heat or work exchange with the environment and then returns to its initial state. The Rankine cycle is used to theoretically determine the efficiency of a turbine system. The Rankine cycle may use different types of working fluids where water is the most common one (Alvarez, 2006).

The single Rankine cycle contains four different steps before returning to the initial state, see Figure 3-6;

1. The cold working fluid in the initial state is pressurized at constant entropy.
2. The liquid is heated at constant pressure in in the boiler by an external heat source. The outcome is saturated dry vapor.
3. The vapor is expanded at constant entropy over a turbine, generating electricity.
4. The steam is being condensed at a constant pressure to a cold liquid, and the cycle is completed.

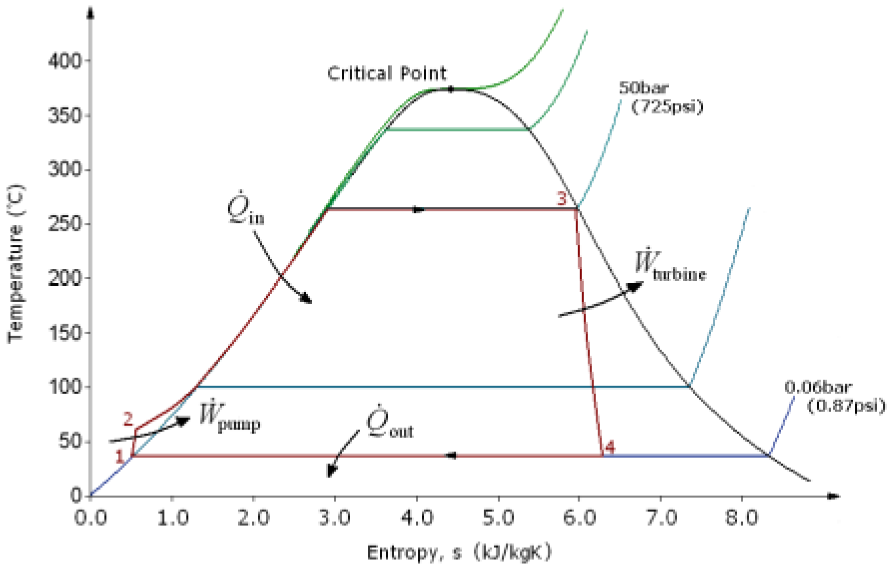

Figure 3-6 TS - Diagram of the rankine cycle (Wikipedia, 2015)

In reality there are no isentropic processes, there are always small losses. In order to make calculations easier, usually isentropic processes are approximated before applying an efficiency factor that describes how close to an isentropic process the real process really is (Alvarez, 2006).

Usually there are more than four steps in the cycle. The energy outtake is usually divided into two parts with an overheating process between them and the working fluid could be heated with excess heat before entering the boiler (Alvarez, 2006).

The ideal thermodynamic cycle is called the Carnot cycle and has no losses. It represents the maximum energy that could be extracted from a thermodynamic process. The highest possible theoretical efficiency is called the Carnot efficiency (Alvarez, 2006).

3.1.2.3. Absorption cooling

The absorption cooling process works like any other cooling machine around the principle that cooling is the same as removing heat. The difference is that there is no compressor in an absorption machine. The compressor work is instead being done by input heat and the heat removed in this process is the face change energy for the cooling medium (Alvarez, 2006). The system consists of four steps illustrated Figure 3-7:

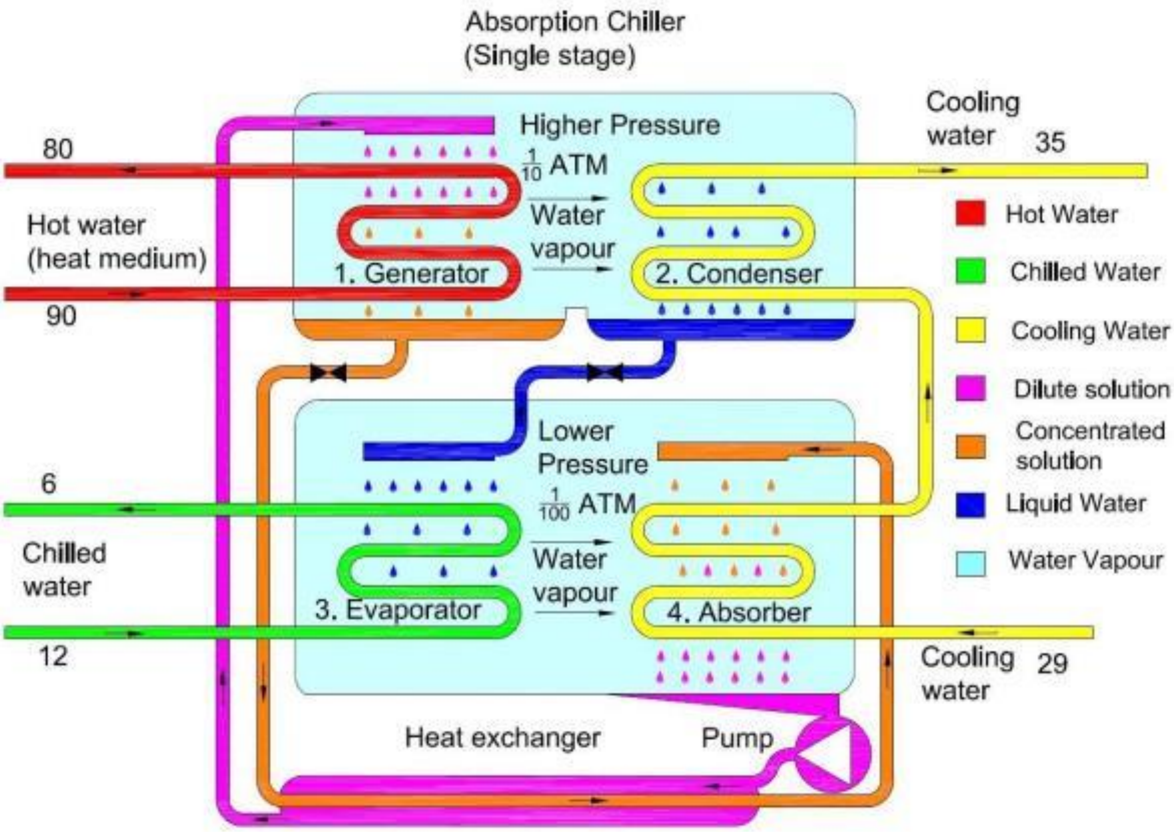

Figure 3-7 Absorption cooler single stage (Simons boilers, 2015)

1. A generator where the input power in form of heat separates the refrigerant from the desiccation liquid, this is done by boiling the solution.
2. The refrigerant gas is lead to a condenser where it is condensed to liquid form after the separation.
3. The refrigerant is then lead to the evaporator where it is being sprayed onto the chilled water. The pressure in the evaporator is low, close to a vacuum. This is necessary for the phase shift process to take place at a lower temperature. When the refrigerant evaporates it "steals" the heat for the phase change from the water, hence cooling it.
4. The evaporated refrigerant is again condensed into liquid and then the concentrated desiccation fluid is used to absorb the refrigerant. The desiccation fluid is very hydrophilic and this reaction will keep the pressure low in the evaporator.

The desiccation/refrigerant solution is then pumped or led by circulation heating back to the generator. The absorption machine needs a cooling flow in the condenser and the absorber. This is used to condensate the refrigerant and to take away the excess heat from the forming reaction (Alvarez, 2006). The COP or coefficient of performance is between 0.4 and 0.7 for an ammonia / water absorption machine (Alvarez, 2006).

3.1.3. Flue gas cleaning

When the flue gas has exchanged the majority of its heat in the steam boiler, it has to be cleaned from pollutants that are produced during combustion. There are two types of pollutants in the flue gas: dust and gaseous emissions. Typical pollutants in dust form are fly ashes and heavy metals, while NO_X, SO_X and HCl are in gaseous form (European Commission, 2006).

The content of pollutions in the flue gas depends mainly on the waste composition, but also on the quality of the incineration process. To reduce emissions into the environment the flue gas has to be cleaned and treated. There are five main groups of methods that are used for treating the flue gas from pollutions. These are: particle filters, dry treatment and semi-dry treatment, wet treatment and NO_X treatment (Alvarez, 2006).

3.1.3.1. Particle filters

To get rid of the dust particles in the flue gas, different kind of particle filters can be used. This method deals only with the particle issue while the gaseous emission problems remain.

Cyclones: In a cyclone the larger particles in the flue gas is whirling in a circular motion and hit the walls of the cyclone due to the centrifugal force. When the particles hit the walls it falls down to the bottom of the cyclone while the particle free flue gas is released through the top of the cyclone (Alvarez, 2006).

Electric filter: In an electric filter the flue gas pass an electrically charged field. The voltage in the field gives the particles a negative charge. These negatively charged particles stick to a positively charged electrode, and is separated from the flue gas. This method is more effective than the cyclone method and it can also be used in an early stage since it is not dependent on the temperature (Alvarez, 2006).

Fabric filters: These filters consist of textile tubes where the flue gases can pass through, but where the dust particles are captured. When the textile tubes are full it can be cleaned by different methods like shaking, pulse jets and air blowing. The most common method is the pulse jet, where high pressure air forces the particle cake to release from the textile tube. When released it is dropped to the bottom of the filter house and gathered for further process. If activated carbon or lime is injected to the flue gas before the fabric filter the cleaning will be more effective (European Commission, 2006). The different particle filters are shown in Figure 3-8.

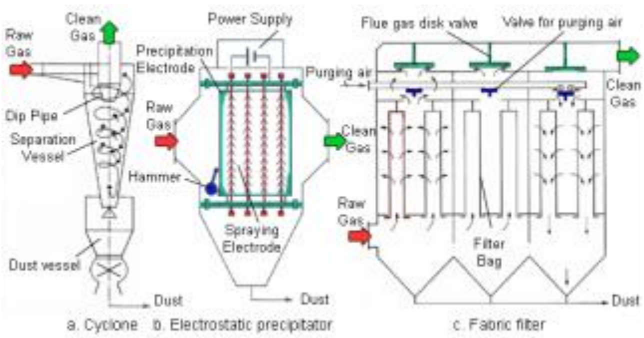

Figure 3-8 Particle filters (Waste-to-energy Research and Technology Council, 2015)

3.1.3.2. *Dry treatment*

The dry treatment is used for both gaseous and dust pollutions. With this method lime is added as an absorbent to the flue gas in special reactors. The lime neutralizes and binds the gaseous acidic parts of the flue gas, such as sulphuric acid and hydrochloric acid, shown in equations 3-3 to 3-6. When passing a fabric filter the absorbed gaseous pollutions get stuck in the fabric filter (Alvarez, 2006).

To improve the cleaning process activated carbon is added to the flue gas before the fabric filter**.** Dioxins and heavy metals bind to the activated carbon and get separated from the flue gas in the particle filter. Other dust pollutants also get separated in the fabric filter. Excess absorbents can be reused in the process. The dry residues from this method have to be stored safely on a controlled landfill (Alvarez, 2006).

Equation 3-3

$$Ca(OH)_2 + SO_2 = CaSO_3 + H_2O$$

Equation 3-4

$$Ca(OH)_2 + SO_2 + \frac{1}{2}O_2 = CaSO_4 + H_2O$$

Equation 3-5

$$Ca(OH)_2 + 2HCl = CaCl_2 + 2H_2O$$

Equation 3-6

$$Ca(OH)_2 + 2HF = CaF_2 + 2H_2O$$

3.1.3.3. *Semi dry treatment*

The semi-dry treatment is a similar method to the dry treatment, see Figure 3-9 for an overview of its main components. In this method the absorbents are added in a mixture with water to create a sludgy mass. When the hot flue gas reacts with this mixture, water is vaporized and toxins are bounded to the absorbents. Pollutants and flue gas is again separated in the filter. Similar to the dry treatment the dry residues from the particle filters has to be stored at regulated landfills (European Commission, 2006).

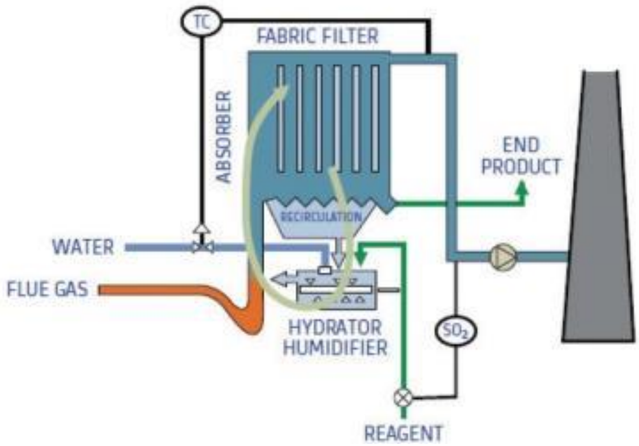

Figure 3-9 Semi dry treatment system

3.1.3.4. Wet treatment

Wet treatment is a more advanced method than the dry treatment methods. In this method the flue gas is cleaned from pollutants in several steps which include different kind of wet scrubbers. If the flue gas contains a lot of dust particles a pre filter is used before the wet treatment. In the first step of the wet treatment the flue gas is cooled down to approximately 60 ^{o}C in the quencher. After the quencher the flue gas is passed to a wet scrubber which contains water with a low pH. In this scrubber HCl, HF, heavy metals and mercury are captured in the water solution. In the third step the pH is raised to a neutral level by adding lime. The SO_2 in the flue gas reacts during scrubbing with lime to form calcium sulphite, which after oxidization forms calcium sulphate and gypsumIn the last step the flue gas is reheated, see Figure 3-10 (Alvarez, 2006).

To clean the flue gas from dioxins it is passed through a fabric filter with activated carbon. The residue water from the wet treatment is contaminated and must be taken care of. This process is described in Section 3.1.4.1. The wet treatment can better handle flue gases with high content of sulphur compared to the dry treatment. The residues from the wet treatment are also easier to handle. On the other hand the wet treatment has a higher investment and operational cost (European Commission, 2006).

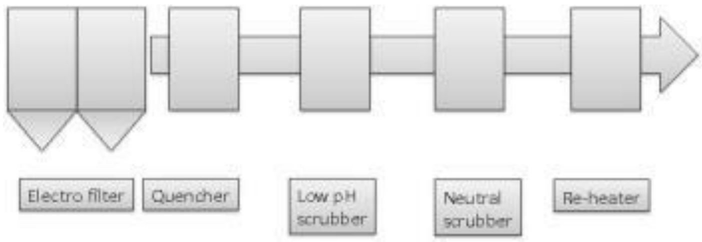

Figure 3-10 Wet flue gas cleaning system

3.1.3.5. NO_X Treatment

There are two main methods used to reduce the level of NO_X in the flue gas; these are the selective catalytic reduction, SCR, and the selective non catalytic reduction, SNCR. It is shown that these methods not only decrease the NO_X content in the flue gas but also it decrease the level of dioxins in the flue gas (European Commission, 2006).

3.1.3.5.1. SCR

In the SCR method ammonia or urea is added to the flue gas before it is passed to a catalyst. The catalyst is usually based on titanium oxide with vanadium. When the NO_X reacts within the catalyst it is reduced to nitrogen and water, Equation 3-7. Before the flue gas can undergo a SCR treatment it has to be free of dust particles and have a temperature of 200 ^{o}C. This requires reheating of the flue gas after the particle filter which is energy demanding and decreases the energy output. The SCR method can reduce the NO_X emissions with 70-90% (Alvarez, 2006).

Equation 3-7

$$NO_x + \mathrm{CO(NH_2)_2} = N_2 + H_2O$$

3.1.3.5.2. SNCR

SNCR is a non-catalytic method where ammonia or urea is used as reductants. With this method NO_X is reduced to nitrogen and water during the incineration process. The process takes place in the temperature range 850 – 1,100 ^{o}C. The SNCR method reduces less NO_X compared to the SCR method, but it is not as expensive to install. The amount of chemicals used in the SNCR method is however larger which increases the operational cost. Usually the SNCR method decrease NO_X emissions with up to 50%, but it can also achieve reductions of up to 70-80% (Alvarez, 2006).

3.1.4. Residues from waste incineration

The residues from the waste incineration are dross and flue gas cleaning residues such as: fly ash and particle cakes from different kind of filters. Where wet treatment is used, sludge is also a residue.

The dross is produced from unburned particles in the combustion process. If a moving grate incinerator is used the weight of the dross can be up to 10-20% of the input waste. Sieved and sorted dross can be used in the construction industry as a complement to gravel. The dross can also be used in road construction and as a final cover on landfills. The disposal of dross needs to meet the local environmental regulations (RVF, 2005).

The residues from the flue gas cleaning contain toxins and needs to be treated carefully. There are several techniques to make sure that dioxins and heavy metals in the residues not leak into the environment. A commonly used technology is solidification, where the residue is mixed with lime or cement to produce a solid mass. The solid mass binds to the toxic pollutions and prevents leakage to the environment. The mass is finally stored at sanitary landfills. The total residues from flue gas cleaning are around 3-5% of the total fuel weight, if the moving grate technology is used (European Commission, 2006).

3.1.4.1. Water treatment

Contaminated water from the wet treatment has to be cleaned before it is discharged to the environment. This is done by the same technology used in municipal sewage treatment. In the first step of this technology precipitant and flocculants binds the heavy metals in the waste water. The flocculants are separated in sedimentation pools. Lastly the water is cleaned through sand filters and filters with activated carbon. This treatment concentrates almost all the pollutions in sludge which is processed as flue gas residues (European Commission, 2006).

3.1.5. Drying techniques

It is possible to improve the quality of solid fuels by increasing the share of dry substance during a drying process. In the drying process moisture in the fuel is evaporated and absorbed by a drying media, usually air, steam or flue gas. By reducing the moisture content in the fuel the heating value increases (Berntsson, Thorson, & Wennberg, 2010).

Some advantages from drying solid fuels are (Berntsson, Thorson, & Wennberg, 2010):

- More heat produced per unit fuel because of a higher heating value.
- Higher yield of electricity per unit of fuel.
- Reduced flow of flue gas, since less moisture have to evaporate in the furnace.
- Increased temperature in the furnace, which improves the capacity of furnace where heat is transferred to the steam cycle.
- Possibility to use low quality heat, for example district heating, to gain primary energy in form of electricity.

There are several techniques used for a drying process. The quality of the drying fuel and heat source available for drying are parameters that decide the suitable drying technique. Some commonly used techniques are presented below.

Fluid bed dryer: In a fluid bed dryer particle fuel is dried in a pneumatic drying process. Flue gas, steam or heated air can be used as a drying medium. This drying technique is very effective but demands pre-treatment (Berntsson, Thorson, & Wennberg, 2010).

Bed dryer: In the bed dryer technique the solid fuel is placed on a moving bed. Heated air is blown through the bed of solid fuel to evaporate and absorb moisture. The air can be heated through a heat exchange from a low quality source, for example district heating. The final moisture level on the fuel vary depending on the flow of the fuel and heated air, the thickness of the solid fuel on the bed as well as the temperature of the heated air. The bed dryer has a relatively low electricity usage (Berntsson, Thorson, & Wennberg, 2010). The bed drying technique is explained in Figure 3-11.

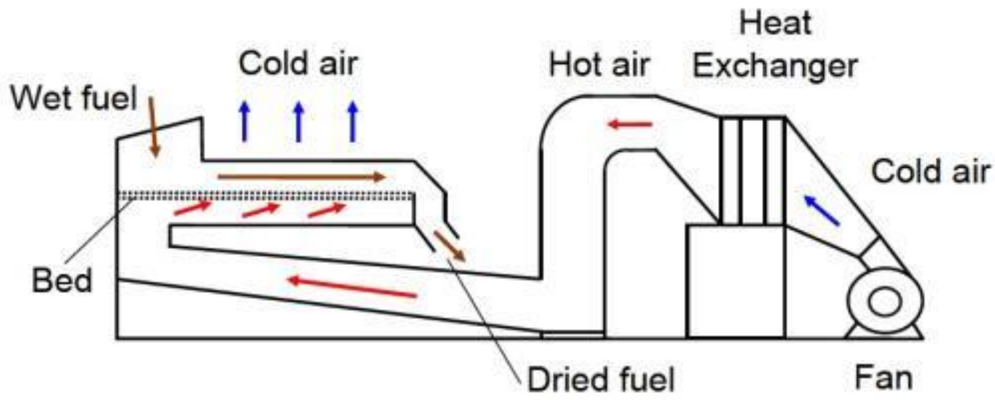

Figure 3-11 Bed drying technique (Berntsson, Thorson, & Wennberg, 2010)

Drum dryer: In the drum dryer the solid fuel is passed through a rotating drum where air is used as the drying medium. Drum dryers are usually heated directly by burners. An advantage with this technique is its flexibility to handle different fuel sizes and moisture levels (Berntsson, Thorson, & Wennberg, 2010).

If the fuel is supposed to be used in a CHP plant it is preferable if the drying system can use a low quality source, in this case the CHP itself can produce the energy used for the drying system. It is also important to choose the right drying method considering what type of boiler is available (Johansson, Larsson, & Wennberg, 2004).

A fluidized bed boiler has the advantage of being able of using fuels with a wide range of moisture content. The fluidized bed can use all types of dryers but the fuel has to be pre-treated before being used in the boiler (Berntsson, Thorson, & Wennberg, 2010).

A roster boiler can also process fuel with a variety of moisture levels, but it is not recommended that the moisture level of the fuel is below 30%. If the moisture level is lower than 30% it can be hard to control the incineration process. The bed dryer is a suitable drying technique for a roster, since it does not require any pre-treatment (Berntsson, Thorson, & Wennberg, 2010).

An example of a successful CHP plant with integrating drying system is the Swedish plant ENA Energi AB (Berntsson, Thorson, & Wennberg, 2010). They integrated a bed dryer heated by district heating to their roster CHP plant. With the bed dryer they could decrease the moisture level of the incoming fuel from 45-48% to 35%. The integrated bed dryer used at the ENA Energi AB plant increased the electricity production with around 10%.

3.2. Biogas

Another common waste-to-energy technology is anaerobic digestion to make biogas from organic waste. Organic parts of the waste have a low calorific value due to the higher moisture content. This makes it more feasible to use in biogas production than incineration.

3.2.1. Anaerobic digestion

Anaerobic digestion is a process in which organic material is broken down to the hydrocarbon methane and carbon dioxide. This is a naturally occurring process that also takes place in swamps and lakebeds or in other places where there are none or a limited availability of oxygen (Mellbin, 2010).

The digestion is carried out from microorganisms that produce enzymes that help to break down the organic material in different steps where it is gradually digested into smaller compounds. In each step the rest product is the substrate for the next step (Mellbin, 2010).

Hydrolysis is the first step in the digesting process. Larger compounds like carbohydrates, proteins and fats are broken down to more soluble compounds by enzymes that the microorganisms are exuding. The enzymes are cutting up the large molecules into smaller pieces that the micro bacteria are able to digest. The smaller compounds that are formed are amino acids, sugars, peptides, alcohols and fatty acids (Mellbin, 2010).

The next step is fermentation where the products that are formed in the hydrolysis step are processed. This is a metabolic process that converts sugars to fatty acids, gases and alcohols. The products in this stage are organic acids, alcohols, ammoniac, carbon dioxide and hydrogen (Mellbin, 2010).

In the anaerobic oxidation the products from former stages as alcohols and fatty acids are broken down by microorganisms into mostly hydrogen, acetates and carbon dioxide (Mellbin, 2010).

In the last step the methanogens are transforming mostly carbon dioxide, hydrogen and acetates to methane. Depending on which of the substrates the microorganisms prefer they are divided into hydrogenotrophs and acetotrophs, in a normal biogas reactor both of the types are present (Mellbin, 2010).

As this is a biochemical reaction being done by microorganisms, an important step is to keep the colony of microorganisms healthy and thriving. The microorganisms are built up by carbon (C), oxygen (O), nitrogen (N), Hydrogen(H), Sulphur(S), phosphorus (P), Sodium (N), Potassium(K), Magnesium(Mg), Calcium(Ca) and Chlorine(Cl). These are also the elements that need to be present to keep the colony alive. Other than this, certain vitamins and metals like Nickel (Ni) and Iron (Fe) are necessary. The microorganisms are also sensitive to temperature, pH and acidity level, it is therefore important to measure these quantity's regularly in a production (Mellbin, 2010).

3.2.2. Substrates

Although the origin and composition of the substrate may vary, the substrate is generally a mix between proteins, fats and carbohydrates. This is the organic material that is being broken down to biogas during the anaerobic digestion (Carlsson & Uldal, 2009).

The carbohydrates are generally a composition of sugars of different sizes. The rule of thumb here is that the larger the molecule, the harder for the microorganisms to break it down. If there is too much of the large molecules, there is a risk that the processing time will get to long. On the other hand, if there is too much of the smaller molecules there is a risk that the production rate of fatty acids will be too high, which will lower the pH (Mellbin, 2010).

There are generally three different types of fats: saturated fats, monounsaturated fats and polyunsaturated fats depending on how many double bonds there are between the carbon atoms. The saturated fats are more stable and thus harder for the microorganisms to process. However the most common type of fats is triglycerides that are built up by three long chain fatty acids and a glyceride molecule. The microorganisms can easily process the glycerides, but the longer fatty acids can cause trouble in the system (Mellbin, 2010).

Proteins are amino acids fixed with peptide bindings. These need to be broken down by enzymes before they can be digested by the micro bacteria. The amino acids are broken down to organic acids and ammonia. The ammonia is helping to keep a high pH in the system, but could be harmful for the microorganisms in too high concentrations (Mellbin, 2010).

3.2.2.1. TS-Content

The TS-content is a measurement that tells how much of the content is left when the material has been heated up to 105 ^{o}C. This gives a good indication of how easily pumped the material is. Usually material with a TS-content over 10-15% needs some sort of pre-treatment to be pumped efficiently in the process (Carlsson & Uldal, 2009).

3.2.2.2. VS-Content

The VS-content or volatile solids is a measurement of how much a fraction of the content will be combusted at 550 ^{o}C. This is a good measurement of how large the organic fraction of the substrate is, and gives an indication of the methane exchange (Carlsson & Uldal, 2009).

3.2.2.3. COD

COD or chemical oxygen demand is a measurement of how much oxygen is needed to fully break down an amount of organic material in water. This is also used for calculation the fraction of organic material (Carlsson & Uldal, 2009).

3.2.2.4. C/N-Ratio

The ratio between the carbon and nitrogen content in the substrate is used as a key performance indicator. Usually a value between 15-30 is to prefer. A lower value, meaning there is too much nitrogen, could result in formation of ammonia, which is toxic to the process. A too large ratio meaning lack of nitrogen, this slows down the digestion process. The optimal value is dependent on the exact composition of the substrate (Carlsson & Uldal, 2009).

3.2.3. Systems

The biogas quality is dependent on how sophisticated the system being used is and the quality of separation of the input substrate. The easiest example of a biogas system is to just harness the biogas from an enclosed landfill. This is done by making a series of gas wells and as the gas is lighter than air it will extract itself.

There are usually some benefits from pre-treatment of the input substrate. The most common type of pre-treatment is mechanical, where for example bags that are containing the substrate are cut up and objects that might be harmful for the process are separated. This could be done with a magnet and/or certain filters that sort out large components for example. The objective here is to make the substrate more accessible for the microorganisms, and regularly this is positively correlated with a smaller particle size (Mellbin, 2010).

The particles are grinded down into smaller particles that are mixed with water. This makes the sludge easier to pump in the system. When waste from slaughter is being used a hygeinazation process could be needed. This usually consists in heating the substrate to 70 ^{o}C during an hour, this is done to make sure that harmful bacteria are removed and is compulsory if the sewage is to be used as fertilizer (Mellbin, 2010).

After the pre-treatment and separation there are different types of reactors. The most common type the continuously stirred reactor, where the substrate is stirred over time. The substrate is pumped in continuously and the rest could be taken out by pump or sewage system, the gas is lighter and could thus be taken out at the top. Another common type of reactor is a reactor with a continuous flow, but where the undigested substrate is not mixed with the digested. This is done by putting the substrate input in one end of the tank and the digested sludge in the other, between them the substrate is moved continuously with stirring mechanisms. There are also types of reactors where the acidity step and the methanogese step are split up in two steps, this allows optimization of each process individually (Mellbin, 2010).

3.2.4. Products

When using anaerobic digestion as a method of utilizing waste-to-energy, there are different products formed.

3.2.4.1. Grades of biogas

There are different types of biogas, and from the digesting processes you usually get a gas that contains 50-75 % methane, the rest is mainly carbon dioxide but also contains some fractions of sulphuric compounds. The quality of the gas is strongly correlated with the substrate being used (Carlsson & Uldal, 2009).

This gas is not pure enough to use in vehicles, but could still be used in stoves and some motors. To use the gas in vehicles, it needs to be purified so that it contains in the order of 95 % methane. This purification is rather costly, but could be proven worth it, if the availability of green-energy in form of heat and electricity is already large, and there is a lack of green fuels (Mellbin, 2010).

3.2.4.2. Fertilizer

The biodegraded waste from the digestion still containins a lot of nutrients and can be used as fertilizer in the agricultural industry. The quality of the waste as a fertilizer is very dependent on the composition of the substrate from the beginning, and will need to be analyzed before use. The fertilizer is rich in N, P and K, though the exact composition is depending on the substrate and the process (Carlsson & Uldal, 2009).

3.3. Environmental aspects of WtE

All energy production from power facilities generates emissions to air and water, as well as residues from unused fuel and fuel gas cleaning (European Commission, 2006).

The impact of the emissions depends on the amount of emissions and on local conditions such as geology, hydrology and how other emissions impact the area (European Commission, 2006).

To control the emissions from waste incineration plants the EU has set up the Waste Incineration Directives, WID. The maximum daily discharged emissions generated by waste incineration are specified in Table 3-1 below (European Commission, 2006).

Table 3-1 Daily emission standards from Waste Incineration Directive

Parameter	Unit	WID (Annex VI)
Total dust	mg/Nm^3	10
HCl	mg/Nm^3	10
TOC	mg/Nm^3	10
CO	mg/Nm^3	50
HF	mg/Nm^3	1
SO_2 and SO_3	mg/Nm^3	50
NO_X	mg/Nm^3	200
Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V	mg/Nm^3	0,5
Hg	mg/Nm^3	0,05
Cd + Tl	mg/Nm^3	0,05
Dioxins and furans	ng/Nm^3	0,1

(WRAP, 2012)

The impact to global warming from different greenhouse gases can be measured by a Global-warming potential, GWP index, see Table 3-2. This index compares how much heat a certain mass of greenhouse gas traps in the atmosphere relative to the same amount of carbon dioxide, hence carbon dioxide have the GWP value 1. The GWP value depends on the absorption of infrared radiation by a given gas and its residence time in the atmosphere. The GWP index is calculated over different time intervals, usually 20, 100 and 500 years. In this report the GWP value for 100 years will be used.

Table 3-2 GWP 100 values IPCC 2007

Gas	GWP100
Carbon dioxide CO_2	1
Methane CH_4	25
Nitrous oxide N_2O	298

(IPCC, 2007)

In the following paragraphs a general description for some environmental aspects and emissions from waste incineration are described.

3.3.1. GHG

Emissions of greenhouse gases such as carbon dioxide, CO_2, methane, CH_4, and nitrous oxide N_2O increase global warming. Carbon dioxide is the most common of these greenhouse gases, approximately 82% of the anthropogenic emissions. CO_2 is mainly generated from combustion of fossil fuels, either for electricity generation, transportation or industrial use. CO_2 generated from combustion of biofuels is seen to be climate neutral. The amount of CO_2 emissions is proportional to the carbon level in the fuel. Carbon dioxide is absorbed by plants in the biological carbon cycle (EPA United States Environment protection agency, 2015).

Methane, CH_4, is a gas that is formed by anaerobic digestion of organic compounds. Methane is a much stronger greenhouse gas than carbon dioxide. One kg of methane has the same impact on the climate as 25 kg of carbon dioxide. Methane is usually emitted to the air from extraction of coal and natural gas, livestock and agricultural sector and by decay of organic waste in landfills (EPA United States Environment protection agency, 2015).

Nitrous oxide, N_2O, is emitted to the air from industrial and agricultural activities. It is also emitted during combustion of fossil fuels and MSW. Nitrous oxide can be emitted from waste incineration if the combustion temperature is insufficient and if there is a lack of oxygen. The level of nitrous oxide often correlates to the level of CO. Nitrous oxide contributes 298 times more per kg to the global warming then 1 kg of carbon dioxide. Nitrous oxide is also ozone-depleting (EPA United States Environment protection agency, 2015).

A waste incineration plant will decrease the amount of greenhouse gases emitted compared to a coal or diesel plant. The carbon dioxide emissions from waste incineration is less than from a coal condense facility. Levels of nitrous oxide are controlled by a high quality combustion process. The methane emission level will decrease drastically with a waste incineration plant due to no methane emission in the incineration process and smaller amount of waste disposed at landfills (European Commission, 2006).

3.3.2. Dioxins

Dioxins are a collective name for around 200 organic chemical compounds that contains chlorine. Dioxins are environmental pollutants with a high toxic potential and slow biodegradation. They are toxic to humans and animals and can bio-accumulate in fatty tissues since they are lipophilic (European Commission, 2006).

Dioxins can form at incomplete and low temperature combustion where chloride is present in the fuel. Industrial manufacturing processes generate dioxins as an unwanted by-product in for example bleaching of paper pulp and smelting. Waste incineration used to generate dangerous levels of dioxins due to incomplete burning. But thanks to modern flue gas cleaning technology, a better controlled incineration process and stricter regulations the air emission of dioxins from incineration is very low today. Today most of the dioxins from incineration are fixated in the fly ash. The fly ash is considered hazardous and disposed at controlled landfills. Using recommended techniques waste incineration will make dioxins emissions very low (European Commission, 2006).

3.3.3. Particles and dust

Particles in the air come naturally from volcanos, forest fires, sandstorms and pollinations. These particles tend to be bigger than particles caused from human activities such as traffic, fireworks, industries and combustion of bio fuel, waste, coal and oil products. In Europe, around 90 % of all the particles in the air have been caused from natural activities and 10 % from human activities, but in cities the contribution from anthropogenic particles is much higher. Smaller anthropogenic particles can more easily be inhaled and cause health risks in form of lung diseases and cancer (European Commission, 2006).

Dust emissions from incineration plants mainly consist of fine fly ash particles. The flue gas cleaning system greatly cleans the flue gas from dust and particles, and the emissions will be within the standard regulations. Dust can also be emitted when waste is unloaded into the bunker. A negative pressure in the bunker will decrease these dust problems (European Commission, 2006).

3.3.4. Acidification

Anthropogenic acidification is mainly caused by emissions of nitrogen - and sulphuric oxides from combustion. Some of the sulphuric oxide and nitrogen oxide react with vapour in the clouds to form acids and will later fall as acid-rain. The acid-rain causes acidification in lakes and forests (European Commission, 2006).

3.3.4.1. Sulphuric oxides, SO_x

Sulphuric oxides are created during incineration of fuels containing sulphur, and almost all fuels contain sulphur. Municipal waste contains low levels of sulphur since it mainly consists of organic waste or plastics. The most common sources of sulphur in waste is paper and plaster boards. Flue gas cleaning systems can capture over 80% of the sulphuric oxides to emit to the air. The separated sulphur is bound in residue as gypsum and calcium sulphite (European Commission, 2006).

3.3.4.2. Nitrogen oxides, NO_x

Nitrogen oxides are formed by the reaction of the nitrogen in the fuel or air with the oxygen in the air. In waste incineration the main nitrogen oxides produced are nitric oxide, NO (approximately 95 %) the rest is NO_2.Production of NO_X in waste incineration is usually low due to low temperatures in the afterburner chamber. The NO_X level from waste incineration plants can be decreased by controlling the incineration process and SNCR/SCR techniques (European Commission, 2006).

3.3.5. Heavy metals

Heavy metals are highly toxic and dangerous for the environment. The amount of heavy metal emissions depends mainly on the quality of the incoming waste. Examples of heavy metal emissions from waste incineration are mercury, cadmium and thallium compounds, as well as lead, chromium, cobalt among others (European Commission, 2006).

Mercury can usually be found in municipal waste in the form of batteries and thermometers. To reduce mercury levels it is important to collect these items before incineration. Sources of cadmium in the municipal waste are electronic devices and batteries. Thallium is not present in MSW, but can be found in hazardous waste. Small amounts of other heavy metals can be found in different electronical devices and hazardous waste (European Commission, 2006).

Heavy metals can be found in both the bottom ash and the fly ash. Proper waste management can reduce the amount of heavy metals in the incoming waste. After incineration heavy metals are captured in activated coal in the flue gas system (RVF, 2005).

3.3.6. Carbon monoxide, CO

Carbon monoxide is an odourless toxic gas that is produced from incomplete combustion of carbon based compounds. Incomplete combustion takes place if there is insufficient oxygen locally or insufficient temperature to complete the combustion. High levels of CO can create explosive mixtures in the flue gas. When CO is emitted to the atmosphere it is oxidised to CO_2. By controlling the incineration process the CO level can be decreased. A low level of CO in the flue gas can be seen as a quality measure of the combustion (European Commission, 2006).

3.3.7. Hydrogen chloride, HCl

Hydrogen chloride is a gas that is acid when high concentrations are solved in water. The hydrogen chloride is produced during the incineration of chloride or organic chloride compounds. In MSW approximately 50% of the chloride comes from PVC plastics. The hydrogen chloride has an impact on plant growth if solved in water. The flue gas cleaning system decrease levels of HCl emitted to the air within the standard regulations (European Commission, 2006).

3.3.8. Hydrogen fluoride, HF

Hydrogen fluoride is an acidic gas, formed during combustion of fluorinated compounds. In MSW the main sources are fluorinated plastics and textiles. HF is highly soluble in water and can have an impact on plant growth. Levels of HF are regulated in the flue gas cleaning system (European Commission, 2006).

3.4. Economical models

There are different kinds of investment calculations to determine if an investment is financially viable or not. In this report the payback time and the net present value, NPV, models are used. These two models are among the most commonly used methods by businesses. To be able calculate these models the investment cost and annual cash flow from the different plants has to be estimated (Gavelin & Sjöberg, 2012).

3.4.1. Payback model

The payback method calculates the time it takes for an investment to be recovered based on its annual profits. The payback time of an investment is important when determining whether to proceed with a project or not. If an investment has a longer payback time then the lifetime of the investment it is not a profitable investment. A short payback time is desirable. The payback time is calculated by dividing the investment cost with the annual cash flow as shown by Equation 3-8 (Gavelin & Sjöberg, 2012).

Equation 3-8

$$Payback\ time\ =\ investment\ cost/annual\ cash\ flow$$

Estimations of investment cost and annual cash flow are presented in Chapter 5.6.

3.4.2. NPV model

The net present value method, NPV, determines the present value of an investment by the discounted sum of cash flows received from the project during the investments estimated lifespan, Equation 3-9 (Gavelin & Sjöberg, 2012). A zero net present value means that the project will repay the investment cost plus a required rate of return. When the net present value is zero the rate of return is called internal rate of return, IRR. If the net present value is positive it means that the investment is financial viable. A negative net present value means that the project won't be profitable in comparison to another investment with the stated rate of return (Gavelin & Sjöberg, 2012).

Equation 3-9

$$NPV\ =\sum_{t=1}^{T}\frac{Ci}{(1-r)^t}-Co$$

Box 3-1 Parameters in Equation 3-9

NPV = Net present value
Co = Initial investment cost
T = Estimated lifetime of investment
r = discount rate/rate of return
Ci = Annual cash flow

4. Method

The work during this master thesis has been divided into three different work periods: preparation work, field study and final work.

During the preparation stage an extensive literature study was conducted, to gain knowledge about waste-to-energy techniques and waste management. This literature study was the base for the background section and the theoretical framework in this project. During this stage of the project a model was made to simulate the energy output of a waste-to-energy plant. This model was based on thermo-dynamical formulas and incineration theory from Alvarez (2006). For biogas production key numbers from Substrathandboken (2009) were used. Two other models were made to evaluate the plants economic and environmental feasibility.

To get a deeper knowledge of waste-to-energy techniques, two field trips were arranged: in February to Borlänge Energi's waste-to-energy incineration plant and in April to Uppsala Energi's biogas plant.

The field study was conducted in Kutai Kartanegara, Indonesia between May 13th and July 6th. The majority of the work was performed in the subdistrict of Tenggarong. Shorter field trips were also made to the sub-districts Muara Jawa and Muara Kaman as well as to the regions Samarinda and Balikpapan. During these field trips data about the waste and waste management in the region was collected. If no documented information was available the data was collected through interviews. During these interviews and field trips a translator was used. The waste data retrieved was used as input in the waste-to-energy plant model.

Other data that was necessary for either the economical, energy output or environmental model was received from the various offices, see Table 4-1. Information and interviews in Indonesian were translated to English with the help of a translator.

In the final work stage the data retrieved during the field study in Indonesia was used as inputs in the models and the results were analysed and summarized. To complete the economical results, cost information had to be complemented by relevant suppliers and prior studies. During the final work uncertain variables were analysed with the help of a sensitivity analysis.

In addition to the pre-feasibility study a small report about the Middle Mahakam project and a promotional article about the pre-feasibility study were completed. These can be seen in Appendix A and Appendix B.

The following sections will describe the methodology for each subject in more detail. The first section describes the different scenarios, systems and estimated waste supply used for the modelling. The other sections will describe methods for: energy production, economical calculations, environmental calculations and sensitivity analysis.

Table 4-1 Summary of the data collection

Place of Information	Type of Information	Information for	Translator needed
Balitbangda	Survey Document	LPG use Background info	Yes No
Tenggarong Landfill	Interview Observation (pictures)	Waste management	Yes
Tenggarong Waste Management Office	Documents Interview	Waste data (amounts) Cost information	No Yes
Tenggarong Waste pickers	Interview Observation (pictures)	Waste management Waste management	Yes Yes
PLN	Documents	Electricity price Energy demand	Yes Yes
Bappeda Office	Documents	Regional background Cooling	No No
Energy office	Documents	Biogas cost	Yes
Transportation office	Documents	Transportation cost	Yes
Muara Jawa Landfill Waste pickers Waste Bank	 Interview Interview, observation	 Waste management Waste management Waste management	 Yes Yes Yes
Muara Kaman	Survey	Waste management Energy usage Background	Yes
Balikpapan landfill	Documents Interview	Waste data (amount) Waste management	Yes Yes
Samarinda waste management office	Documents	Waste data (amount) Waste Composition	No No

4.1. Scenarios

In this study different scenarios are simulated and evaluated. Various amounts of waste are collected in the different scenarios depending on the size of collection area. If collection is made from larger areas more waste can be supplied which gives a greater energy output. On the other hand larger collection areas will lead to more transports that are costly and cause larger GHG-emissions. The three different scenarios are presented below.

4.1.1. Scenario 1

In Scenario 1, waste is only collected from the Tenggarong district. Since Tenggarong is the most populated district in Kutai Kartanegara and has a central economical and governmental role for the region as well as a central geographical location it serves well as the holder of a WtE power plant. The fact that Tenggarong has a functional infrastructure compared to other districts, is located along the Mahakam River, and already has a functional waste management system also contributes to the choice of Tenggarong as the WtE centre (PKKK, 2015). In the other scenarios it is assumed that Tenggarong is the holder of WtE technology, hence this district will be the centre in all scenarios. Demographic data is summarized in Table 4-2.

Table 4-2 Demographic data of Tenggarong subdistrict

Sub-district	Population	Pop. density people/km^2	Infrastructure	Waste management
Tenggarong	104,044	261	River and roads	Yes

(BPS-Statisitcs of Kutai Kartanegara regency, 2013)

4.1.2. Scenario 2

To supply the WtE technologies with more municipal solid waste the collection area is expanded. In Scenario 2 the sub-districts within a 30 km radius around Tenggarong are included. By using this radius waste from highly populated sub-districts and Samarinda is collected. For demographic data see Table 4-3. All these districts also have good infrastructural connections to Tenggarong (BPS-Statisitcs of Kutai Kartanegara regency, 2013). The type of transportation of waste from all districts will be explained further in Section 4.8.4.2 Waste transport and handling.

The main objective in Scenario 2 was to cover Samarinda. Samarinda is important since the region has both a high population and a high population density. It also has a functional waste management system that generates large amounts of municipal solid waste and is located around 45 minutes from Tenggarong centre (Head of DKPP Samarinda, 2015).

Table 4-3 Demographic data of the rest of the sub-districts in Scenario 2

District/Region	Population	Pop. Density people/km^2	Waste management
Tenggarong Seberang	65,014	149	No
Sebulu	38,930	45	No
Loa Kulu	43,383	31	Some
Loa Janan	61,783	96	No
Samarinda	857,569	1,194	Yes
Total Scenario 2	1,170,709		

(BPS-Statisitcs of Kutai Kartanegara regency, 2013) (Samarinda Green Clean Health, 2014)

Table 4-4 Shows the distance to Tenggarong from the different subdistricts in scenario 2.

Table 4-4 Distance to Tenggarong from the different subdistricts in scenario 2

Scenario 2	Distance road [km]	Distance river [km]
Samarinda	25	44
Sebulu	89	34
Tenggarong sebarang (Sepali)	75.6	12
Loa Kulu	55	-
Loa Janan	42	-
Sum:	234	112

(BPS-Statisitcs of Kutai Kartanegara regency, 2013)

4.1.3. Scenario 3

In Scenario 3 the collection area is expanded further to increase the MSW supply. The main target in this scenario was to include the highly populated regions Balikpapan and Bontang. These regions supply large amounts of waste and have a functional waste management system. To be able to collect the MSW in Balikpapan and Bontang the collection radius is expanded to approximately 150 km. Within this radius, several of Kutai Kartanegara's sub-districts are located. The sub-districts that are located between Tenggarong and Balikpapan or Bontang will be included in this scenario. Other sub-districts in Kutai Kartanegara that have a reasonably high population and also have a functional infrastructure to Tenggarong are included in this scenario. Remote sub-districts with low population and substandard infrastructure will not be included in this scenario. The included sub-districts/regions and important parameters considered are presented in Table 4-5 and Table 4-6.

Table 4-5 Demographic data of the subdistricts in scenario 3

District/Region	Population	Pop. Density people/km^2	Waste management
Samboja	58,171	56	No
Marang Kayu	25,256	22	No
Sanga-Sanga	19,229	82	No
Anggana	34,943	19	No
Muara Jawa	36,839	49	Yes
Muara Badak	42,985	46	No
Balikpapan	715,000	1,421	Yes
Bontang	175,830	350	Yes
Total Scenario 3	2,278,962		No

(BPS-Statisitcs of Kutai Kartanegara regency, 2013) (Head of Balikpapan Waste Management, 2015) (Balitbangda, 2015)

Table 4-6 Distance to Tenggarong from the different sub-districts in Scenario 3

Scenario 3	Distance road [km]	Distance river [km]
Balikpapan	145	171
Kota Bontang	129	163
Marang Kayu (Santan)	114	144
Anggana	-	74
Muara Jawa (Handil)	147	82
Sanga Sanga	72.2	75
Samboja	97	123
Sum:	704,2	832

(BPS-Statisitcs of Kutai Kartanegara regency, 2013)

4.2. Systems

Different WtE techniques generate various energy outputs. To evaluate which technology would be most suitable for the available waste stream in Kutai Kartanegara different systems are simulated.

Three different systems will be evaluated. The systems are explained briefly below. Each system will be analyzed by its economic and environmental performance. The most suitable system will be recommended and explained in more detail in the end of the report.

- **System inc** – The base system consists of a moving grate incineration plant. In this system all received waste will be incinerated. The energy output from the incineration plant is heat and electricity. System inc will be used as the reference system in the study.
- **System inc + dryer** – This system is a moving grate incineration plant with an integrated bed dryer. The bed dryer will dry incoming waste to a moisture content of 40%. All waste is incinerated.
- **System inc + bio** – This System consists of a moving grate incineration plant and a biogas plant. In this system the organic fraction is separated from the inorganic fraction. The inorganic fraction, around 40%, is combusted in the incineration plant and generates heat and electricity. The organic fraction, 60%, is fed into a biogas plant. The biogas plant generates biogas that is used to generate electricity.

4.3. Waste Stream

This section describes the method for determining waste composition and waste supply.

4.3.1. Waste composition

Waste composition data has been retrieved from a DKPP report in Samarinda (Abadi, 2014). Since no conclusive studies have been done on the waste composition in Tenggarong it will be estimated to be similar as the waste composition in Samarinda. This estimation is appropriate due to the regions similarity from a geographical as well as a socio-economical perspective (BPS-Statisitcs of Kutai Kartanegara regency, 2013). The waste composition in Samarinda is used for all regions in this report. The waste composition is used to calculate the elemental composition which decides the heating value. The waste composition and heating value is presented in section 5.2.

4.3.2. Waste supply

The waste supply is dependent on the waste generation and the waste collection. This section will describe the estimations that support the waste supply.

According to PKKK in Tenggarong the estimated waste generation in Kutai Kartanegara is 0.7 kg/ person per day. The same waste generation is used for all districts within the region even if the living standard may vary between urban and rural districts. PKKK also has data for the waste volume put on landfill every year (PKKK , 2014). The Samarinda waste density is used to calculate the amount of waste put on landfill, using Equation 4-1.

Equation 4-1

$$Tenggarong\ waste\ amount\ on\ landfill\ =\ Annual\ volume\ landfill\ *\ waste\ density$$

With help of the total amount of waste put on landfill the collection rate can be calculated, using Equation 4-2.

Equation 4-2

$$Tenggarong\ collection\ rate\ = \frac{Tenggarong\ waste\ amount\ on\ landfill}{(Tenggarong\ waste\ generation\ *\ Tenggarong\ population)}$$

This collection rate does not include the waste fraction that is collected and separated by waste pickers. Hence the actual collection rate would probably by higher than this value. Even so, the collection rate is important since it states the fraction that is put on landfill and in the future can be used for WtE technologies.

The collection rate and waste generation is estimated to be same in the various Kutai Kartanegara sub-districts as it is in Tenggarong, as shown by Equation 4-3.

Equation 4-3

$$Waste\ supply\ subdistricts = \frac{Tenggarong\ waste\ generation}{person} * Tenggarong\ collection\ rate * population\ in\ subdistrict$$

In Samarinda the waste generation is calculated with help from a survey by Badan Lingkungan Hidup, BLH. The survey stated that the daily waste generation was 765 tons, which with Samarinda's population equals to 0.89 kg / person /day (Abadi, 2014).

$$Waste\ generation\ Samarinda\ =\ 765\ ton\ /day\ /\ Population\ in\ Samarinda\ region$$

According to Samarinda waste management, 466 ton municipal solid waste is put on landfills daily in Samarinda (Head of DKPP Samarinda, 2015). With knowledge of the total waste generation the waste collection is calculated with Equation 4-4.

Equation 4-4

$$Waste\ collection\ rate\ Samarinda\ = \frac{Waste\ on\ landfill\ Samarinda}{Waste\ generated\ Samarinda}$$

As in the Tenggarong case this collection rate does not include the waste separated by waste pickers.In Balikpapan only the data on waste supplied to the landfill has been retrieved from Balikpapan waste management. With the data available and the current population in Balikpapan the waste supply per person a day is calculated using Equation 4-5.

Equation 4-5

$$Waste\ supply\ Balikpapan\ = \frac{Waste\ to\ landfill}{Population\ Balikpapan}$$

Since no waste generation or waste separation data is available for Balikpapan, the waste collection rate cannot be calculated.

No waste data at all have been retrieved from Bontang. It is assumed that Bontang has the same waste generation and collection rate as Tenggarong . This seems to be suitable considering the similarities in living standard in the regions (Balitbangda, 2015).

4.4. Waste incineration

The heat generation in the furnace along with the flue gas composition and the steam cycle is simulated in the modelling software Matlab. The model is made in several steps and the methods used are derived from Alvarez (2006). The input to the model consists of the chemical composition and the moisture fraction of the fuel.

4.4.1. Heat production

This section describes the methods used to model all the parameters needed to describe the incineration.

4.4.1.1. Composition of the fuel

In order to simulate the elemental composition of the waste a Matlab model was created. The created Matlab model was based on the same data as the ORWARE model. The ORWARE model is a simulation tool for waste management which is described further in Appendix C.

The input in this model is the specific weight percentage of different waste fractions. The model returns the elemental composition of the waste regarding the most important elements for determining the effective heating value. These elements are:

- Coal
- Oxygen
- Hydrogen
- Sulphur
- Nitrogen
- Moisture
- Ash

These are also the needed input for Dulong's formula that determines the effective heating value (Alvarez, 2006).

4.4.1.2. Air supply

When we know the chemical composition of the fuel, the first step in the combustion modelling process is to calculate the theoretical amount of air needed for complete combustion of the fuel. The most relevant chemical processes involved in the combustion are presented in Equation 4-6 to Equation 4-8 (Alvarez, 2006).

Equation 4-6

$$C + 0_2 = CO_2 \; + \; 33913\frac{kj}{kg}C$$

Equation 4-7

$$H_2 + \frac{1}{2}O_2 = H_2O + 142770\frac{kJ}{kg}H_2$$

Equation 4-8

$$S + O_2 = SO_2 + 10467\frac{kJ}{kg}S$$

Based on these molar equivalencies we can determine the theoretical air demand A_t according to Equation 4-9 (Alvarez, 2006).

Equation 4-9

$$\frac{A_t}{kg_{fuel}} = \frac{4{,}76 * 22{,}7}{100} * \left(\frac{c}{12} + \frac{h}{4} + \frac{s}{32} - \frac{o}{32}\right)$$

In reality the fuel and air does not mix completely, especially not with solid fuels. We are therefore talking about the theoretical air supply and the larger real air supply, A_r. For municipal solid waste, there is a specific airflow factor of 1.5-1.6. Hence the real air supply can be calculated as shown in Equation 4-10 (Alvarez, 2006).

Equation 4-10

$$A_r = 1{,}5 * A_t$$

4.4.1.3. Heating value

When the chemical composition of the fuel is known, the effective heating value, H_i is determined through Dulong's formula, Equation 4-11 (Alvarez, 2006).

Equation 4-11

$$H_i = 0{,}339 * c + 0{,}105 * s + 1{,}21 * \left(h - \frac{o}{8}\right) - 0{,}0251 * f$$

Where c, s, h, o and f respectively are the carbon, sulphur, hydrogen, oxygen and moisture fractions of the fuel.

Dulongs formula's starting point is the released energy from the three most relevant combustion processes in Equation 4-6 to Equation 4-8, the steam forming enthalpy of water and Avogadro's law: "Equal volumes of any gas has the same amount of molecules at the same temperature and pressure" (Alvarez, 2006).

4.4.1.4. Flue gas composition

The assumption made in the model is that complete combustion occurs and that the reactions taking place in the combustion process are according to Equation 4-6 to Equation 4-8. An assumption here is that nitrogen is an inert gas. The flue gas composition is then derived from the mass balance of the fuel, and the intake air. When the composition of the flue gas is known, the specific heat can be calculated, this is important for the combustion step (Alvarez, 2006).

4.4.1.5. Combustion

In the combustion model, the released heat from combustion is used to heat up the flue gases. When we know the specific heat of the flue gas, the theoretical combustion temperature is calculated from Equation 4-12 (Alvarez, 2006).

Equation 4-12

$$t_g = \frac{H_i + A_r * cp_a * t_a}{g_r * cp_g}$$

- t_g is the theoretical combustion temperature.,
- H_i is the effective heating value of the fuel.
- A_r is the real air supply.
- cp_a is the specific heat of the air supply.
- t_a is the temperature of the air supply.
- g_r is the real flue gas flow.
- cp_g is the specific heat of the fluegas

(Alvarez, 2006)

When the temperature of the flue gas and the specific heat is known, the enthalpy can be calculated using Equation 4-13.

Equation 4-13

$$i_g = cp_g * t_g$$

4.4.2. Boiler

Initially the gases are cooled down from the theoretical combustion temperature to 155 ^{o}C. This is the temperature that the flue gas cleaning process needs to work properly (European Commission, 2006).

This enthalpy change is used to make steam in the boiler. The temperature is then reduced to 130 ^{o}C in the flue gas treatment process. The last enthalpy change from 130 ^{o}C to 80 ^{o}C is used to preheat the air feed.

4.4.3. Steam cycle

The boiler delivers superheated steam with the temperature 400 ^{o}C and the pressure of 40 bar. The temperature and pressure is reduced down to 160 ^{o}C and 6 bar in a high-pressure turbine, and then heated again to 400 ^{o}C before the low-pressure turbine where it reduced down to the condensing pressure of 0.13 bar and the steam ratio of 0.95. In the low-pressure turbine, a fraction of the steam is linked to preheating the feed water. The program finds the solution that gives the optimal efficiency of the process.

Table 4-7 Efficiencies used in the the model of the powerplants

Turbine isentropic efficiency	85%
Generator	98%

(Axelsson & Kvarnström, 2010)

The information in Table 4-7 has been used in previous studies and has also been confirmed as standard with different manufacturers.

The steam is then condensed against DH/absorption cooling-grid before returning to the feed water tank. If there is excess heat after the cooling process this is cooled against the Mahakam River. The Mahakam River is assumed to be an infinite cooling sink.

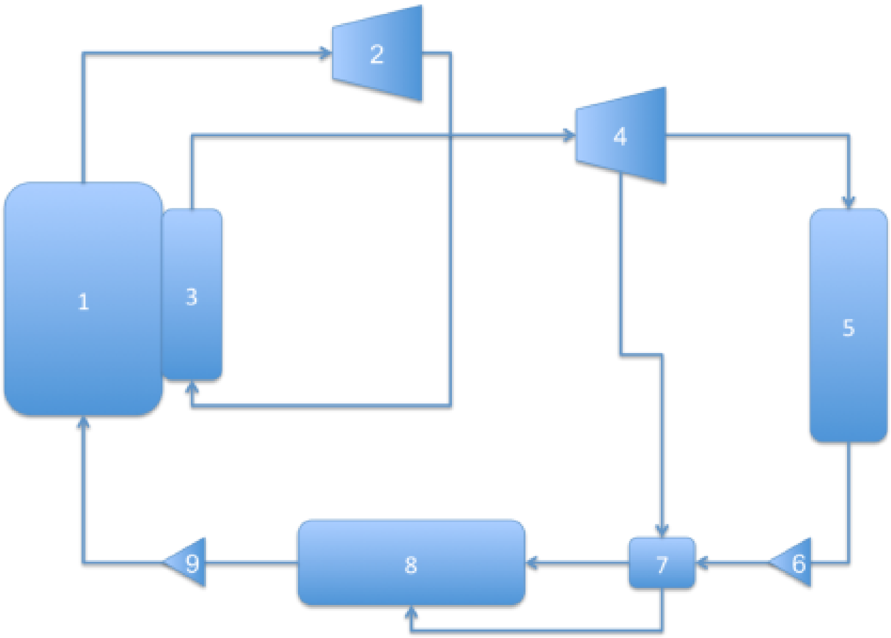

Figure 4-1 Flowchart of the steamcycle process

A steam-cycle model was made in Matlab. The model is based on commercial techniques, with the following components. A boiler (1), a high pressure turbine (2), super-heater (3), low-pressure turbine (4), condenser (5), pump (6), heat exchanger (7) and feed water tank (8). See Figure 4-1 Flowchart of the steamcycle processfor an overview (Alvarez, 2006).

In the Matlab steam-cycle model the power output and heat output is calculated. These calculations are based on mass and energy balances. This states that the sum of energy flow into one point is equal to the sum of energy flowing out of it, see Equation 4-14 (Alvarez, 2006). The same applies to the mass flow.

Tabell 4-8 Paramteres in the energy balance

Explanation	Unit	Parameter
Power	[W]	P
Enthalpy	[kJ/kg]	h
Mass flow	[kg/s]	m

Equation 4-14

$$P_{in} = h_{in} * m_{in} = h_{out} * m_{out} = P_{out}$$

The steam feed from the boiler is calculated from the actual energy outtake in the boiler, meaning the enthalpy change from Point 9-2 and Point 2-4. The power in the boiler is divided by this enthalpy change and this gives the mass flow of steam, Equation 4-15 (Alvarez, 2006).

Equation 4-15

$$steamfeed = \frac{P_{boiler}}{H_{turbin1} + H_{turbin2}}$$

The energy outtake in both the turbines and the condenser is based on the enthalpy change, the isentropic efficiency and the steam feed in the turbine according to Equation 4-16 and Equation 4-17 (Alvarez, 2006):

Equation 4-16

$$Power_{turbine} = Steamfeed * (H_{before} - H_{after})$$

Equation 4-17

$$H_{after\ is} = \frac{H_{before}}{n_{is} * (H_{before} - H_{after})}$$

The mechanical energy from the turbine is then applied to the electrical efficiency of the generator (n_{gen}), Equation 4-18 (Alvarez, 2006).

Equation 4-18

$$Power_{generator} = Power_{turbine} * n_{gen}$$

The power flow to the absorption cooling grid is based on all the enthalpy left in the steam after Turbine 2 and the condenser pressure that is set to 0.05 bar corresponding to a void of 95 % from tables in Alvarez (2006). All the steam is condensed to water, described in Equation 4-19 and Equation 4-20 (Alvarez, 2006).

Equation 4-19

$$H_{condensor} = H_{before} - H_{after}$$

Equation 4-20

$$Waterfeed_{absorption} = Steamfeed \frac{(H_{condensor})}{(T_{out} - T_{in}) * Cp_{H2O}}$$

Equation 4-21

$$Power_{absorbtioncooling} = Waterfeed_{absorption} * H_{condensor} * COP_{abs}$$

This is applied to the water flow in the absorption cooling grid that is calculated with the assumption that the cold water has a temperature of 25 ^{o}C and is heated to 115 ^{o}C, a temperature that the absorption cooling machine needs to work properly, this is described in Equation 4-21 (Alvarez, 2006).

4.5. Absorption cooling

The section absorption cooling describes the methods used to determine the parameters needed to calculate the technical aspects of cooling.

4.5.1. Opportunities for district cooling

Our assessment of the area is that there are two large opportunities for district cooling in the Tenggarong city area: local government offices and the Royal World Plaza.

4.5.1.1. Local government office

The local government has according to Bappeda, the local institution for planning, 27,363 m^2 office areas that need to be cooled in order to be comfortable workspaces. At the moment this is done by electrically powered air conditioners (Bappeda, 2015).

4.5.1.2. Royal World Plaza

The Royal World Plaza is right now under construction and is going to be a multi-storey shopping mall situated very close to the office of the local government. The floor area of the mall will be 32,007 m^2 according to the Bappeda (2015).

4.5.2. Estimation of cooling capacity needed

As there are no available numbers on installed cooling capacity in the office or any done estimation of needed cooling capacity in the Royal World Plaza we are using key numbers from IV produkt's guide to estimate sizing of cooling aggregate. The model is very simple and assumes that 70 % of the total floor area needs to be cooled, further it assumes that you need between 80-85 W of cooling power/m^2 cooled floor area, as described in Equation 4-22 (IV produkt, 2008). In the estimation the higher value, 85 W will be used.

Equation 4-22

$$Cooling\ power = 0.7 * Floor\ area * 85$$

4.5.3. Estimation of cooling capacity available

The cooling capacity, COP for an absorption-cooling machine is about 0.7 (Alvarez, 2006). This is being applied to the amount of excess heat available from the process after electricity and drying energy outtake according to Equation 4-23.

Equation 4-23

$$Cooling\ capacity = excess\ heat * COP_{abs}$$

4.6. Drying technique

The energy demand for the drying technique depends on the moisture of the input fuel and the wanted output moisture level. The drying bed dryer needs energy in form of heat and electricity. The heat is used to heat the drying air and the electricity is used for fans.

According to Johansson et al. (2004) the heat demand for bed drying technique is 3.9 – 4.5 MJ/kg evaporated moisture. The electricity use is according to the same study 0,11 – 0,18 MJ/ kg evaporated moist. These estimations are made under Swedish conditions and might differ slightly to the conditions in Kutai Kartanegara.

The amount of evaporated moisture per second depends on the moisture of the input fuel, the demanded moisture on the output fuel as well as the amount of dried fuel, see Equation 4-24 (Johansson, Larsson, & Wennberg, 2004). With Equation 4-25 and the key values for drying calculations in Table 4-10 the heat and electricity power demand used by the dryer is calculated (Johansson, Larsson, & Wennberg, 2004).

Equation 4-24

$$\mathrm{m_{ev}} = \frac{M_{in} * m_{fuel} - M_{dem} * m_{fuel}}{(1 - M_{dem})}$$

Table 4-9 Explanations of the variables in Equation 4-27

Evaporated moisture	[kg/s]	m_{ev}
Input moisture content	[%]	M_{in}
Total fuel weight	[kg/s]	m_{fuel}
Demanded moisture content	[%]	M_{dem}

Equation 4-25

$$Heat\ demand\ (MW) = M_{heat} * m_{ev}$$

Equation 4-26

$$Electricity\ demand\ (MW) = M_{el} * m_{ev}$$

Table 4-10 Key values for the drying calculations

Parameter	Value (Unit)	Source
M_{heat}	4.2 (MJ/kg evaporated moist)	Värmeforsk rapport 881
M_{el}	0.15 (MJ/kg evaporated moist)	Värmeforsk rapport 881

(Johansson, Larsson, & Wennberg, 2004)

4.6.1. Air flow bed drying technique

The drying air flow is estimated to be 60-70 m^3 hour per kg evaporated moisture (Johansson, Larsson, & Wennberg, 2004). This is used to calculate the airflow in Equation 4-27. The airflow is used to calculate bed dryer costs. In the estimation the airflow value of 65 m^3 has been used.

Equation 4-27

$$Drying\ air\ flow\ per\ hour\ = 65 * \ Evaporated\ moisture\ kg\ /\ h$$

4.7. Biogas production

To estimate the potential production of biogas in the area, a biogas model was developed. The model is based on key values from substrathandboken (2009) and the substrate is assumed to be what is referred to as household waste, Table 4-11.

Table 4-11 Key values from substrathandboken from the reference substrate household waste

Key values	Value	Unit
Biogas production	204	Nm^3/ton WW
Methane production	128	Nm^3/ton WW
Energy value in the gas	1.26	MWh/ton WW

(Carlsson & Uldal, 2009)

The model will return the values as presented in Table 4-12.

Table 4-12 Return values of the biogas model

Volume of the biogas	Nm^3
Volume of methane in the gas	Nm^3
Total energy in the gas	MWh
Energy value of the gas	kWh/Nm^3
Rate of methane in the gas	%
Weight of the gas	kg

The code corresponding to the program is found in Appendix D.

4.8. Economy

The following section will describe the methods and estimations used for the economic models.

The exchange rates in Table 4-13 will be used for the costs and incomes.

Table 4-13 Exchange courses

Variable	Value	Source
IDR/SEK	1,630	valuta.se 25/8 - 2015
SEK/USD	8.38	valuta.se 25/8 - 2015
SEK/EUR	9.64	valuta.se 25/8 - 2015

4.8.1. Investment cost incineration plant

The total investment cost of the WtE incineration plant has been estimated with expertise from specialized suppliers. The investment cost includes the cost of necessary components recommended by suppliers. These costs are rough estimates that are based on earlier projects in Asia. Price estimations from various suppliers are shown in Table 4-14.

Table 4-14 Investment cost from various suppliers

Supplier	Price	Source
Low-Price, Chinese supplier	70,000 USD/ton received waste a day	Camilla Winther
Mid – Price, Korean supplier	100,000 USD/ton received waste a day	Camilla Winther
High price, European supplier	650 EUR/ton received waste a year	Camilla Winther
European supplier, Martin GmbH	470 EUR/ton received waste a year	Erich Bauer

(Winther, 2015) (Bauer, 2015)

These costs include all the main components in a WtE incineration plant, which is: Funnel, Moving grate, Boiler, Turbines, Generators, Flue gas cleaning system, Heat exchangers etc (Winther, 2015).

None of the costs include any building costs, connection to the electricity grid or any grid for district heating. The approximated numbers are only valid for large scale projects. If the waste supply is less than 400 ton a day, the costs will be slightly higher per supplied ton (Winther, 2015).

Smaller plants are approximated to cost 20% more compared to the larger sized scale prices (Winther, 2015). Construction costs are estimated to be around 20% of the technical component investment. This approximation comes from earlier power plant projects (Lybert, 2015) (Winther, 2015). According to Camilla Winther, Asia manager at Babcock Wilcox, the Low-price Chinese suppliers are most commonly used for projects in Asia. The Chinese suppliers usually use licensed technology from Europe or Japan. In this report both the low price Chinese supplier and the European supplier, Martin GmbH is evaluated.

4.8.1.1. Investment Biogas

The cost approximation is based on interviews with representatives from Kembang Janggut biogas plant and consultant reports from ÅF and Biosystems regarding different biogas projects, Table 4-15. The values from the interview correspond to the obtained values from the consultant reports.

Table 4-15 Biogas plant in Kembang Janggut, the numbers with *are estimations and calculations.

Biogas plant	Value	Unit
Power output	2	MW
Cost	5	M$
Efficiency $_{electric}$	41	%
Running time *	8,000	h/yr
Amount of waste*	31,000	Ton WW received waste a year
Specific cost*	161.3	USD yr/ton WW received waste a year

(Bappeda technical department, 2015)

The specific cost of 161,3USD /ton WW received waste a year will be used to estimate the investment cost of a biogas plant.

4.8.1.1. Investment cost district cooling substation

To be able to harness the cooling power, an investment in a substation needs to be made. Included in a cooling substation is heat exchanger and controlling systems, the specific cost of typical substations is shown in Table 4-16.

Table 4-16 Specific cost for cooling substations sek/kW installed effect

Power [kW]	Cost [sek/kW]
0-200	1,000
200-400	800
400-1,500	700
1,500+	550

(Energimarknads inspektionen, 2013)

Furthermore investments in piping and the actual absorption-cooling machine are also needed. The cost for an absorption-cooling machine excluded piping on the cold side, planning and project management is shown in Table 4-17.

Table 4-17 Specific cost for an absorption cooling machine sek/kW installed effect, key ready

Power [kW]	Cost [sek/kW]
0-300	6,000-12,000
300-400	8,000
400-500	5,000
500+	4,000

(Energimarknads inspektionen, 2013)

4.8.1.2. Investment cost bed dryer

Johansson et al. (2004) has summarized the cost estimates for bed drying techniques from different suppliers. The report came up with the following simplified equation, Equation 4-28. The price in this equation includes components, building and ground preparation work.

Equation 4-28

$$Price = \left(0.2 * \left(Drying\ air\ flow\ per\ \frac{hour}{1000}\right)^{0.8}\right) [Milion\ SEK]$$

4.8.2. Annual cash flow

The annual cash flow is calculated as the yearly income subtracted by the yearly expenditure, Equation 4-29 (Gavelin & Sjöberg, 2012).

Equation 4-29

$$Annual\ cash\ flow = revenues - expenditures$$

4.8.3. Revenues

WtE incineration plants usually have two major incomes and one smaller. The two major incomes are energy revenues and tipping fees. Sales of residues as use to road construction are the minor income (RVF, 2005).

4.8.3.1. Energy Revenue

The energy revenues will come from sales of electricity and absorption cooling.

The yearly income from the sales of electricity will be determined by a set tariff price per kWh times the total net generated electricity in kWh. According to earlier studies and data from PLN the tariff cost is 0,81SEK/kWh or 0,1 USD/kWh (PLN, 2014). The income from electricity sales is calculated according to Equation 4-30.

Equation 4-30

$$Electricity\ income = Tariff * net\ generated\ electricity$$

4.8.3.2. Absorption cooling

When comparing the absorption cooling solution to a standard solution, a COP of 3 will be used for a compressor cooling machine, this will be applied to the needed cooling power and the price for electricity according to Equation 4-31.

Equation 4-31

$$Cost\ cooling\ with\ compressor = \frac{Cooling\ demand}{COP_{kompressor}} * Price_{electricity}$$

4.8.3.3. Tipping fee

The tipping fee is usually paid per ton received waste. This fee is paid by local authorities and is supposed to cover landfill costs, taxes, transportation etc. In this writing moment there are no tipping fees on landfills in the investigated area, hence there will be no initial tipping fee in the economical calculations (PKKK, 2015).

4.8.3.4. *Sales of residue*

Residues can replace other materials in road construction work. The material used for road construction today costs 67,000 IDR/m^3, the residues will be valued accordingly (Fathillah, 2015). The income from sales of residues is calculated as Equation 4-32.

Equation 4-32

$$Yearly\ sales\ of\ residues\ =\ 67\ 000\ IDR/m^3\ *\ m^3\ generated\ residues\ a\ year.$$

4.8.3.5. Biogas Revenues

The electricity production from the biogas plant is calculated with Equation 4-33 where the electric efficiency is 42% (Kembang Janggut, Bappeda).The incomes from electricity sales will be calculated as shown in Equation 4-30.

Equation 4-33

$$Energy_{electric} = Energy_{biogas} * Efficiency_{electric}$$

4.8.4. Expenditures

The WtE incineration plant will have some yearly expenses. The following expenses will be included in the cash flow calculation: maintenance, salaries, transportation cost, support fuel cost and chemical usage cost.

4.8.4.1. *Maintenance*

Maintenance and reparation of the power plant is needed. According to Bauer (2015) the annual maintenance cost is estimated to 2% of the total investment cost.

The bed dryer also needs maintenance, Johansson et al. (2004), estimate the annual maintenance of the bed-dryer to be 2% of the initial bed dryer cost.

4.8.4.2. *Waste transport and handling*

The sub districts and cities that have an existing waste handling system right now are Tenggarong, Muara Jawa, Samarinda, Bontang and Balikpapan (PKKK, 2015).

The quantified cost for waste handling has been based on the costs for waste handling in Tenggarong. The information that has been collected from Tenggarong regards the cost for operating the landfill and collecting the waste from the city, including personal, and fuel, see Table 4-18 to Table 4-20.

Table 4-18 Data from Tenggarong waste handling

Data from Kutai Kartanegara	Constant	Unit	Source
Cars for waste handling	21		PKKK
Fuel usage / car week	12	l	PKKK
Cost for diesel	7,500	IDR/l	Pertamina
Cost fuel / car week	100,000	IDR	PKKK
Salary waste collecting driver	2,900,000	IDR/month	PKKK

(PKKK, 2015)

The costs for waste handling were quantified in the unit SEK /ton according to Equation 4-34.

Equation 4-34

$$Waste\ handling\ cost = \frac{Cost\ for\ fuel + Cost\ for\ drivers\ salary}{Amount\ of\ collected\ waste}$$

More specific calculations can be found in Appendix E and Appendix F.

The specific cost in the different sub-districts was calculated according to Equation 4-35.

Equation 4-35

$$Specific\ cost = Waste\ handling\ cost * Amount\ of\ collected\ waste$$

To be able to operate a centralized WtE-plant there will also be costs associated with the transportation of waste between different sub-districts. The infrastructure in terms of roads is varied in the region and some of the sub districts cannot be reached by car only, but have to be accessed from the Mahakam River.

The Mahakam River provides a natural way to transport goods over distances, especially when there is no demand on the speed of transportation. Transportation on the river with a barge is much cheaper than a transport on the road and will be considered firsthand in the calculations for transportation costs.

Table 4-19 Data from Tenggarong local government regarding transportation

Data from Kutai Kartanegara	Constant	Unit	Source
Loading capacity river barge	7,000–8,000	Ton coal	Balitbangda
Cost for river transport	0.02	USD/ton km	Balitbangda
Density of Samarinda waste	260	kg/m^3	DKKP (Samarinda)
Reloading cost river	3.9	USD/ton	Balitbangda
Driving speed	1.96	min/km	Measurements
Loading capacity truck	8	m^3	PKKK

Table 4-20 Data from literature used in the transportation and waste handling calculations

Data from literature	Constant	Unit	Source
Density of coal (hardcoal)	800	kg/m^3	KTH
Length of a mile	1.609	km	Balitbangda
Density of Samarinda waste	260	kg/m^3	DKKP (Samarinda)
Fuel consumption truck	0.05-0.159	l/ton km	Appendix E

The transport cost on the river is combined from two parts, see Equation 4-36.

Equation 4-36

$$Cost\ transport\ river = Transport\ cost + Reloding\ cost$$

The combined cost for road transport contains from two parts, see Equation 4-37.

Equation 4-37

$$Cost\ transport\ road = Drivers\ salary + Fuel\ cost$$

The cost for transporting goods on the river and the road were quantified in the unit SEK/ton km. To get the specific and total costs for river and road transports the Equation 4-38.

Equation 4-38

$$River/road\ cost = \frac{Cost}{ton * km} * Distance * Amount\ of\ waste$$

In Scenario 1 there are no additional transportations. In Scenario 2 and 3 the cost for transportation is calculated as in Equation 4-39.

Equation 4-39

$$Transport\ cost = Transport\ road + Transport\ river$$

The costs are then finally combined into the total cost fort transportation for the different scenarios.

4.8.4.3. Salaries

Following tables shows the estimated number of personnel and salaries for the different suggested WtE power plants. Estimated salaries are retrieved from a Hitachi report pre-feasibility study (Hitachi Zosen Corporation, 2012). Number of employees for the scenarios has been estimated with the help of suppliers and similar sized WtE-plants. Workers that pre-treat the waste and workers that take residues to landfill are not counted for.

The report from Hitachi Zosen Corporation (2012) has estimated the salaries for the different kind of workers in Indonesia as the following, Table 4-21:

Table 4-21 Salaries for employees in a power plant in Indonesia

Manager: 35.15 million IDR / month / person
Engineer: 23.4 million IDR / month / person
Operator: 5.8 million IDR / month / person

(Hitachi Zosen Corporation, 2012)

The number of workers, salaries and annual salary expenses can be seen in Table 4-22. The number of employees has been estimated from similar sized plants in Sweden.

Table 4-22 Estimations of numbers of employees and annual salaries

Type of worker	Scenario 1	Scenario 2	Scenario 3	Salary IDR/month/person
Manager	2	4	5	35.15 million
Engineer	7	14	18	23.4 million
Operator	12	23	30	5.8 million
Total personnel	21	41	53	
Total Salary IDR/year	3,644.4 million	7,219.2 million	9,251.4 million	

4.8.4.4. Support fuel

The WtE plant needs support fuel for start-up and shut-down. The estimated use of support fuel is roughly 100,000 m^3 natural gas annually for a WtE plant with the thermal capacity of 80 MW (Bauer, 2015). According to this estimation the use of support fuel is around 1,250 m^3 / Thermal capacity MW. See Equation 4-40 for the calculation of support fuel used.

Equation 4-40

$$Support\ fuel\ =\ 1\ 250\ m^3 * MW\ Thermal\ capacity\ WtE\ plant$$

The price on natural gas can fluctuate much during short periods. In this thesis the average natural gas price in Indonesia between February – July 2015 has been used. The average price over this period was 0.35 Euros /Nm^3 (Index mundi, 2015). The annual cost of support fuel is calculated with Equation 4-42.

Equation 4-41

$$Price\ support\ fuel\ =\ Amount\ of\ support\ fuel\ used\ *\ 0{,}35$$

4.8.4.5. Chemicals

The chemical usage and prices for flue gas cleaning is based on Bauer's (2015) rough estimations and recommendations, shown in Table 4-23.

Table 4-23 Estimations of chemical usage and prices in the flue gas cleaning process values with * are in l/ton and SEK/l

Chemicals	Usage kg /ton waste fuel	Price SEK/ kg
Lime	20	0.92
Activated carbon	1.2	6.7
Ammonium hydroxide	4*	1.8*

(Bauer, 2015)

4.8.4.6. Residual landfill

Since there are no tipping fees at the landfill in Tenggarong, there will not be any charges for tipping the unused residues at the landfill. Around 5% of the ingoing waste has to be treated at controlled landfills (RVF, 2005).

4.8.4.7. Biogas operating costs

The posts considered in running costs for a biogas plant will be:

- Salaries
- Electricity need
- Maintenance

The needs for personal and electricity are obtained by studies of consultant reports from ÅF and Bio systems. All results can be seen in Appendix G.

Table 4-24 Estimations of running costs for a biogas plant

Biogas plant	Value	Unit
Personal need	1+1	Engineer+Operator
Personal cost $_{engineer}$	23.4	MIDR/month
Personal cost $_{operator}$	5.8	MIDR/month
Maintenance cost	2	% of investment
Electricity need	85,000	kWh /kton WW

The cost for maintenance and personal, Table 4-24, are supposed to be the same for the biogas plant as for the incineration plant.

4.8.4.8. Running cost district cooling

The running costs of the cooling substation and the absorption machine will be calculated as only maintenance.

The standard value of 2% of the investment cost / year will be used.

4.9. Environmental impact

The environmental results in this report will be based on the emissions of GHG. In the present system the majority of GHG emissions come from the current landfills and the fossil based energy production. In a WtE system the emissions will come from the WtE incineration plant and the transportation of waste.

The burning of organics or biogas from waste is considered carbon dioxide neutral and will not be considered in the environmental impact assessment. Since it has been hard to measure hazardous emissions and pollutions from current landfills, open dumping and burning of waste, these emissions will not be accounted for in the environmental result. Due to uncertainties in the treatment methods of uncollected waste no environmental calculations will be made on this waste fraction. This has to be remembered when comparing the different scenarios.

The following sections describe the methodology of calculation for each of the GHG emission sources.

4.9.1. Transport and waste handling

The calculation of CO_2 emissions from transport is based on Guidelines for Measuring and Managing CO2 Emission from Freight Transport Operations (The Europeean Chemical Industry Council, 2011), shown in Table 4-25.

Table 4-25 Emission factors for river transportation

Data from literature	Constant	Unit	Source
Emission factor upstream	28.3	gCO_2/ton km	CEFIC
Emission factor downstream	14.7	gCO_2/ton km	CEFIC
Emission factor canal	17.4	gCO_2/ton km	CEFIC
Size of a TEU	38.5	m^3	Wikipedia
Emission factor from road transport	2.64	Kg/l diesel	Appendix E

In Scenario 3 there are a few legs of transport in the sea, this will be weighted with the same emission factor as a canal, see Table 4-25.

The emissions from boat transport are calculated using Equation 4-42.

Equation 4-42

$$Emission = emissionfactor * distance * load$$

The emissions from road transport and waste handling are based on the amount of fuel used and the carbon content in the fuel according to Equation 4-43. The amount of fuel used is also used in the section for transportation cost and is described thoroughly in Appendix H.

Equation 4-43

$$Emission = Amount\ of\ fuel * emissionfactor\ from\ road\ transport$$

The emissions are then summarized in the different scenarios.

4.9.2. Waste incineration

During the combustion of waste CO_2 is produced. The amount of CO_2 produced in the flue gas depends on the waste composition and the air flow in the system. The amount of CO_2 in the flue gas is calculated in the Matlab script "combustion". The main formulas is summarized in, Equation 4-44 where $\frac{44}{12}$ is the molar massratio between CO_2 and C. The whole script can be seen in Appendix D. It is assumed that it is a full combustion. The flue gas cleaning system will not reduce the level of CO_2 emissions.

Equation 4-44

$$CO2\ in\ kg\ =\ waste\ supply\ kg\ *\ fossile\ carbon\ content\ in\ waste\ *\ \frac{44}{12}$$

4.9.3. Biogas production

No environmental impact from biogas production will be considered. The CO_2 emissions released when burning the gas for electricity is considered to be CO_2 neutral as no fossil carbon is released to the atmosphere, Equation 4-45.

Equation 4-45

$$CH_4 + O_2 = CO_2 + H_2O$$

4.9.4. Current situation

The methods used to calculate GHG emissions from the current situation are presented below.

4.9.4.1. Electricity production

The majority of the electricity in the Mahakam system is generated from diesel powered power plants, PLN. For comparison with the WtE incineration plant, the amount of CO_2 emitted from a diesel power plant generating equal power production as the WtE plant is calculated.

Reports from IEA, EIA, Volker-Quasching and the Blueskymodel estimates the CO_2 emissions per generated kWh electricity with diesel power as accordingly, Table 4-26:

Table 4-26 Emissions from diesel powered electricity production

Source	g CO_2 / kWh
IEA	690
EIA	757
Volker - Quaschning	785
Blueskymodel	821
Average value	764

(EIA, 2015) (IEA, 2012) (Bluskymodel, 2004) (Volker-Quaschning, 2015)

The estimated amounts differ since the sources use different power plant efficiencies in their calculations. The average value 764 g CO_2 per kWh will be used in this report.

The total amount of CO_2 emitted from the diesel generated power plant will vary with the size of the WtE plant it will be replaced by, this is calculated in Equation 4-46:

Equation 4-46

$$CO2\ emitted\ =\ 764 * \frac{generated\ kWh}{year}$$

4.9.4.2. Landfill

Disposal of MSW, industrial and agricultural waste at landfills produce significant amounts of methane gases, CH_4. The methane is produced during anaerobic digestion of organic material. In additional to the methane gas landfills also produce carbon dioxide, CO_2, and smaller amounts of nitrous oxide, N_XO. The total amount of CH_4 from landfills corresponded to 3-4% of the global greenhouse gas emissions according to IPCC (2006).

In order to estimate CH_4 and CO_2 emissions a FOD-model, (First Order Decay) from IPCC has been used. This method has been developed for national and regional inventories and was most recently updated in 2006. The method works for specific sites, but it demands accurate site parameters and waste composition data (Pipatti & Svardal, 2006). Parameters for landfills in hot and humid climates have been gathered from IPCC Vol 5. Chap. 3 and waste elemental composition data has been retrieved from ORWARE.

The IPCC method calculates the GHG emission by determining the annual amount of decomposed degradable organic carbon, DOC, and converts this to CH_4 emissions (Pipatti & Svardal, 2006). This method is described below.

First the amount of decomposable DOC, DDOC, in the landfill is estimated from the annually disposed waste using Equation 4-47. Different types of waste contain different levels of decomposable DOC. To calculate the total mass of decomposable DOC deposited the different DOC values and fractions have to be added (Pipatti & Svardal, 2006).

Equation 4-47

$$DDOCm = W * DOCf * MCF * DOCX$$

- DDOCm = Mass of decomposable DOC deposited, Mg
- W = Mass of waste deposited, Mg
- DOCx = Degradable Organic Carbon from different waste compositions in one year times the fraction of the total waste, Mg C/Mg waste
- DOCf = Fraction of DOC that can decompose
- MCF = CH4 correction factor for aerobic decomposition in the year of disposal, fraction

(Pipatti & Svardal, 2006)

Since the CH_4 produced is described by a first order function, the produced amount only depends on the accumulated reactive material, the decomposable DOC is decomposed by a reaction constant k, that differ depending on waste composition. Step two is to calculate the accumulated decomposable DOC using Equation 4-48 (Pipatti & Svardal, 2006):

Equation 4-48

$$DDOCma(T) = DDOCmd(T) + (DDOCma(T-1) * e^{-k})$$

- T = inventory year
- DDOCma(T) = Accumulated decomposable DOC in the landfilling at the end of year T, Mg
- DDOCmat(T-1) = Accumulated decomposable DOC in the landfilling at the end of year (T-1), Mg
- DDOCmd(T) = DDOCm deposited at the landfilling in the year T, Mg
- k = reaction constant y-1

The decomposed DOC depends on the reaction factor and the amount of accumulated decomposable DOC in the landfill. The decomposed DOC is calculated by Equation 4-49 (Pipatti & Svardal, 2006):

Equation 4-49

$$DDOCm\ decomp(T) = DDOCma(T-1) * (1 - e^{-k})$$

The amount of CH_4 is found by multiplying the decomposed DOC with the CH_4 fraction in the generated landfill gas and the CH_4/C molecular weight ratio, Equation 4-50 (Pipatti & Svardal, 2006):

Equation 4-50

$$CH4\ generated(T) = DDOCm\ decomp(T) * F * M[CH4]/M[C] * (1 - OX)$$

- CH4 generated(T) = amount of CH4 generated from decomposed material
- F = fraction of CH4, by volume, in generated landfill gas.
- M[CH4]/M[C] = Molucelar weight ratio between CH4 and C,= 16/12
- OX = Oxidation factor
- DDOCm decomp(T) = decomposed DOC at the end of year T, Mg

All the parameter values have been obtained from IPCC, specified for tropical climate (Pipatti & Svardal, 2006).

4.9.5. Comparison

In the comparison the emissions from the current landfills and energy production will be compared to the emissions from WtE energy production and waste transportation for each scenario. The more waste that is collected, the less will be put on landfill and more fossil based energy can be replaced. Comparisons will be made for each scenario.

4.10. Sensitivity analysis

In order to adjust for uncertainties in the data collection and to see how the result changes for certain key parameters a sensitivity analysis is implemented. As already mentioned the study will investigate various WtE systems with different waste collection areas. The use of two suppliers will highlight the importance of investment cost. The final key parameter that will be changed is the moisture content of the waste. It is changed for the following reasons:

- The moisture content is uncertain since the ORWARE model base its values on European waste. Asian MSW has a higher organic fraction and contain more moisture according to reports from World Bank (1999)
- By varying the moisture content, the MSW calorific value and hence the total energy production will vary. To investigate for the importance of moisture content, calculations with 5%, 10% and 15% higher moisture content compared to the base case will be analysed.

The formulas for changed moisture content can be seen in the Matlab script Startwaste, Appendix D.

5. Result

This section will present the current waste management system and results from the modelled simulations, the section is divided into waste management, waste stream, energy production, economics and environmental. The most interesting results are presented in figures and tables. For more details and all results see Appendix I.

5.1. Waste management in Kutai Kartanegara

The waste management system is not fully developed in the Kutai Kartanegara region, only Tenggarong and Muara Jawa have waste management systems. In Tenggarong the local government is responsible for the waste management, the same department also has responsibility for roads and buildings (PKKK, 2015). A summary of the waste management system in Tenggarong is shown in Figure 5-1.

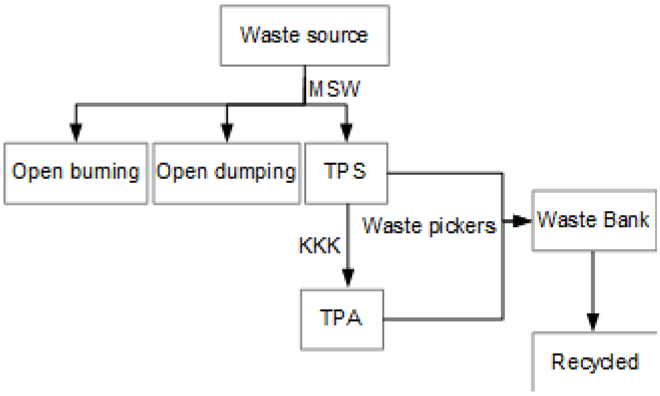

Figure 5-1 Flowchart of waste management in Kutai Kartanegara

In Tenggarong's waste management system every household, hotel, school and small business is responsible to collect their generated waste and put it in temporary containers, TPS. These temporary containers are placed along streets and close to neighbourhoods. The TPS come in different sizes and types. Sometimes there are three separate containers: organics, inorganics and B3 - batteries, metal, electronics etc. Other types have only one large container where organics is supposed to be on one side and inorganics on the other. Even if there are possibilities to separate the waste types in the TPS, organic and inorganic waste are usually mixed in the different containers, which can be seen in Figure 5-2 (PKKK, 2015).

Figure 5-2 Picture showing different types of TPS in Tenggarong

The TPS containers are emptied two times a day by waste trucks, Figure 5-4. There are in total 21 trucks that collect the waste in Tenggarong over an area within a 15 km radius of Tenggarong city centre. Every household, hotel and small business have to pay 3 000 IDR/month to get access to the waste collection service according to the local regulations. The waste is transported and dumped at the local landfill, TPA, at the moment there is no tipping fee at the landfill. The local market has their own truck that they take to the landfill, see Figure 5-3 (PKKK, 2015).

Figure 5-3 Waste collection at the local market in Tenggarong

5.1.1. Landfill

The landfill in Tenggarong is a controlled landfill, which means that they are covering the waste with a layer of sand once a week; it has been controlled for three years. The landfill also has pools where leachate is cleaned by chemicals and tests of the water quality is taken every day.

When the landfill was created it was placed at a distance from the city but since the city has expanded and it is now located pretty close to Tenggarong housing. Some fractions of the organic waste is separated and used for production of fertilizer. The fertilizer is then sold to the public. A temporary small scale construction has been built to extract some landfill gas from the landfill. At the moment only small amounts of gas is collected, and it is used for cooking on site (PKKK, 2015).

Figure 5-4 Pictures of Tenggarong landfill

5.1.2. Waste Pickers

Waste pickers make a living out of separating and collecting waste either at TPS's or at the landfill, TPA, see Figure 5-5. The waste that they are looking for is: plastic, paper, metal, glass and cardboard, but they also collect other valuable waste that can be sold or reused. The waste is separated by type at waste picker stations and is then sold to waste banks in Tenggarong or Samarinda. There are a total of 15 waste picker stations in Tenggarong. The waste pickers are useful since they reduce the amount of waste put on landfill and increase recycling which is desirable.

The waste that is not put on TPS or taken care of by waste pickers is either dumped illegally or burned, see Figure 5-6 (Waste picker, 2015).

Figure 5-5 Pictures of waste pickers and separation in Tenggarong

Figure 5-6 Open burning in Tenggarong

5.1.3. Waste management in sub-districts

An example of alternative waste management systems in Kutai Kartanegara and the waste management in neighbouring regions are presented below.

5.1.3.1. Muara Jawa

Tenggarong is not the only sub-district in Kutai Kartanegara that has a working waste management system. The sub-district Muara Jawa also has an established system that can meet some of the districts demand.

Muara Jawa is a sub-district in the south east part of Kutai Kartanegara, two and a half hour drive to Tenggarong and a one hour drive to Balikpapan. The district has 8 villages and a total population of around 40,000. The largest villages are Muara Jawa Ulu, 14,407, and Muara Jawa Pesisir, 9,159 (Head of Muara Jawa waste management, 2015).

The local district office has together with a local NGO, developed a waste management system that covers the two largest villages in Muara Jawa, resulting in a 58% cover rate over the region (Head of Muara Jawa waste management, 2015).

In the first step of the waste management procedure households throw their household waste in containers and trashcans placed around neighbourhoods and streets. Households can separate plastic, cardboard, glass, metal and other valuable waste from these containers and bring to a separation unit. At the separation unit the separated waste is weighted and documented in a personal check book. The separated waste is then sold to a waste bank, driven by the NGO. Some plastic waste is kept by households, since they can make handicraft from it and sell to the market, see Figure 5-7. There are 12 separation units in Muara Jawa and they are set-up in collaboration with the NGO (Head of Muara Jawa waste management, 2015).

Figure 5-7 Separation unit and handicraft in Muara Jawa

The waste bank buys the separated waste from the units, and the income is distributed between the households based on their documented check book. Separation units collect their money around every third month. Prices vary depending on type of waste. In the end of the week the collected waste is transported by truck to Samarinda where it is sold to waste brokers. There is one waste bank with 6 employees in Muara Jawa (Head of Muara Jawa waste management, 2015).

The rest of the waste in the containers are collected daily by trucks and dumped at the local landfill. This process is run by the NGO. The trucks collect both the waste from households and from the industries nearby. Some industries keep their organic waste and process it to fish food. For the waste collection, the NGO obtain 10,000 IDR/month as a collection fee from every household and a 2,500,000 IDR/month or 5,000,000 IDR/month collection fee from industries, depending on the size of the industry. In total the NGO income from collection fees is 24,000,000 IDR/ month. This income is not sufficient to expand the collection area to the other villages. A study from 2013 estimated that a total of 11 ton waste per day were collected and dumped at the landfill (Head of Muara Jawa waste management, 2015).

The NGO has received a 0.5 ha large area from the Muara Jawa community to use as landfill. The area is a large pit surrounded by forest and there is no covering or treatment of the waste on the landfill, Figure 5-8. A few waste pickers separate the valuable waste that was not separated at the separation unit. These waste pickers sell the separated waste directly to waste brokers. The Muara Jawa community and the NGO have a vision to obtain energy from the waste in some way, but they do not have the funding or knowledge about different techniques to fulfil this vision (Head of Muara Jawa waste management, 2015).

Figure 5-8 Uncontrolled landfill Muara Jawa

5.1.3.2. Waste management Samarinda and Balikpapan

The waste management system in Samarinda and Balikpapan basically follows the same procedure as in Tenggarong, but on a larger scale due to the greater population. The collection rate in Samarinda is around 70%, while it is said to be close to 100% in Balikpapan. Samarinda have one semi sanitary 10.5 Ha landfill and one 30 Ha sanitary landfill. At the semi sanitary landfill some of the landfill gas is collected for energy use. Balikpapan has a 27 Ha landfill area. This area is divided into different zones used in various manners. One zone collects landfill gas that is distributed and used in 150 households close to the landfill. Another zone produces 15 kW electricity using methane gas. The methane gas is generated from a small field of separated organic waste. The generated electricity is used for lighting at the landfill area (Head of DKPP Samarinda, 2015) (Head of Balikpapan Waste Management, 2015).

5.2. Waste streams

The waste stream includes the composition and supply of waste. These values will ultimately decide the potential energy output of the waste. In this section the composition and amount of collected waste from the different scenarios is determined. The future potential growth of waste in the region will be evaluated briefly.

5.2.1. Waste composition in Kutai Kartanegara and Samarinda

A research report issued by the DKPP Samarinda in 2014 states the total composition of waste in the Samarinda region. In the study waste composition from different sectors such as housing, hotel, market, office and school was evaluated. The Figure 5-9 shows the weighted average of waste composition from these sectors in Samarinda. The same research concludes the waste density to be 260 kg/m3. Figure 5-10 shows the waste composition when the organic fraction is separated (Abadi, 2014).

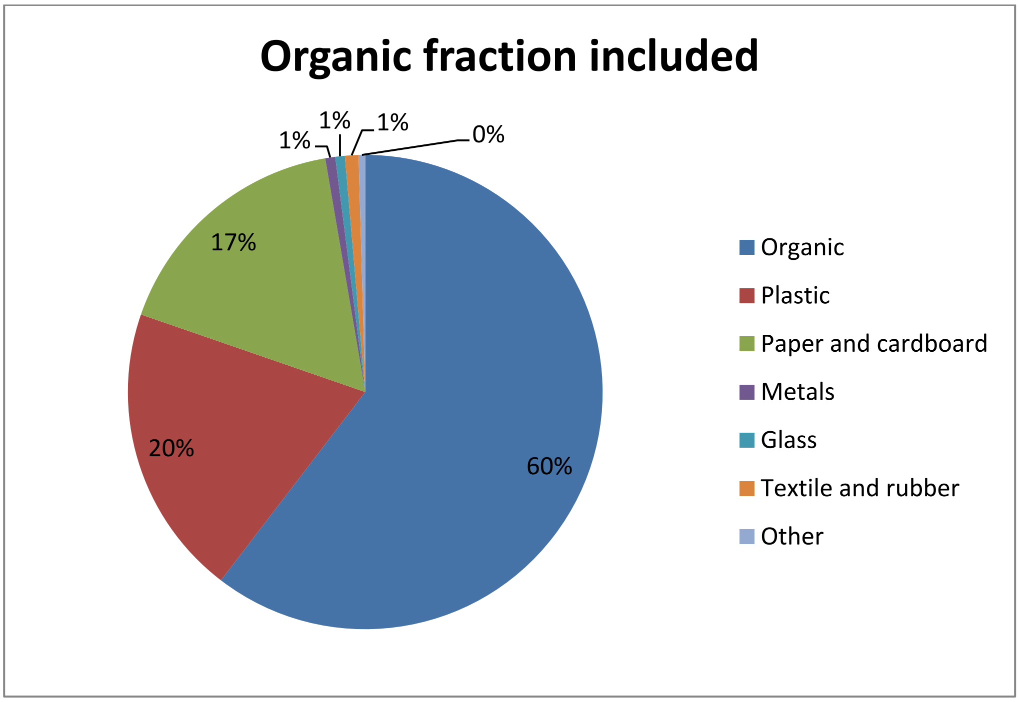

Figure 5-9 Waste composition

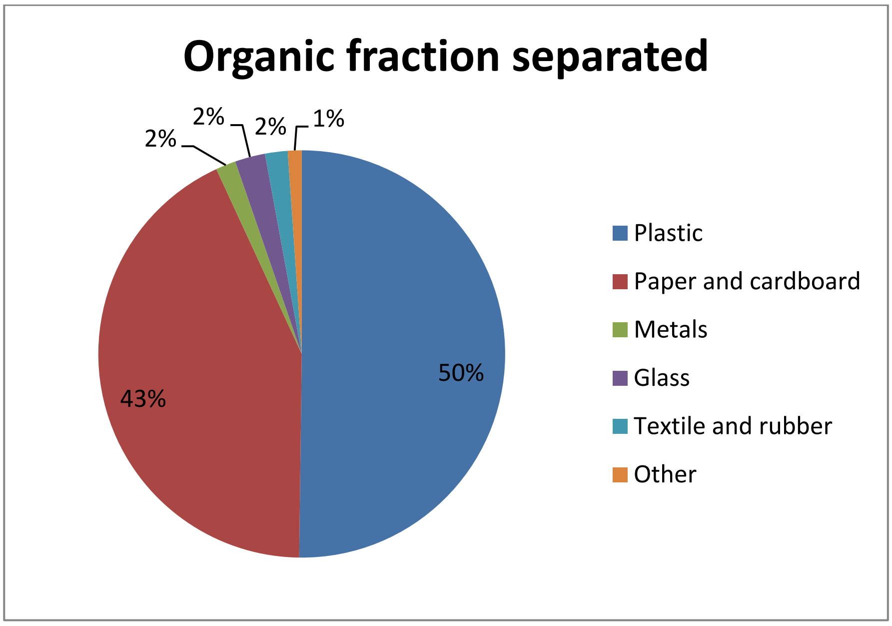

Figure 5-10 Waste composition separating organic fraction

The waste composition in the remote districts of Kutai Kartanegara might contain a slightly higher percentage of organic waste and a little bit less paper and plastics due to lower living standards (Abadi, 2014). A higher organic waste share will lower the calorific value because of higher moisture content. Even so the Samarinda waste composition will give a good estimate for the maximum calorific value of waste in the region.

5.2.2. Waste supply

This section will present the waste supply for the different Scenarios. Estimated costs for waste handling can be seen in Appendix J.

5.2.2.1. Scenario 1

The total amount of generated waste in Tenggarong, Scenario 1, is estimated to be 72.8 ton a day which adds up to 26,583 tons per year. This equals to a yearly volume of 102,242 m^3 using the Samarinda waste density. Data from PKKK show that 58,468 m^3 is put on landfill every year. This equals to 15,152 tons waste annually (PKKK , 2014). The waste composition above gives the organic and inorganic fraction.

From the 26,583 tons yearly waste generated, 15,152 tons are collected and transported to the landfill, as shown in Table 5-1. This results in a 57% collection rate. However the actual collection rate of municipal solid waste might be higher since some parts of the waste is separated by waste pickers in the temporary waste containers (PKKK , 2014).

Table 5-1 Waste amounts in Tenggarong subdistrict

District	Waste/day (ton)	Waste/year (ton)	Organic waste/year	Inorganic waste/year
Tenggarong	41.5	15,152	9,152 ton	6,000 ton

(PKKK , 2014)

5.2.2.2. *Scenario 2*

According to DKPP in Samarinda is 466 ton waste per day is disposed at landfills. This equals to 170,090 tons a year (Head of DKPP Samarinda, 2015). The waste supply from the Kutai Kartanegara sub-districts are shown in Table 5-2

The waste supplied in Scenario 2 is presented inTable 5-3.

Table 5-2 Waste amounts from Scenario 2

District	Waste/day (ton)	Waste /year (ton)	Organic waste/ year (ton)	Inorganic waste/ year (ton)
Samarinda	466	170,090	102,730	67,360
Tenggarong Seberang	26	9,468	5,718	3,749
Sebulu	16	5,670	3,402	2,268
Loa Kulu	17	6,318	3,791	2,527
Loa Janan	27	8,998	5,399	3,600
Total	552	200,544	120,326	80,218

(PKKK , 2014) (Samarinda Green Clean Health, 2014)

Table 5-3 Waste amounts in Scenario 2

Scenario	Waste/year (ton)	Waste/day (ton)	Organic waste/year	Inorganic waste/year
Scenario 2	591	215,696.2	130,280.5	85,415.7

It is clear how the amount of waste increase when the collection area is expanded. Most of the waste collected in Scenario 2 is from Samarinda.

5.2.2.3. *Scenario 3*

The local authorities responsible for Balikpapan waste management and sanitary landfill have measured the waste supply to the sanitary landfills to 365 tons a day, which gives a total waste supply of 133,225 tons a year. According to local authorities almost all municipal waste is collected in the region (Head of Balikpapan Waste Management, 2015).

Bontang has a population of 175,830 people, this gives a daily waste supply of 70 tons and a yearly supply around 25,623 tons (Balitbangda, 2015).

The added sub-districts in Scenario 3 supply 31,664 ton waste annually, see Table 5-4.

Table 5-4 Waste amounts from the East of Kutai Kartanegara regency including all the districts in Scenario 3

Districts	Population	Waste/day (ton)	Waste/year (ton)	Organic waste /year (ton)	Inorganic waste /year (ton)
East Kutai	217,423	86.8	31,664	19,125	12,539
Balikpapan	715,000	365	133,225	80,468	52,757
Bontang	175,830	70	25,623	15,467	10,140
Total	1,108,423	522	190,512	114,307	76,205

(Balitbangda, 2015) (PKKK , 2014) (Head of DKPP Samarinda, 2015)

The waste supply in Scenario 3 is presented in table 5-5.

Table 5-5 Waste amounts from Scenario 3

Scenario	Waste/day (ton)	Waste/year (ton)	Organic waste /year (ton)	Inorganic waste /year (ton)
Scenario 3	1,112.9	406,208.5	245,349.9	160,858.6

As the two major cities Kota Bontang and Balikpapan are included in Scenario 3 the total waste supply is increased even further compared to Scenario 2. The estimated waste handling costs for the different scenarios are presented in Appendix J.

5.2.2.4. Future waste supply

The future growth of municipal waste in the Kutai Kartanegara region will mainly depend on three variables: increased consumption due to increased living standard, population growth and a higher collection rate.

Since Kutai Kartanegara is a developing region it is easy to assume that the living standard and waste generation will increase in the upcoming years. At the same time the population will grow with around 3,6% annually in this region. The collection rate might also increase due to better infrastructure and awareness of waste management problems. It is hard to estimate how much the living standard and collection rate will affect the waste supply rate, but an educated estimate of an yearly increase of around 6% for the total waste supply rate seems to be appropriate. This increase rate is similar as the documented waste increase in Balikpapan (Head of Balikpapan Waste Management, 2015).

With a 6% increase of waste the different scenarios will provide the following amount of waste in 2025.

Table 5-6 Estimations of future waste supplies

Scenario	Waste amount , 2015 (ton)	Waste amount, 2025 (ton)
Scenario 1	15,152	27,135
Scenario 2	215,696.2	386,279
Scenario 3	406,208.5	727,456

(PKKK , 2014) (Head of Balikpapan Waste Management, 2015)

The future waste composition will also be more similar to high income regions when the economy develops. This means that the waste will contain a higher fraction of plastic and paper, and a lower fraction of organics. Thus, the heating value will increase (Hoornweg & Bhada-Tata, 2012).

5.3. District cooling

The total cooling demand of the Royal world plaza and local government offices is 3.53 MW as shown by Table 5-7.

Table 5-7 Estimation of cooling capacity for Royal World Plaza and the local governments offices

Cooling power	RWP	Office	Sum
Floor area [m^2]	32,007	27,363	59,370
Cooled area [m^2]	22,404.9	19,154.1	41,559
Power need [MW]	1.90	1.63	3.53

(Bappeda, 2015)

5.4. Heating value

Table 5-8 and Table 5-9 show the heating values for the different moisture content. In System inc, the heating value varies depending on the moisture content. In System inc + dryer, the bed dryer control the outgoing moisture content, hence a constant heating value. In System inc + bio only the moisture content of the inorganic fraction will affect the heating value.

Table 5-8 Heating value varying moisture content with and without dryer

Heating value no drying or separation				
Moisture in%	48	53	58	63
Heating value (MJ/kg)	11.95	10.5	9.1	7.6
Heating value drying no separation				
Moisture out%	40	40	40	40
Heating value (MJ/kg)	14.08	14.08	14.08	14.08

Table 5-9 Heating value varying moisture content, separated organic fraction

Heating value separation of organic fraction				
Moisture %	10	19	28	37
Hi (MJ/kg)	26.01	23.22	20.37	17.51

The data above shows how the heating value depends on the moisture content. Higher moisture content will lead to a lower heating value. By pre-treating the MSW with a dryer, the heating value is raised since the moisture content can be controlled and lowered. By separating organic fractions with high moisture content and only used the inorganic fraction for combustion, the heating value is raised even further.

5.5. Heat and electricity production

In this section the energy production for the various energy systems in each scenario is presented, see Figure 5-11 and Figure 5-12. Each system is simulated with the four different moisture contents mentioned above. The most interesting results are shown below.

To see how the waste stream affect the energy output, the reference system, System inc, was simulated with waste streams from the different scenarios. See Figure 5-11.

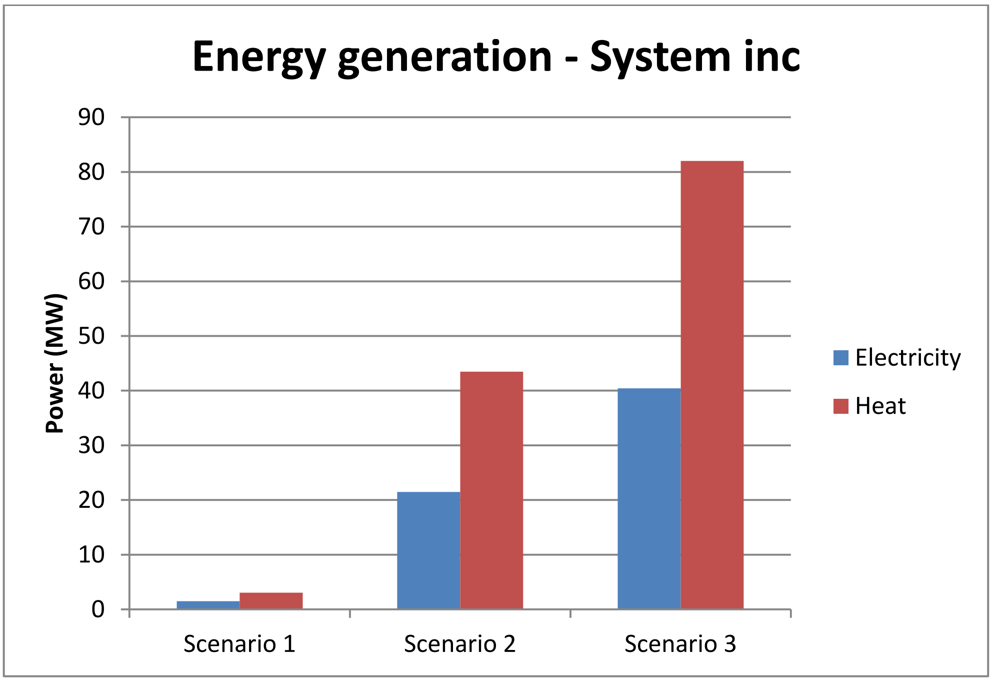

Figure 5-11 Energy production, System inc, different scenarios

Figure 5-11 shows how the energy production increases with the waste flow. This result is logical since more fuel will produce more energy, and it is the same for all systems.

By using different WtE systems over a set amount of supplied waste, the electricity and heat production using different systems can be evaluated. To evaluate how the systems respond to changes in fuel quality, the moisture content in the waste was varied from 43% to 63%, see Figure 5-12.

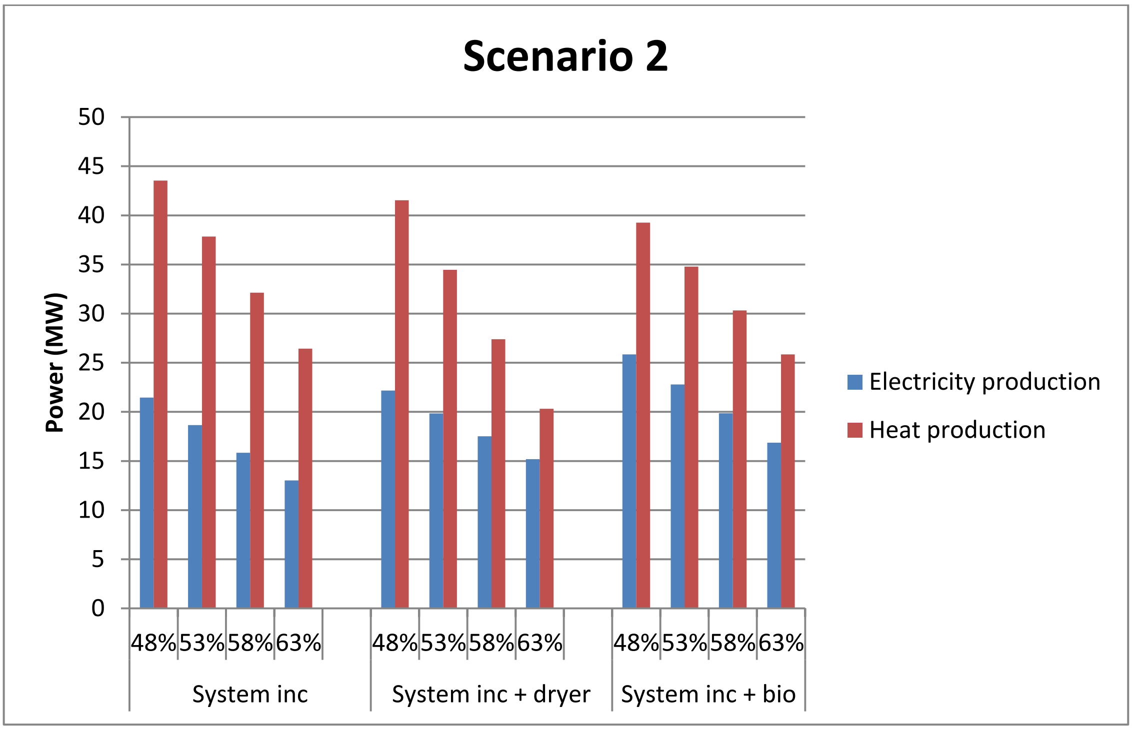

Figure 5-12 Energy production different systems, set amount of waste stream with different waste

The result from Figure 5-12, shows that the energy production is dependent on the fuel quality. When the moisture level increases the produced heat and electricity decreases. Figure 5-12 also shows that the electricity production increases when an integrated bed dryer is used. The bed dryer use thermal heat, hence the net heat production decreases. When the organic fraction is used for biogas production and the inorganic fraction is used for incineration the net electricity production is increased even further. Since the biogas production plant in System inc + bio does not produce any heat the heat production decreases compared to the other systems. The simulations were made with the waste supply in Scenario 2, but the ratio of energy production between the different systems and moisture content would be the same for all Scenarios. Appendix I shows the energy generation for all systems and scenarios in more detail.

5.6. Economic results

To assess the feasibility of a power plant it is important to know the predicted economical results. In this section the investment cost, annual cash flow, pay-back time, net present value and internal rate of return are presented. The costs are based on estimations. This should be considered when analyzing the results.

5.6.1. Investment costs

The different systems need different investments. These investment costs depend on the supplied amount of MSW. The price of the investment also depends on the supplier. In this study the cost from two suppliers, European and Chinese, is presented. The investment cost for the different systems and scenarios are presented below, in Figure 5-13 to Figure 5-15. Neither one of these total costs includes a connection to the electricity grid nor waste separation facilities in systems where it is needed.

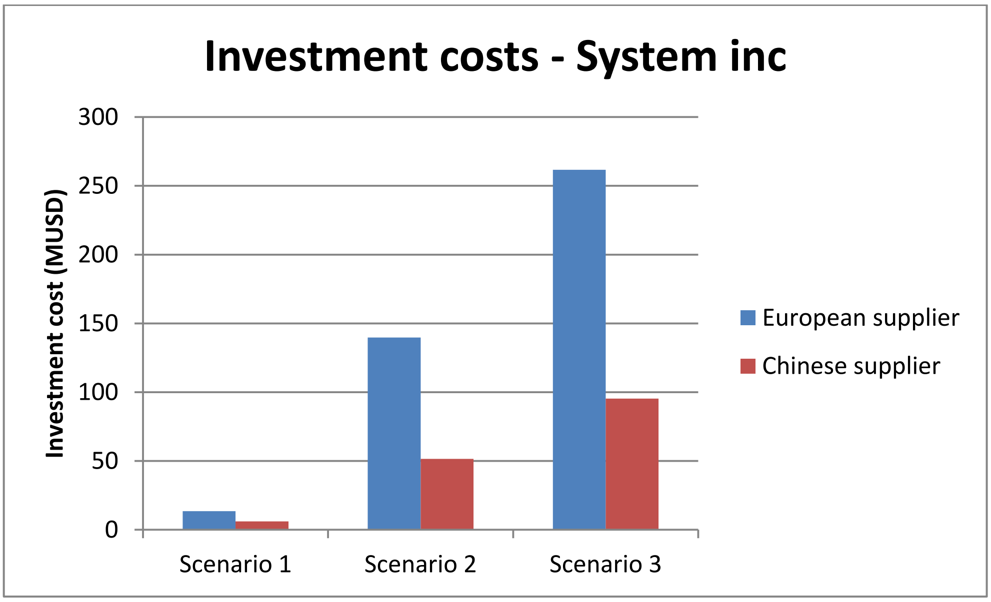

Figure 5-13 Investment costs for different Scenarios and suppliers

There is a big difference in investment cost from scenario to scenario. This is obvious since larger scale projects require larger scaled plants. There is also a big difference between the two suppliers. The European supplier is around three times as expensive as the Chinese supplier. The large price difference will affect all economical comparisons between the suppliers throughout the study. Figure 5-13 show the investment cost for System inc, the other systems will have the similar relationship between investment cost and chosen scenario.

The investment costs of the various systems are shown in Figure 5-14. The figure shows the result for Scenario 2, but the ratio between systems and suppliers is the same for all scenarios.

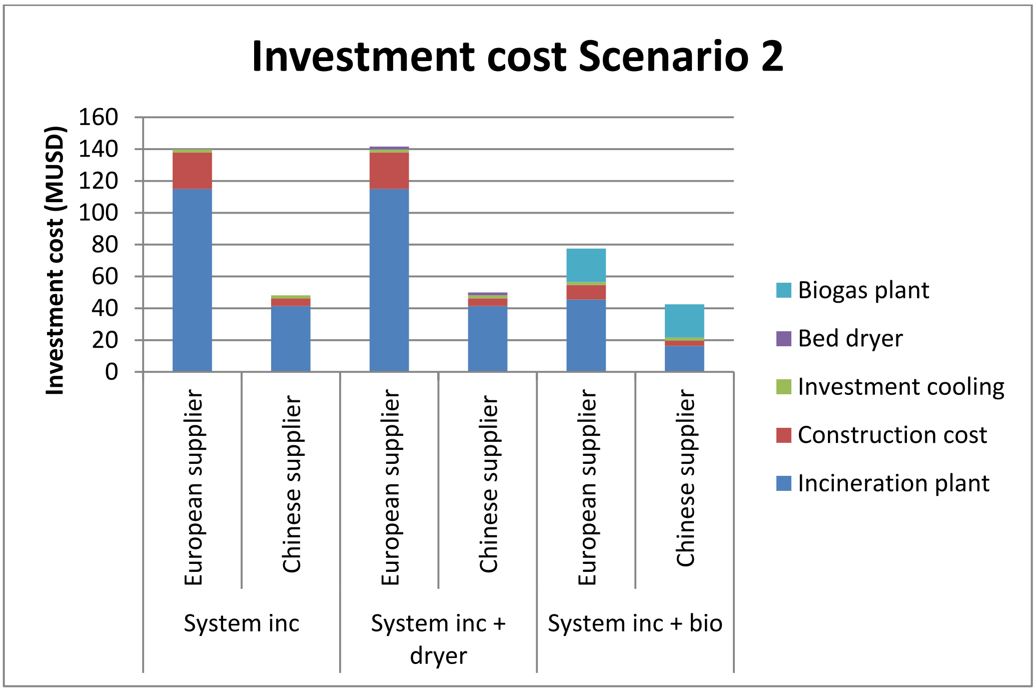

Figure 5-14 Investment cost for the various systems, scenario 2

As can be seen in Figure 5-14, the investment cost for the incineration plant and construction cost sum up the majority of the total investment for System inc and System inc + dryer. The higher construction cost for the European supplier, Martin GmbH, is a consequence of the higher initial incineration plant cost. System inc + dryer, with an integrated dryer is slightly more expensive since an investment of a dryer is necessary. The investment cost of the dryer is almost negligible since it is such a small fraction of the total investment. System inc + dryer is 1 to 3% more expensive than System inc depending on supplier.

The investment cost of System inc + bio, with an integrated biogas plant is considerably lower compared to System inc and System inc + dryer. The cost reduction can be explained by the design of the incineration plant. When the waste is separated in organic and inorganic fractions less waste has to be burned. Hence the cost for the incineration plant will decrease. The investment cost of a biogas plant per received ton waste is lower than for the incineration plant, which will lead to a lower investment cost in total.

The cost reduction between System inc + bio and the other Systems will be most significant for the European supplier since it has the highest incineration investment cost. The reduction in percentage compared to System inc, Scenario 2 is shown in Table 5-10.

Table 5-10 Total investment cost for the different Systems in Scenario 2

Scenario 2	Total investment cost (MUSD)		
Supplier	System inc	System inc + dryer	System inc + bio
Martin GmbH	140	142	77
Chinese supplier	48	50	43
	Percentage out of System inc (%)		
Supplier	System inc	System inc + dryer	System inc + bio
Martin GmbH	100	101.3	55.4
Chinese supplier	100	103.5	82.4

The investment cost for absorption cooling is constant for all systems since the cooling demand will not change depending on the system. The heat produced by each system is more than sufficient to cover the cooling demand. The absorption cooling investment takes a large share of the total investment for Scenario 1, see Figure 5-15. In the other Scenarios the investment cost for cooling, stands for a much smaller share of the total investment cost.

The moisture content in the fuel will only affect the investment cost of the bed dryer, since the bed drying cost is proportional to the drying need. To see how much the investment cost will vary with the moisture content, System inc + dryer is simulated with various fuel qualities.

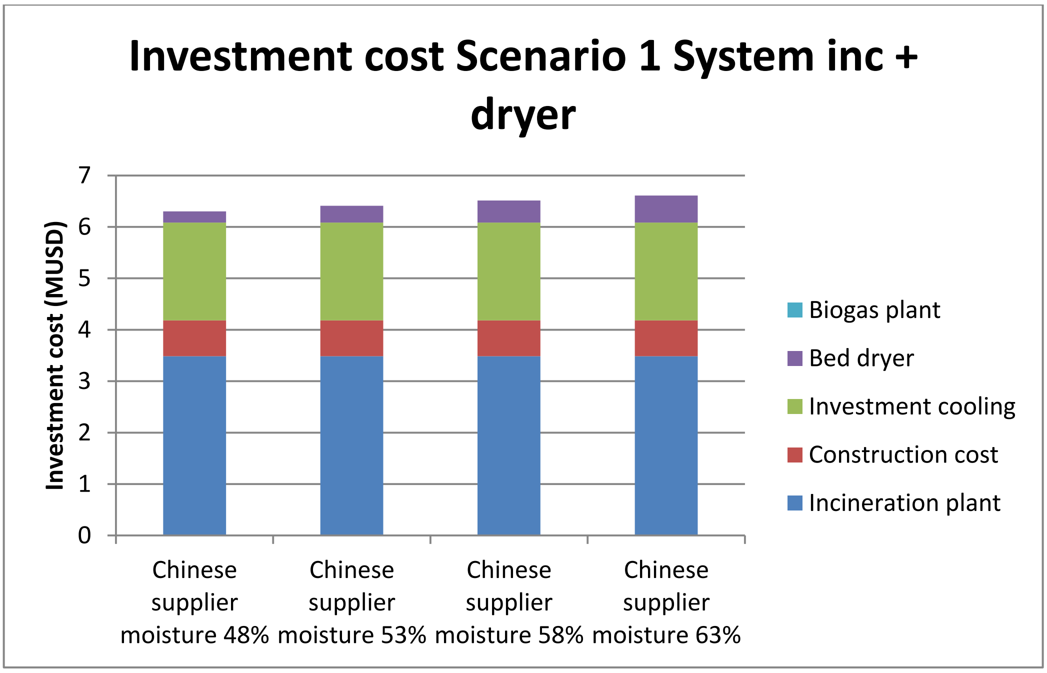

Figure 5-15 Investment cost for System inc + dryer, Scenario 1 different moist content

As can be seen in Figure 5-15, the total investment does only change marginally for the different moist levels. For Scenario 1, with Chinese suppliers the plant with the highest moist content will only cost 4% more than the plant with the least moist content. The percentage differences in total investment due to varied moisture content will not be larger than that for any Scenario or supplier.

5.6.2. Cash flow

The yearly cash flow is the net value from the annual revenue and operational expenses. The tables and figures in this section present the incomes, expenses and annual cash flow for the different scenarios and systems. More detailed data over specific income and expenses for each scenario can be found in Appendix I.

5.6.2.1. Revenue

The WtE plants receive their annual revenue from sales of electricity, absorption cooling and residues. The size of the WtE plant is crucial for the annual revenue. A larger plant will produce more electricity and heat, hence the revenue will increase, see Figure 5-16.

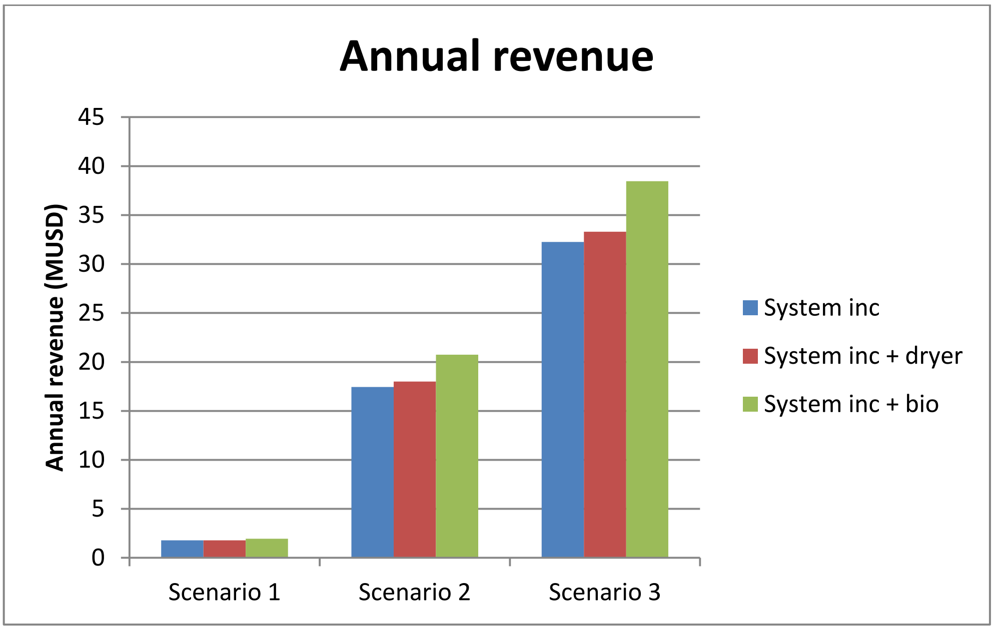

Figure 5-16 Annual revenue for all Systems, Scenario 1,2 and 3

As already mentioned in energy production 5.3 the systems will generate different amounts of heat and electric energy. System inc + bio generates electricity from both the incineration plant and the biogas plant and has a greater electrical output, and will accordingly deliver higher revenue.

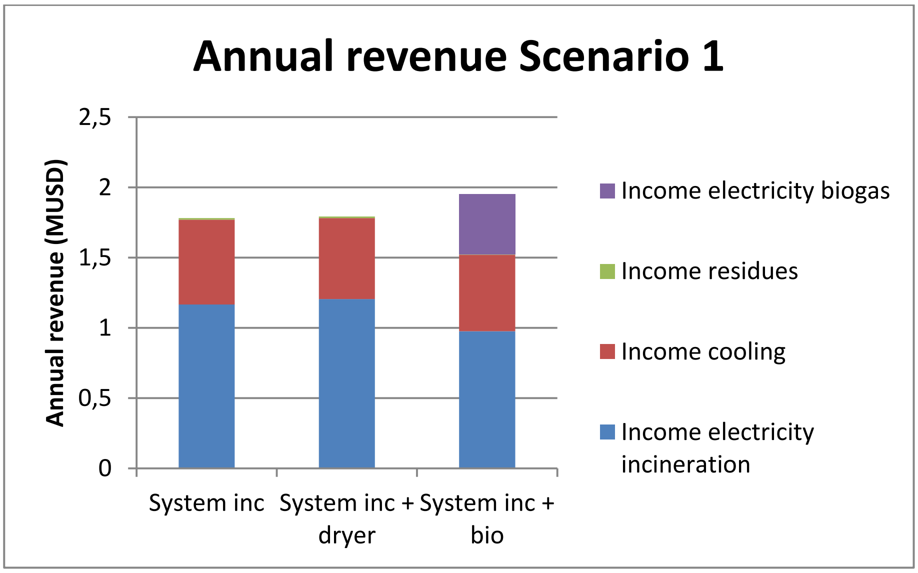

Figure 5-17 Annual revenue for Scenario 1

By comparing revenue from Scenario 1 with Scenario 2, Figure 5-17 - Figure 5-18, it is easy to see how the share of revenue from cooling decrease compared to the total revenue with increasing amount of MSW. This can be explained by the limited cooling demand. In Scenario 1 all produced heat can be used for absorption cooling, but in Scenario 2 only a small share of the produced heat can be used, the same result accounts for Scenario 3 as can be seen in Appendix I. The rest of the heat in these scenarios cannot be used with the current cooling demand. The revenue from sales of residues is marginal compared to the other revenues. This revenue is an economical bonus compared to just disposing the residues at landfills.

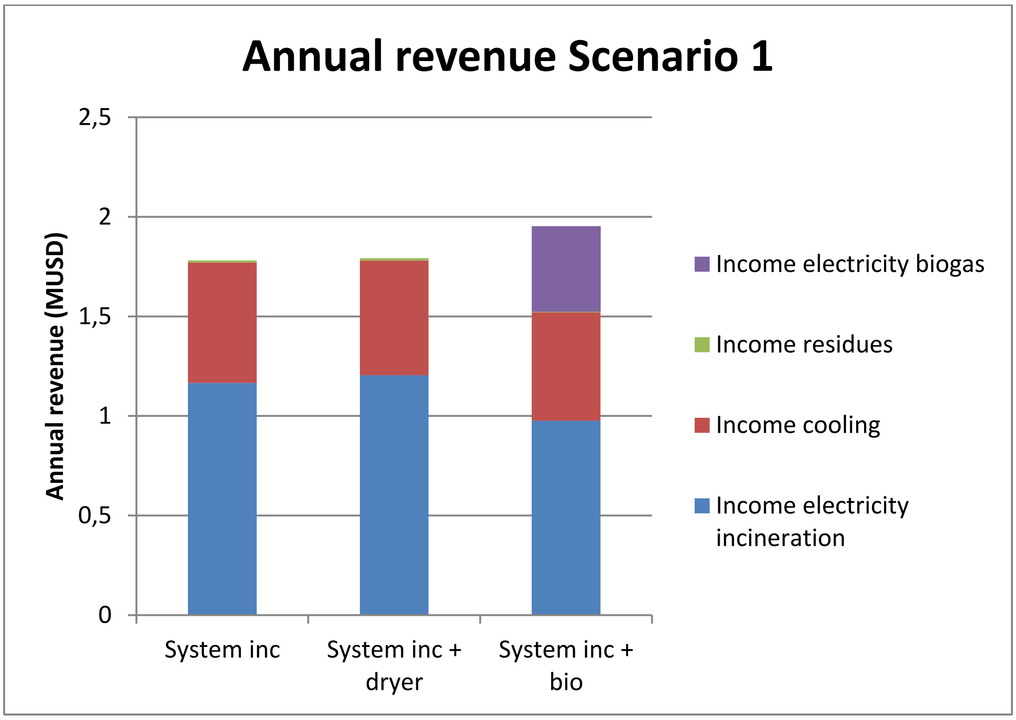

Figure 5-18 Annual revenue for Scenario 2

Since the annual revenue depends heavily on the energy output it is logical that the revenue will decrease with a decreasing heating value. A lower quality fuel will produce less energy hence the revenue will decrease. The annual revenue for Scenario 2 and System inc + bio is shown in Figure 5-19. The revenue from all Scenarios and Systems have the same trend when it comes to varying heating value.

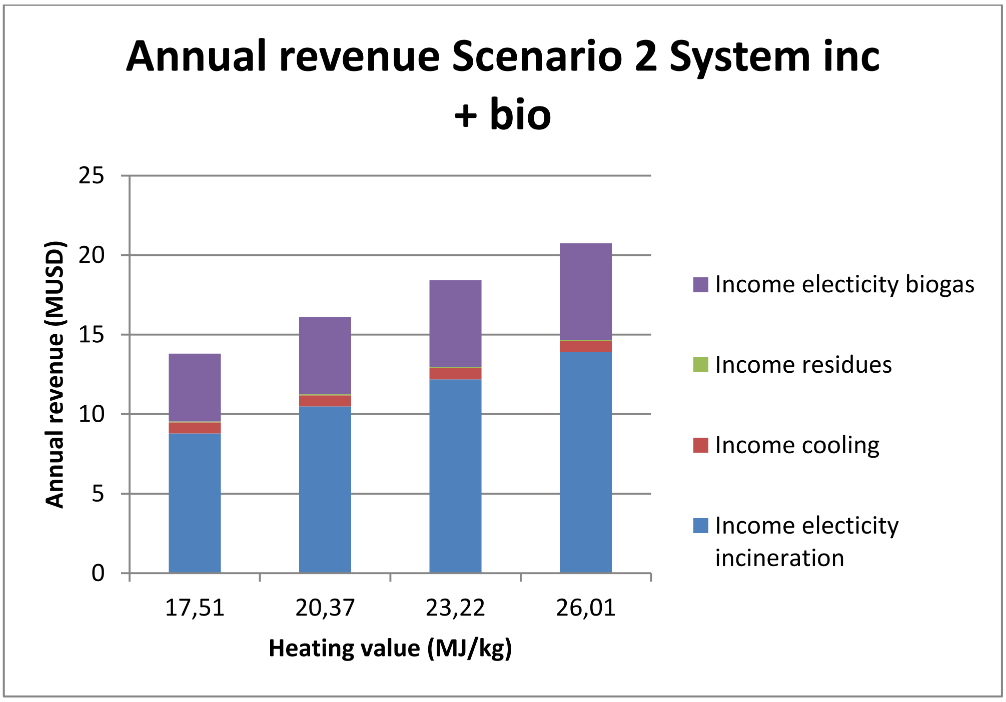

Figure 5-19 Annual revenue Scenario 2 System inc + bio

The income is not dependent on the supplier since it is estimated that they deliver technology with the same quality.

5.6.2.2. Expenses

The annual expenses are operational costs such as: maintenance, salaries, fuel support, transportation of waste and chemicals for flue gas cleaning. The expenses will, like the incomes, increase with plant size, see Figure 5-20. A larger plant needs more personal and maintenance to operate. More supplied waste demand more transportation, and when the collection area increases the waste has to be transported longer distances. An increased feed of waste demands larger boiler and flue gas systems; this will increase the cost for support fuel and chemicals for flue gas cleaning. Since the incineration plant in System inc + bio is smaller compared to System inc and System inc + dryer it will have less maintenance, support fuel cost and chemical cost.

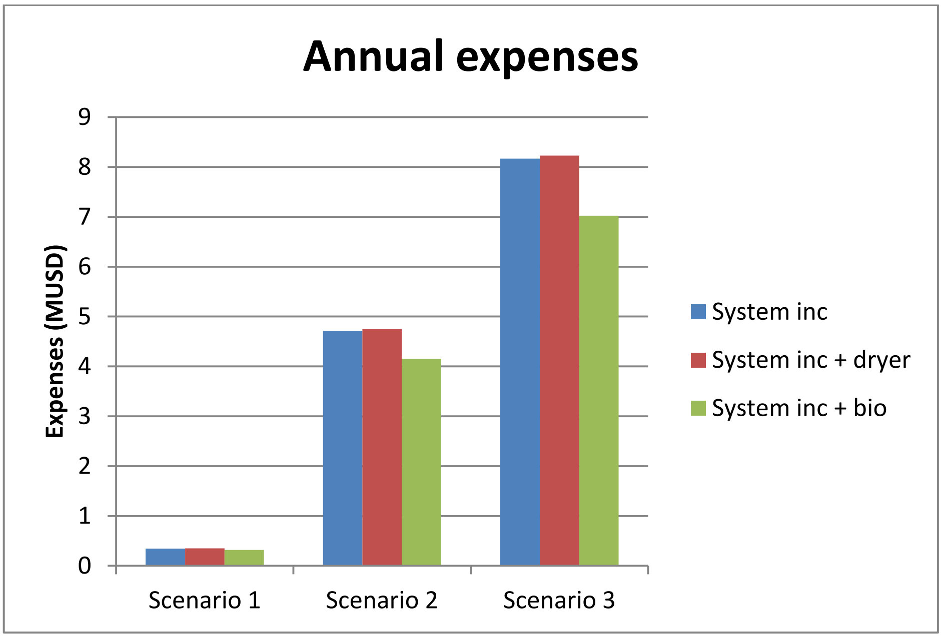

Figure 5-20 Annual expenses different Systems and Scenarios

The individual expenses for Scenario 1 can be seen in Figure 5-21 below. The diagram clearly shows that salaries are the major expense for Scenario 1. It also shows how System inc + bio has lower expenses due to a lower chemical and maintenance demand. In Scenario 1 there is no transportation cost since the used waste is only collected from Tenggarong.

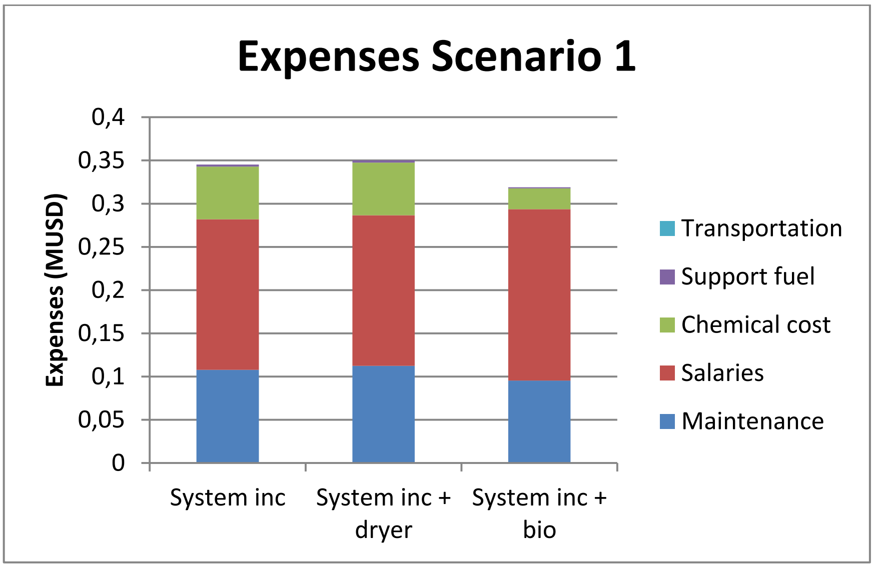

Figure 5-21 Expenses Scenario 1

When comparing expenses in Scenario 1 with Scenario 2 one can see that transportation has become the major expense, see Figure 5-22. The salaries expenses are a smaller share out of the total expenses due to large scale advantages. The share of expanses in Scenario 3 is similar to the ones in Scenario 2, see Appendix I. Estimations for all transportation costs can be seen in Appendix K.

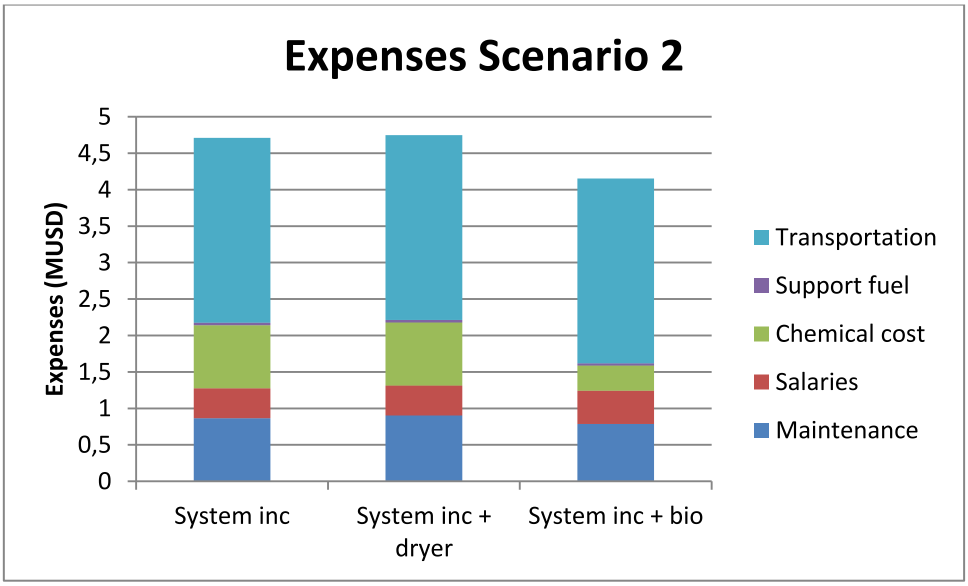

Figure 5-22 Expenses Scenario 2

The expenses will also vary depending on the supplier, all scenarios and systems will have similar expense differences regarding suppliers as shown in Figure 5-23. The only expense that will change is the maintenance cost. Since the maintenance cost is based on the initial investment it will decrease with a cheaper supplier. Whether this relationship is accurate or not can be discussed.

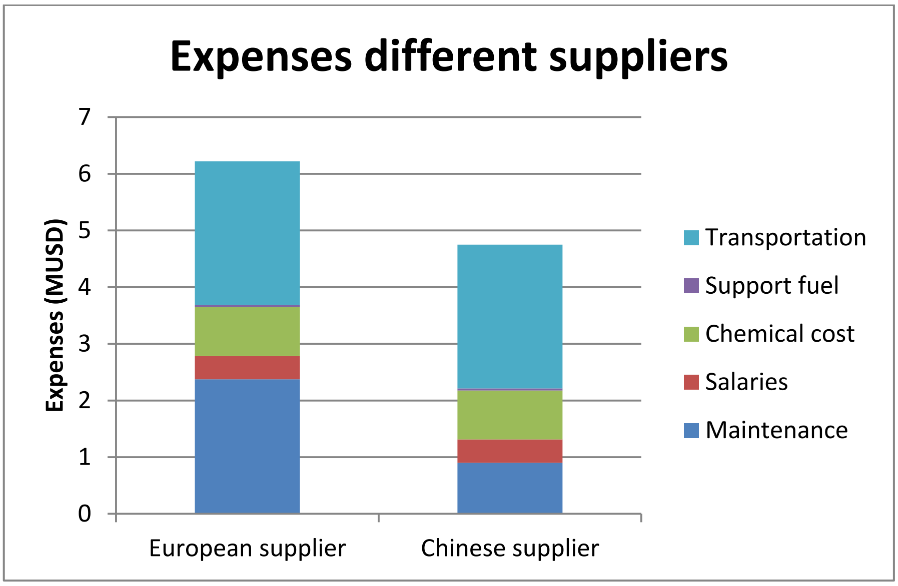

Figure 5-23 Annual expenses for different suppliers, System inc + dryer Scenario 2

The expenses are more or less the same for the different moisture contents. The only cost that is affected is the support fuel. Since this cost only is a small fraction of the total cost the expenses can be seen as independent of moisture content.

5.6.2.3. Annual Cash flow

With the recently explained incomes and expenses the annual cash flow for the different systems in Scenario 2 is shown in Figure 5-24.

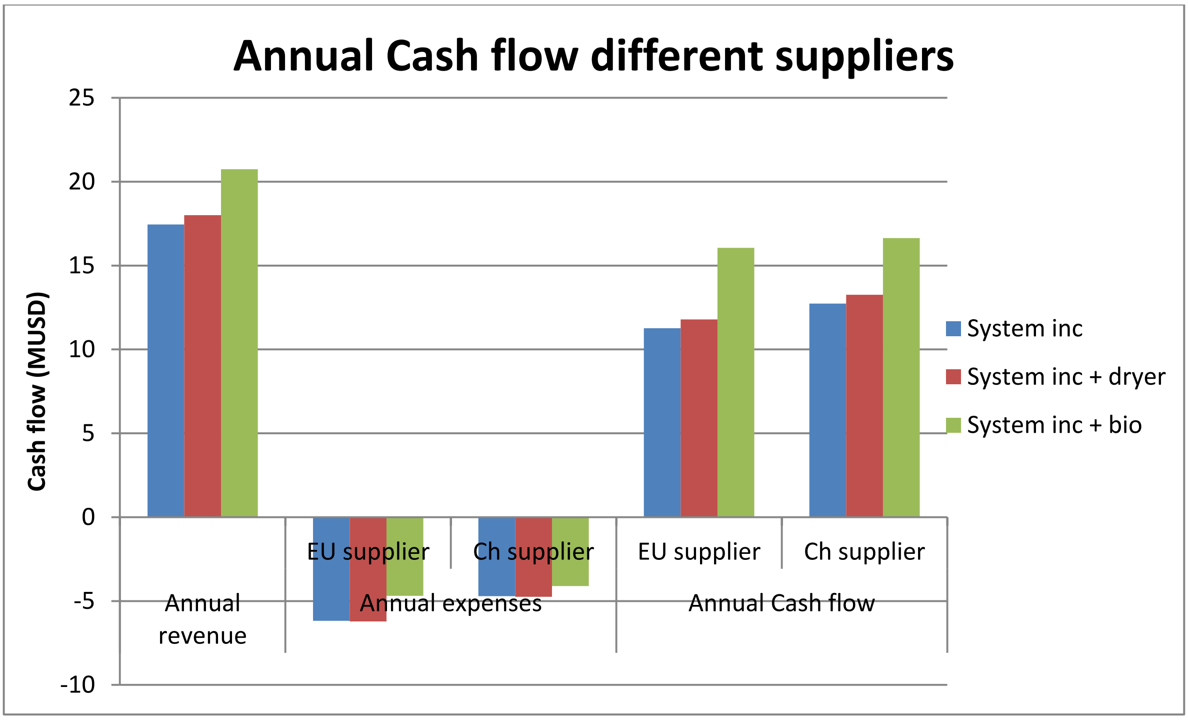

Figure 5-24 Cash flow for the different Systems in Scenario 2

The diagram clearly shows that System inc + bio have the highest annual incomes and also the lowest expenses, hence it also has the highest annual cash flow. Since the incomes and expenses for each system is proportional to the amount of fuel received. System inc + bio will be best for every scenario. From the figure it is also clear that the Chinese plant will give a slightly higher annual cash flow. As already mentioned this can be explained by the lower maintenance cost that the Chinese supplier has.

5.6.3. Economic performance indicators

As the different scenarios, systems and moistures produces different energy outputs, the return on investment will differ. To measure the value of investment economic performance indicators such as NPV and the closely linked IRR has been considered. When calculating NPV, a discount rate of 8% has been used, and the IRR has been calculated after 20 years. As shown in previous sections the income will differ between systems and scenarios, this will make a large difference in payback time.

5.6.3.1. Payback time

The payback time is directly dependent on the systems initial investment and the annual cash flow. The following figures show how the payback time changes for different suppliers, systems, scenarios and moisture content.

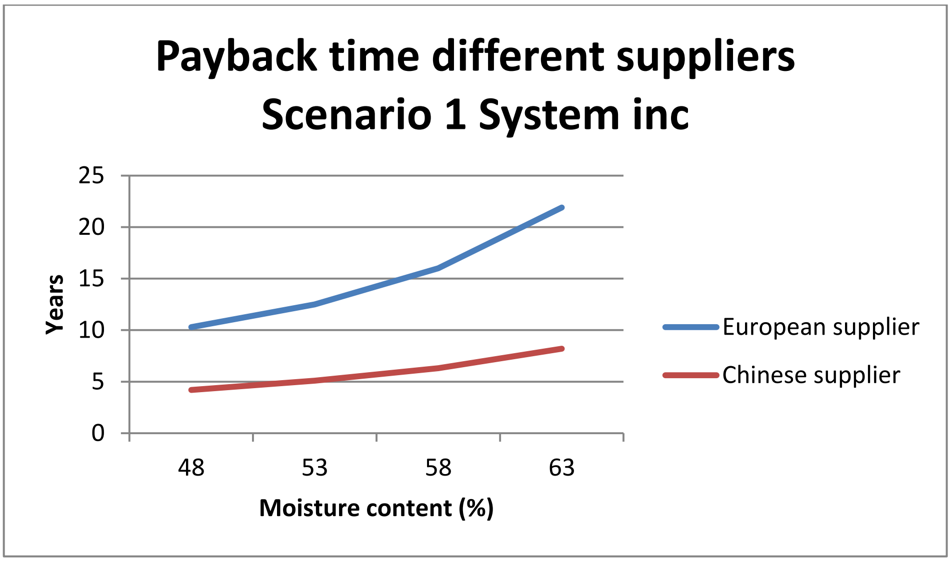

Figure 5-25 Payback time for System inc different suppliers, various moisture content

Figure 5-25 show the payback time for System inc in Scenario 1. It is clearly shown how the payback time differs with various moisture content, and also how it changes with the supplier. These observations are reasonable since the yearly income decrease with higher moisture content.

Obviously the payback time will be shorter for the Chinese supplied plants compared to the European supplied plant, since the investment cost differ significantly but the yearly income is the same. The payback time for the European supplier will be around 3 times higher compared to the Chinese supplier for all systems and scenarios. The rest of the payback results will only show the Chinese supplier results.

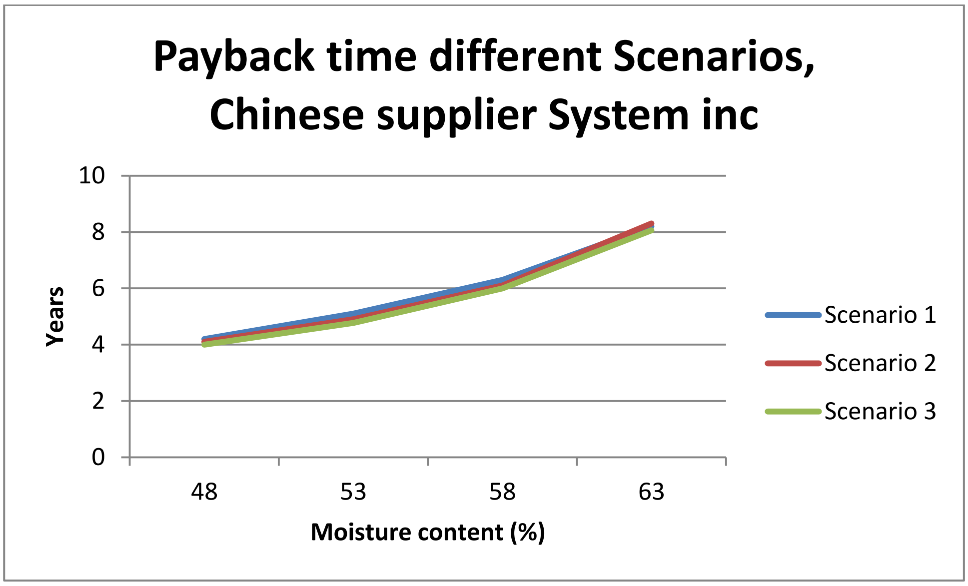

Figure 5-26 Payback time for System inc different scenarios, various moisture content

Figure 5-26 show how the payback time for System inc varies for the different scenarios. As can be seen the payback time is independent of the scenario for this system. By comparing with Figure 5-26 where the payback time for system inc + dryer for the difference scenarios are shown, it is observed that Scenario 1 has a higher payback time. This can be explained by the reduced heat production from System inc + dryer, where some heat is used for drying. The reduced heat production mainly affects Scenario 1 since the revenue from this scenario has a higher share of sales of absorption cooling. The result for System inc + bio with different scenarios is similar to Figure 5-26, these results show that the payback time will decrease slightly with an expanded collection area.

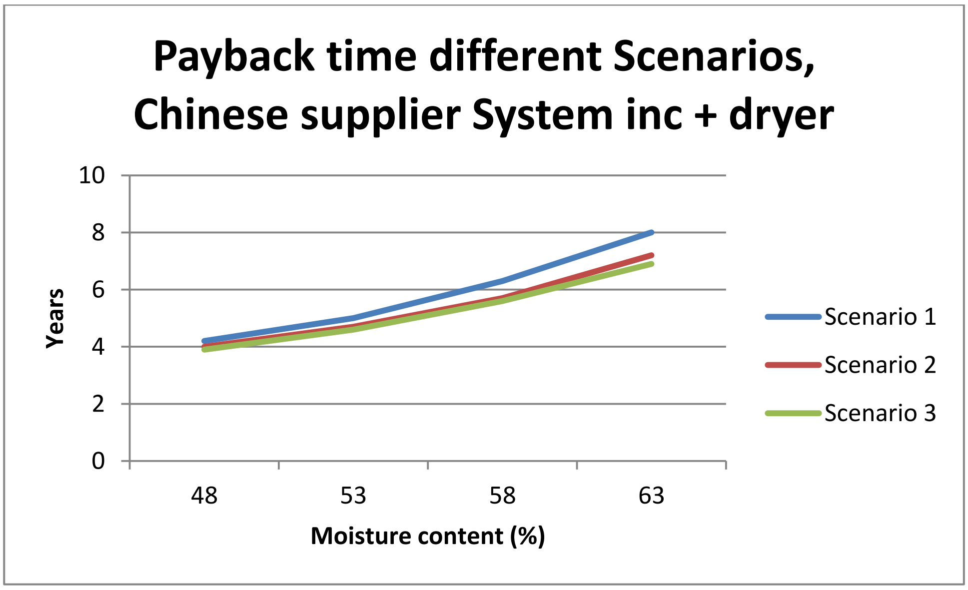

Figure 5-27 Payback time for System inc + dryer different scenarios, various moisture content

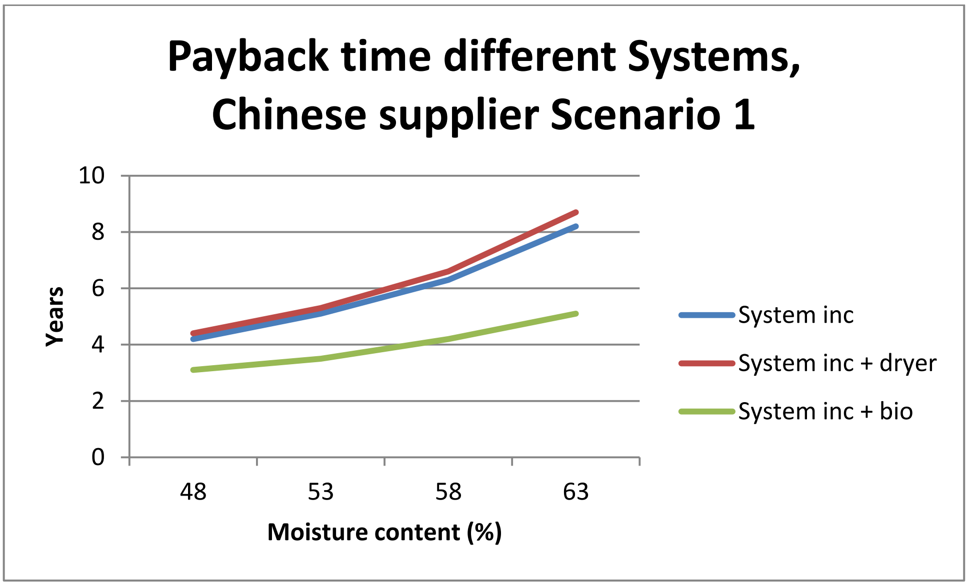

Figure 5-28 Payback time Chinese supplier Scenario 1 different systems, various moisture content

In Figure 5-28 the payback time for the various systems are shown in Scenario 1. System inc + bio has by far the lowest payback time, this can be explained by the lower investment cost and higher annual revenue compared to the other systems. In Scenario 1 System inc + dryer has the highest payback time. When comparing with Figure 5-29, it is observed that System inc has the highest payback time. As already mentioned in this section, System inc + dryer has a higher payback time in Scenario 1 due to decreased heat production, where all the heat can be sold. In Scenario 2 where the heat demand is lower compared to the heat production it is better to dry the waste to generate more electricity. System inc + bio is always the best system due to low investment costs and high electricity production. Payback time for the systems in Scenario 3 has the same relationship as Figure 5-29.

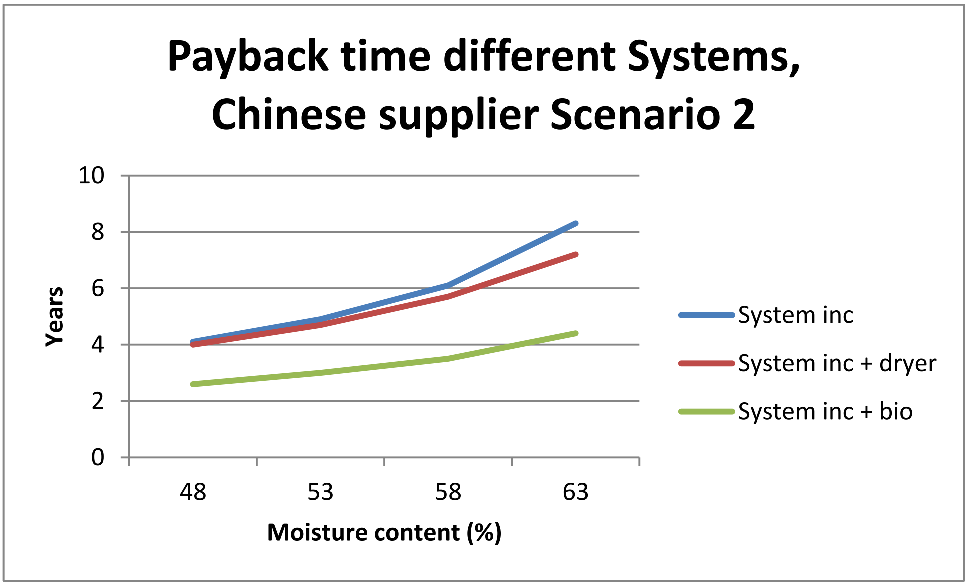

Figure 5-29 Payback time Chinese supplier Scenario 2 different systems, various moisture content

5.6.3.2. NPV and IRR

Figure 5-30 to Figure 5-31 compares all the scenarios with a European and a Chinese supplier and shows a clear difference. The large difference in investment cost between the suppliers and also the scenarios stand out. In the reference system without a dryer, the system from the European supplier does not reach the payback point under the period of 20 years, this due to the large investment cost. The NPV calculation assumes that the plant is constructed in year 2015.

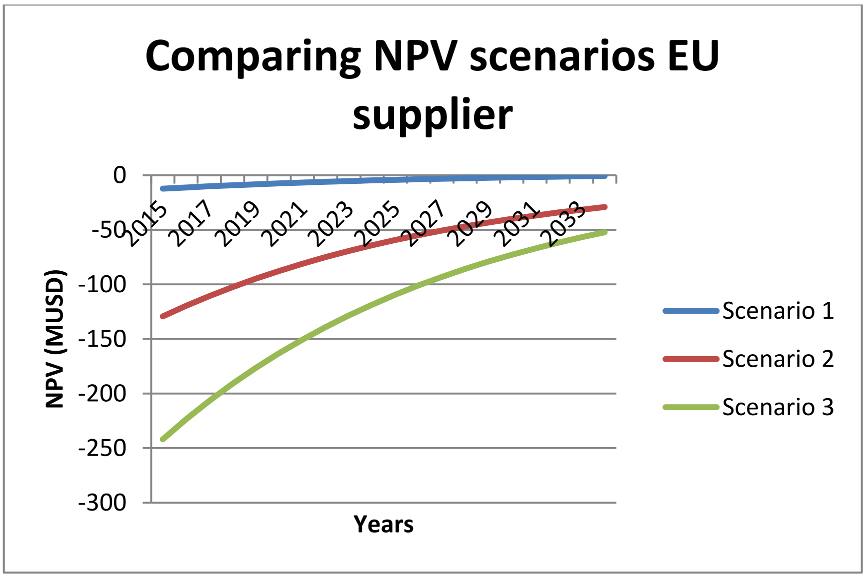

Figure 5-30 NPV values for System inc EU-supplier, different Scenarios

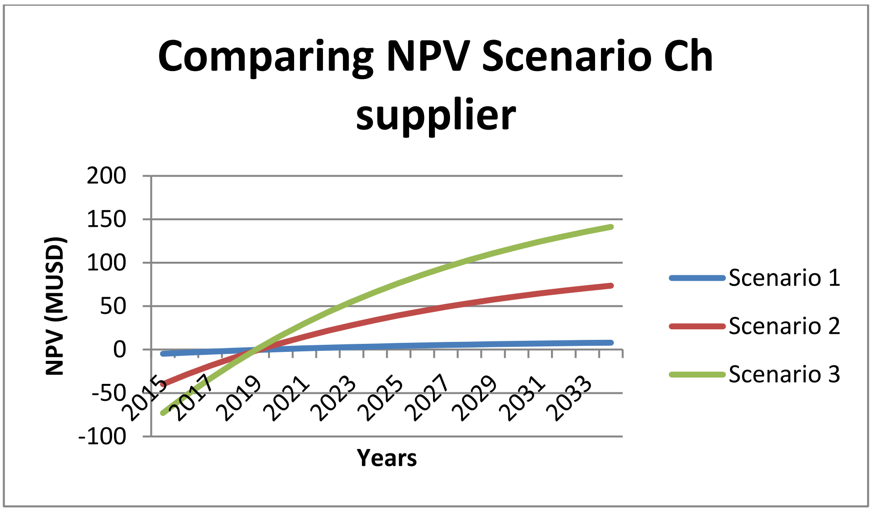

Figure 5-31 NPV values for System inc Chinses-supplier, different Scenarios

Table 5-11 shows the corresponding internal rate of return IRR to each to the simulated NPV values. As suspected, the Chinese supplier produces a higher IRR than the European one, and the difference is scaled up in the larger scenarios.

Table 5-11 IRR for System inc, EU and Chinese supplier, different Scenarios

IRR (%)	Scenario 1	Scenario 2	Scenario 3
EU-supplier	7.3	5	5
Ch-supplier	23	24	25

Figure 5-32 and Figure 5-33 presents the difference in NPV for the different moisture ratios in the fuel. The trend is that the larger moisture ratio, the lower the income. This is because waste with a lower heating value produces less electricity.

All of the scenarios with a Chinese supplier pass the payback point over 20 years and as the heating value gets higher with lower moisture content the NPV value gets higher.

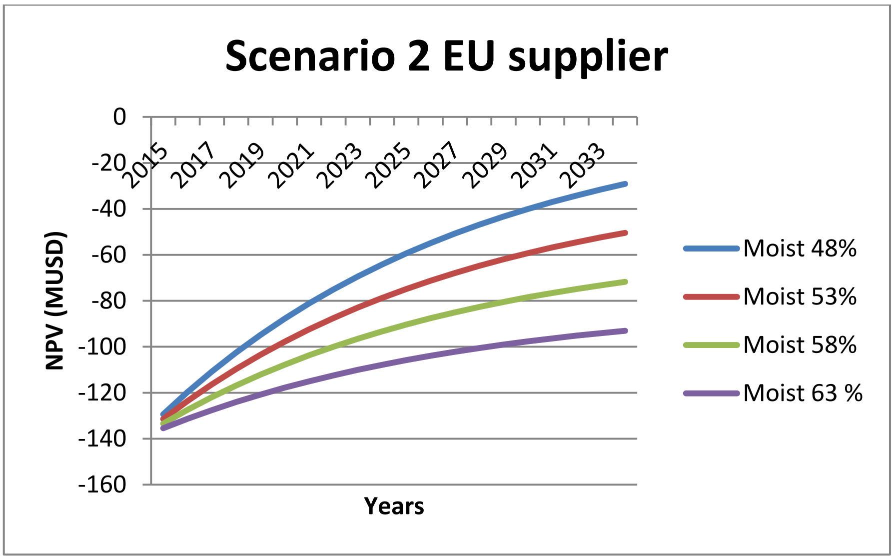

Figure 5-32 NPV value System inc different moisture content, EU-supplier

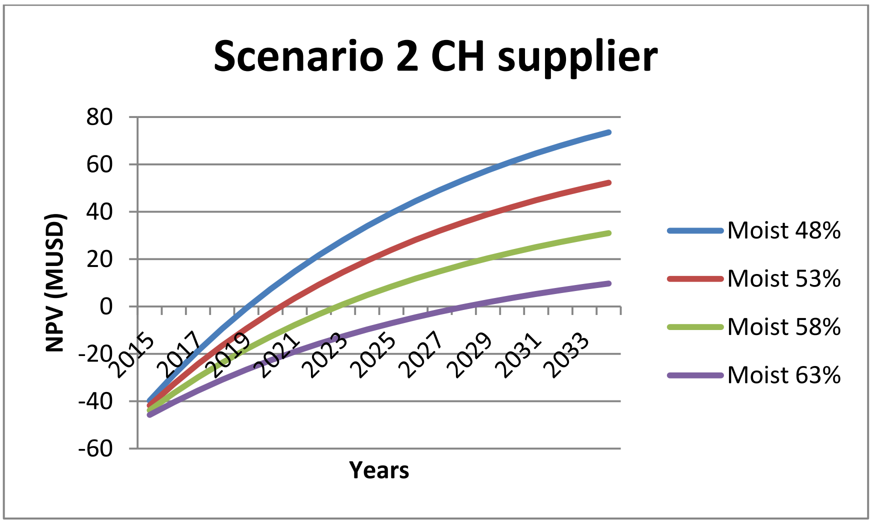

Figure 5-33 NPV value System inc, different moisture content, Ch-supplier

In Table 5-12 the IRR values corresponding to each moisture ratio are presented. The IRR gets lower with a higher moisture ratio as the heat value of the fuel goes down.

Table 5-12 IRR for System inc various moisture content, Scenario 2

IRR	Moist 48 %	Moist 53 %	Moist 58 %	Moist 63 %
Martin GmbH	5	2.6	-0.08	-3.4
China	24	20	15	10.4

In Figure 5-34 and Figure 5-35 we can see the comparison between Systems A, B and C in Scenario 2. System inc + bio clearly stands out and is even in the case with the European supplier reaching the payback point after 5.5 years.

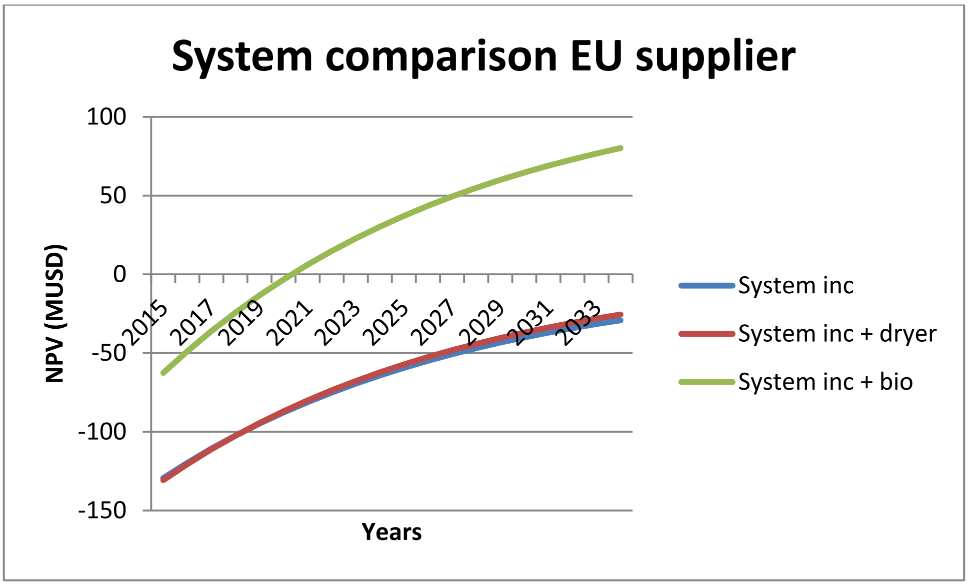

Figure 5-34 NPV value different Systems Scenario 2, EU supplier

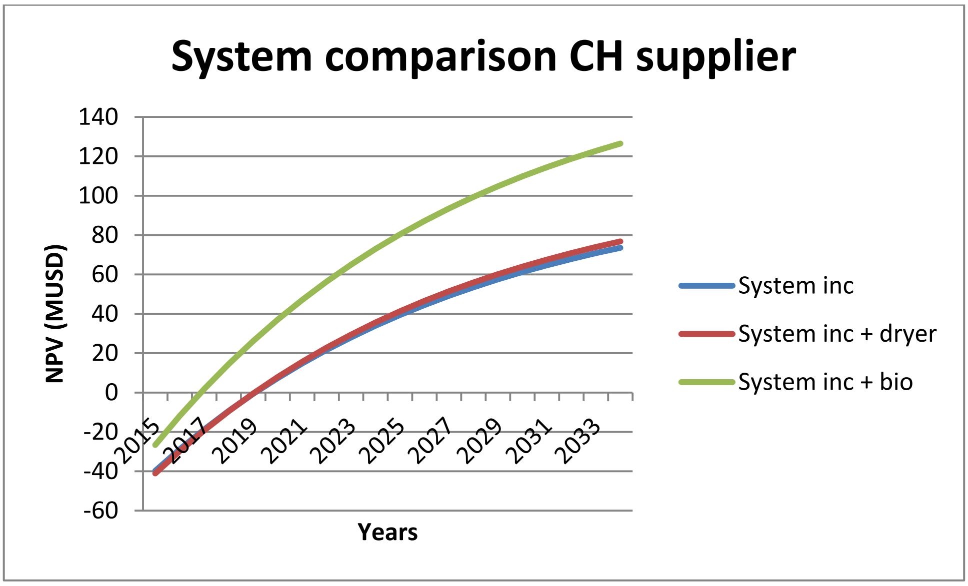

Figure 5-35 NPV value different Systems, Scenario 2, Chinese supplier

Table 5-13 shows the corresponding IRR to each of the systems compared above. System inc + bio is the system that produces the highest IRR.

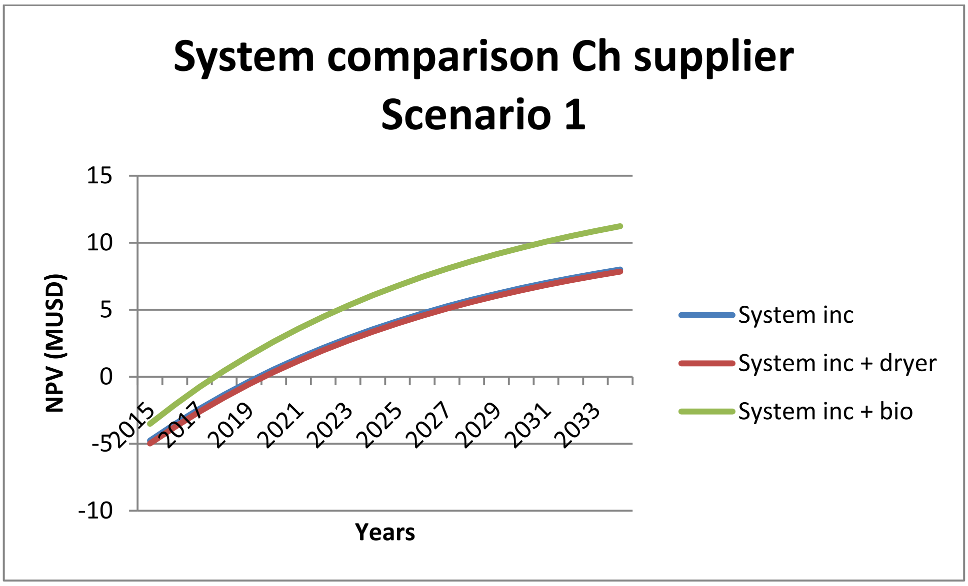

Figure 5-36 NPV value different Systems, Scenario 1, Chinese supplier

Comparing Figure 5-35 and Figure 5-36, System inc is performing better in Scenario 1, this is because a larger part of the excess heat can be sold as absorption cooling.

Table 5-13 IRR Scenario 2 different Systems, European and Chinese supplier

IRR (%)	System inc	System inc + dryer	System inc + bio
Martin GmbH	5.4	5.4	20.2
China	24	24	39

5.7. Environmental result

In the environmental comparison, the GHG emissions from the current operation are compared to the different WtE solutions. The current operation consists of emissions from landfills and emissions from fossil electricity production. In the WtE solutions, the emissions from transport of the waste and emissions from WtE plants are included. The different scenarios are compared so that only the fossil energy production that is replaced in each scenario is considered. As there will be no difference in GHG emissions between the European and the Chinese supplier, the suppliers will not be compared. The GHG emissions from waste handling and transportation can be seen in Appendix L.

Figure 5-37 shows the comparison between the different scenarios with a reference system with a fixed moisture ratio (48%).

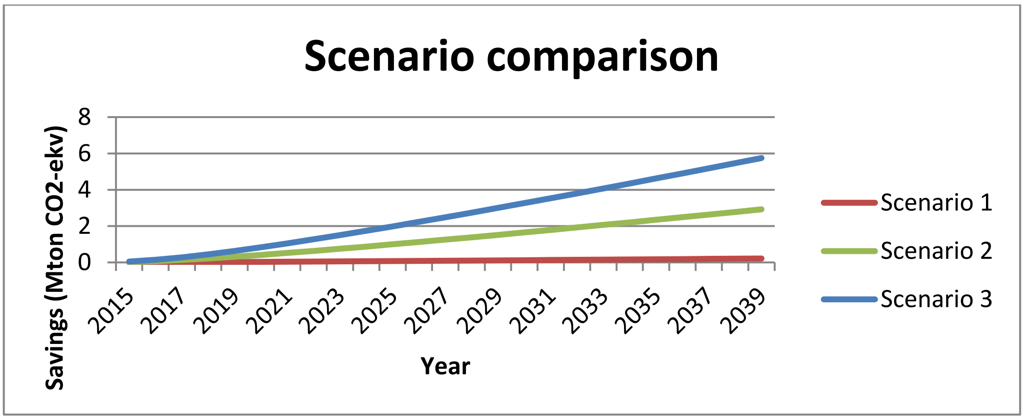

Figure 5-37 Environmental comparison different scenarios

The plot shows the sizeable difference between the scenarios.

In the comparison between different moisture ratios, the reference Scenario 2 and System inc + bio has been used. The comparison is visualized in Figure 5-38.

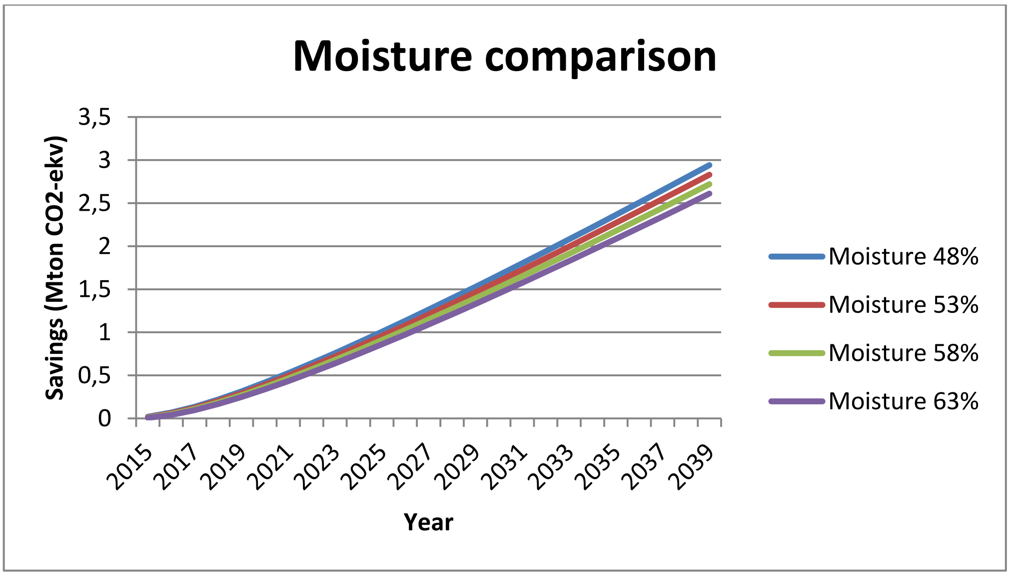

Figure 5-38 Environmental comparison different moisture content System inc + bio, Scenario 2

As the change in moisture ratio in the different fractions affects the amount of waste, the size of the savings will be lower with a higher moisture ratio. This applies to all scenarios.

In the systems comparison, savings with all systems are plotted for Scenario 2 with a fixed moisture ratio (48%) shown in Figure 5-39.

Figure 5-39 Net savings in Mton CO2 ekv for the different Systems

As visualized in the plot, the savings is larger in the system with a dryer compared to without. The dryer is using excess heat to keep the fuel at a stable moisture ratio of 40%, this is returning a higher production of electricity and thus a larger reduction in GHG emissions. In the biogas system, the dryer is replaced with a biogas plant. When using the biogas plant, the organic fraction is separated from the rest of the burnable fuel. This is also resulting in a higher energy value, giving a higher energy output / input waste. At the same time the organic fraction is producing biogas that is generating electricity.

6. Recommended solution and design

Based on the results presented above it is clear that System inc + bio would be the most suitable option. This system generates most electricity and has the best economic and environmental performance. Scenario 2 with waste collection within a 30 km radius around Tenggarong including the Samarinda region would be the best collection area. This area has an existing infrastructure and generates large amounts of waste, which will lead to high electricity and heat production as well as environmental benefits. Expanding the collection area even further as in Scenario 3 will, with the infrastructure available today, not be advantageous or realistic.

The following operational conditions and suggestions are based on the recommended techniques and waste collection scenario for the Kutai Kartanegara region. All operational conditions and suggestions are based on theory, simulations and data summarized in this study.

6.1. Location

At this current stage no location for the WtE plant is decided. We suggest that the plant should be located with the needs for infrastructure, waste supply and energy demand taken into account. By locating the plant along the Mahakam River, close to Tenggarong the plant will have access to good logistical infrastructure, by trucks and boats, and close access to the waste supply. The river will also be used to cool excess heat, however all of this could be found in Samarinda as well.

If the Kutai region and Samarinda regency can cooperate it would be even better to locate the WtE plant in Samarinda due to an even better logistic location. In Samarinda the cooling demand would be higher than Tenggarong, which will lead to higher revenue and a more effective use of the plant output.

6.2. Waste reception

The WtE incineration plant needs a receiving bunker where waste can be stored. The separated waste should be stored separately. The waste provided is collected from the sub-districts located around a 30 km radius of Tenggarong and the Samarinda region. The inorganic bunker should have a storage capacity of around 240 tons daily, which corresponds to bunker volume around 950 m^3. It is recommended to build some kind of cover over the bunker to minimize the effect from heavy rainfall. The waste is fed to the grate with a crane. The organic fraction received is about 360 tons/day this is fed directly into the separating station. The waste will be transported by boats on the Mahakam River or by trucks from Loa Janan and Loa Kulu.

6.3. Design of WtE incineration plant

The WtE incineration plant in Kutai Kartanegara will be designed for an annual incineration of around 100,000 tons separated inorganic MSW. The designed plants will have the capacity to process the collected waste and capacity to handle a future waste increase in the region. The facilities will be operated during 8,000 hours a year. During one month the operation in the facilities will be halted for planned maintenance work. There is normally two or three shorter maintenance stops during one year.

To minimize stress on boiler and turbines and to optimize the combustion the facility must be in continuous operation 24 hours per day. This means that the boiler has to be designed to handle around 12.5 tons per hour. The size of the incineration plant will be approximately 10,000 – 15,000 m^2.

The separated waste will have a heating value around 18-26 MJ/kg. The heating level will vary depending on the moisture content and the grade of separation.

6.3.1. Grate

The recommended technology for the incineration plant is a moving grate. This technology is chosen because of its robustness and its ability to handle waste that not is pre-treated and has a varied composition. For production safety reasons there will be two separate grate and boiler lines. The lines are designed to handle 6.75 ton per hour each. With the highest simulated heating value of 26 MJ/kg the boilers need a thermal capacity of 30 MW each.

6.3.2. Boiler

The waste will enter the air cooled grate into the bottom part of the furnace with the help of a feeder. The waste will be combusted with primary air through the grate and secondary air from nozzles above the grate. Noncombustible residues will leave through the bottom of the grate. The residues are around 10 % of the total weight of the input fuel and will be sold as road construction material. The fuel gases will be combusted to around 1,400 degrees. To complete the combustion it is important to have a sufficient combustion temperature and a good air circulation. To reduce the levels of nitrous oxides ammonia will be injected to the flue gas with a SNCR system. The flue gas is cooled down to 155^{o}C in a heat exchange with a steam cycle before leaving to the flue gas cleaning. Natural gas will be used to maintain the combustion temperature during start up and maintenance.

6.3.3. Flue gas cleaning

The flue gases from the boiler will be treated in a semidry flue gas cleaning system. Lime and activated carbon is added to the flue gas and reacts with gaseous pollutants to form solid products. These solid products and larger particles will be removed from the flue gas in a bag filter. The facility will have emission levels meeting EU standards.

6.3.4. Residues

The bottom ash from the incineration process and fly ash form the flue gas cleaning system will be collected separately. The bottom ash, around 25 ton a day, will be sold as construction material. The hazardous fly ash will be disposed at a controlled landfill. Our recommendation is Balikpapan landfill.

6.3.5. Steam cycle

The boiler delivers superheated steam with a temperature of 400 °C and a pressure of 40 bars. When going on maximum power the boiler will produce 19 kg steam / second. The temperature and pressure is reduced in a high-pressure turbine down to 160 °C and 6 bars. Before entering a low pressure turbine, the steam is superheated to 400 °C. In the low-pressure turbine the pressure is reduced to the condensing pressure of 0.13 bar and it has a steam ratio of 0.95. In the low-pressure turbine, a fraction of the steam is linked off to preheat the feed water, the program is here finding the solution that gives to optimal efficiency (η_{el}=34%) of the process (13 % at 1 bar).

The power produced in the turbines is about 14-21 MW depending on the heating value of the fuel. The generated electricity is distributed to the Mahakam power grid and sold to PLN. The heat output from the condenser to the DH/DC grid will be between 25 and 39 MW, though only about 3.5 of this can be used for cooling. The excess heat between 22-36 MW will be cooled against the Mahakam River.

6.3.6. Existing pipe network

There is no existing pipe network for delivery of excess heat. To be able to deliver absorption cooling to offices and the Royal World Plaza a pipe network has to be installed.

6.4. Design of biogas plant:

The organic fraction, around 150,000 tons, will be processed in a biogas plant. The facilities will be operated during 8,000 hours per year. During one month the facilities will be stopped for planned maintenance work. There is normally two or three shorter maintenance stops during one year.

6.4.1. Pre treatment

The substrate consists mostly of household waste and is supposed to be separated properly before being delivered to the biogas plant. Even so there would need to be a separating unit where objects that could be harmful to the process are removed. This separator would be able cut up and remove plastic bags and remove metallic objects.

To make the biogas outtake optimized and the substrate easy to pump a grinder to make the substrate easier to handle will be needed.

As the plant is not intended to receive any slaughterhouse residues hygienization of the substrate is not needed. However, if the plant is upgraded to receive slaughter residues a hygienization unit will be needed.

6.4.2. Reactor

The reactor type is chosen to be a continuously stirred reactor, this is the most common type and the technology is proven to work. In this type of reactor, the residues are pumped out in the bottom. The reactor will be designed to handle 360 tons/day. The process chosen should be a thermophilic one, due to the continuous high temperature in Kutai Kartanegara Regency. This will also reduce the cycle time for the substrate.

6.4.3. Residues

The residues from biogas plants are rich in nutrients and can be used as fertilizers for growing crops. However the nutrient value of the residues varies greatly depending on the composition of the organic fraction. If the residues are proven to be good material for fertilizer they could be sold, if not they are to be composted.

6.4.4. Energy production

The biogas is being used in diesel generators. There will be between 5 and 8 motors of with a max power of 1 MW each, the number depending on the moisture ratio in the substrate. The motors will be Jehnbacher type j320gs105 or similar model. This is the same setup as the Kembang Jangut biogas plant so there is technological expertise in how to use this type of generators nearby. Another advantage with a smaller motor is that upscaling the effect will be easy. The electricity will be distributed to the Mahakam power grid and sold to PLN.

6.5. Design parameters and environmental savings

Energy output and economical key numbers for the recommended system and scenario are summarized below. Both the highest and the lowest energy value are presented in Table 6-1.

Table 6-1 Design parameters

Moisture ratio	10 %	37 %
Fuel feed (ton/h)	10.7	10.7
Heating value (MJ/kg)	26.01	17.51
Power, boiler (MW)	61.5	40.5
Steam feed (kg/s)	19	12.5
Net electricity incineration (MW)	17.97	11.36
Net electricity biogas (MW)	7.88	5.52
Total power output (MW)	25.85	16.88
Total annual electricity (GWh)	206.8	135
Power, District Heating (MW)	39.26	25.86
Heat demand cooling (MW)	3.53	3.53
Net power thermal (MW)	35.73	22.32
Net thermal energy output (GWh)	285.9	178.6
Investment incineration plant (MUSD)	19.67	19.67
Investment cooling (MUSD)	1.92	1.92
Investment biogas (MUSD)	20.98	20.98
Total investment cost (MUSD)	42.55	42.55
Income electricity incineration (MUSD)	13.89	8.78
Income electricity from biogas (MUSD)	6.10	4.26
Income cooling (MUSD)	0.69	0.69
Income residues (MUSD)	0.06	0.06
Annual revenue (MUSD)	20.75	13.81
Maintenance (MUSD)	0.79	0.79
Salaries (MUSD)	0.41	0.41
Chemical cost (MUSD)	0.35	0.35
Support fuel (MUSD)	0.036	0.02
Annual expenses (MUSD)	4.11	4.10
Annual cash flow (MUSD)	16.65	9.71
Payback time (years)	2.6	4.4
NPV (MUSD)	120.85	52.84
IRR (%)	39	22.4
Coefficients of performance		
Boiler	0.934	0.926
El	0.338	0.338
Heat	0.639	0.639
Total	0.977	0.977

Figure 6-1 shows the environmental comparison between the current operational scenario with landfill and fossil energy production and the WtE with biogas plant. As can be seen an implementation of the recommended technology would reduce the emissions of GHG gases. By 2020 the savings would be around 0.5 Mton CO_2 – equivalents, this correspond to 0.6% out of the 78 Mton CO_2 that has to be saved from the waste sector to meet the National action plan for GHG reduction.

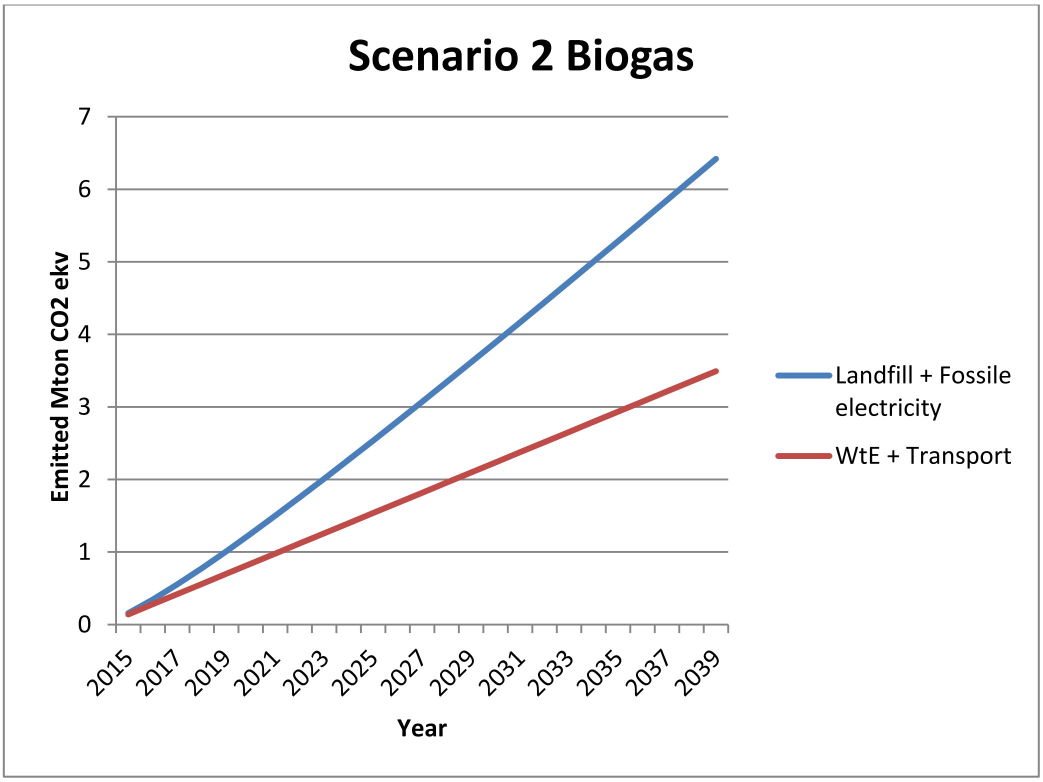

Figure 6-1 Savings Scenario 2 System inc + bio

7. Discussion

It is clearly shown in the study that there are potential for WtE use in Kutai Kartanegara Regency. However profitability and energy output is strongly dependent on both the composition and moisture content of the fuel.

The data gathered from Samarinda and Tenggarong has a very low content of metals, glass and other inert objects compared to composition of whole Indonesia. This could be a result of waste pickers doing a very good job and the metals and glass parts are being separated better in Kutai Kartanegara than other regions.

This in addition to a slightly low moisture content in the European values from ORWARE are leading to a very high heating values compared to other reports from similar regions.

The uncertainties in both the composition and the moisture ratio have led us to simulate moisture contents from 48 to 63 %. Varying the moisture content within this interval produces heating values from 7.5 to 12 MJ/kg for the composition included the organic fraction. This numbers make a huge difference in making a plant profitable or not.

To get a more confident opinion on the heating value of the fuel in the area, these numbers should be investigated further.

Our proposed solution with a biogas plant requires separation of the waste. There is existing infrastructure for waste separation in both Samarinda and Tenggarong that are the major cities in Scenario 2. However, most of the subdistricts do not have waste management at all. Even though there is separated TPS's for organic, inorganic and harmful objects the separation from the households is not working properly at the moment. To increase the separation, information to households and schools is necessary.

A potential problem for the waste pickers might arise when none of the waste is arriving at the landfill. They could still collect waste from the TPS's but this would be a major setback for them. A solution to these problems could be a separation unit close to the WtE-plant. Some of the waste pickers could be employed in the separating plant and that way the social harms from rearranging the system would be lowered at the same time as the waste gets separated properly. It has to be remembered that the work the waste pickers are doing today is very important, without them, none of the waste would be recycled.

As the waste management in the sub-districts is inadequate, a lot of the waste is ending up in the wrong place, either in the woods, in the river or is burned in open burnings. Even though there is proper waste management in Tenggarong and Samarinda, this is a common sight there as well. By establishing stricter laws that prohibit waste dumping and open burnings, this might create incentives to collect the waste on a larger scale and at the same time reduce pollution to the environment. Complemented with a tipping fee on the landfill, this would create incentives both to build the plant and to return all the waste to the WtE plant. There are fears that a tipping fee on the landfill would lead to more open burnings and uncontrolled dumping. But if the fee is accompanied with a plant that could receive the waste free then this should not be a problem.

The more waste that is collected, the less has to be put on landfills, hence larger environmental benefits. However, with the current infrastructure it is not reasonable to collect the waste from the whole area. In the remote sub districts the amounts of waste compared to the potential distance of transport makes it not feasible to transport the waste at the moment. In Balikpapan and Kota Bontang the waste amounts could be feasible to transport but seem unnecessary and it would be a better idea to build a WtE-solution on site. The waste problem in the remote sub-districts will be a problem as long as infrastructure is lacking and waste management is not implemented. Further studies on smaller scale solutions in these areas should be considered.

The models in this study are based on a plant located in Tenggarong. However, locating the plant in Samarinda instead should be of consideration, as this would reduce unnecessary waste transport. Samarinda that has an about 5 times larger population produces 5 times more waste. As transport overall is problematic with current infrastructure this should be in consideration. As Samarinda is a larger city with a larger population there is also a larger potential market for district cooling, that could make a large difference in weather a project is feasible or not.

The economics of such a large-scale project, especially overseas, is varying greatly. We have shown that only the investments in the plant vary between 50 and 144 MUSD depending on the supplier. When considering costs for support fuel and chemicals for flue gas cleaning, these are strongly dependent on location, and depending on the moisture ratio and the composition of the fuel, the heating value varies between 7.5 and 12 MJ/kg. All of these parameters are strongly affecting the economical calculations and has to be investigated further before initiating a project.

Electrification, especially in the sub-districts is low, with an average of 82% in the whole Kutai Kartanegara it sounds decent compared to 76% in the whole Indonesia. But one has to remember that there are also sub-districts that are as low as 17% in electrification and many of these users do not have access to electricity the whole day, but are usually limited to 6h in the afternoon and evening. By expanding the transmission grid and providing these villages with a reliable and sustainable electricity connection, the living standards in the region would rise.

8. Further studies

This thesis has been covering waste-to-energy in the Kutai Kartanegara region. This is a large subject and all details have not been covered. Suggestions of further studies aim to point out studies that could complement this study to get a better foundation for decisions on if and how to build waste management systems in the region. We suggest:

Pick-analysis

- A deeper investigation of the waste composition and moisture ratios in the area by doing a pick-analysis.

Waste management

- Studies of a separation system for waste management. Come up with a suitable solution for the area.
- Studies of the waste management in the sub districts. Come up with a suitable solution for the area.

Heat demand

- A market analysis of the market for district cooling and/or usage of steam

Power grid

- Analysis of the distribution grid, what would happen when introducing a new large power source and what adjustments need to be done?

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Appendix A – Middle Mahakam project

Located in the middle of Mahakam River, there is a 500,000ha area of peat land. It covers three districts but mainly the Kutai Kartanegara. The amount of peat carbon in the area is could be up to 500 million ton (estimation by Unna Chokkalingam et al CIFOR 2005). There are 19 larger villages in the area with a population of about 20000 people.

The area is an important source for fish to the local communities but has also been the main supplier of dried freshwater fish to Java. In the year 2000 the fishermen were able to produce 10tons of dried fish a month, but during the last years the fish population has been decreasing drastically and the monthly production is now down to a ton. A reason to the decreasing population of fish in the area is believed to be the conversions of forest and land to oil palm plantations in the upper stream of the river.

The area is also home to a vast amount of animals and plants that are only to be found on Borneo. Some of them are also considered endangered, like the Siamese crocodile (critically endangered), the Proboscis monkey (endangered), the Malaysian giant turtle (endangered) the Irrawaddy Dolphin (Vulnerable) and the Bornean orangutan (endangered). The site is also a transit place for bird migrations; in other words, the area is to be considered highly significant ecologically and should be conserved and restored.

Figure A-1 Forest fire at Sebangau forest, Central Kalimantan, Photo by CIMTROP

The largest threats to the area are reported to be, expansion of oil palm plantations and forest fires.

Until 2010, an area of 99,500ha has been converted to oil palm plantations. Based on estimations from the ministry of forestry, the development of oil palm plantations in Kutai Kartanegara had reached about 760000ha. In the middle Mahakan river area there are currently 13 existing oil palm plantation licenses. However, there are only two of these licenses that has been taken in use, because of difficulties with flooded areas and refuseage to give up land from the local communities.

Forest fires are listed as one of the largest threats to the biodiversity in the area and the conclusion is that most of the causes of fires have been man made.

REDD

The UN-REDD programme and REDD+ solution is an initiative to reduce emissions from deforestation and degradation and can be traced back to the climate meeting COP-13.

The aims for the initiative are to;

> "Create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to

sustainable development. "REDD+" goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks."

The three phases towards REDD+ implementation are;

Phase 1: Developing a REDD+ strategy supported by grants

Phase 2: Implementing a REDD+ strategy, supported by (a) grants or other financial support for capability building, and enabling policies and measures and (b) payments for emission reductions measured by proxies.

Phase 3: Continued implementation of REDD+ strategy in the context of low-carbon development, payments for verified emission reductions and removals.

REDD in Kutai Kartanegara

As there is an awareness of the situation in the subdistricts, the local government has in cooperation with local NGO's and the village leaders, carried out a proposal for low emission development in the middle Mahakam area.

In 2013, the local government designated 72,766ha of peat land for restoration, this to reduce the negative effects of ex, oilpalm plantations. They also declared that no new permits or licenses for oilpalm plantations will be allowed on this site.

The proposed activities for low emission development in this area are divided into two phases, a preparation phase and an implementation and monitoring phase. In the first phase developing a REDD+ strategy according to the first two REDD+ phases are included.

Right now the project is in the first phase and we have attended several of the village councils both in the villages and in the sub district center. During these meetings we have got a unique first hand look on decision-making and we also had the opportunity to ask the villagers a couple of questions about their waste and energy situation.

Evaluation of the energy and waste situation

In order to evaluate the energy and waste situation in the villages of the middle Mahakam river area, two fieldtrips to the subdistrict were arragned. The most remote villages in the Muara Kaman district, Desa Muara Siran, Liang Buaya and (Muara Kaman centrum). A survey was also handed out to 14 out of 19 of the villages in the area.

The villages in the middle Mahakam river area are between 124 – 1100 households and the main occupations are depending on the village shifting from oilpalm plantation workers to fishermen and farmers. Most of the villages do not have grid connection or road connection, but are instead reached by riverboat. Due to the remoteness of the villages no waste pickup is now available in the subdistrict villages. The waste management in the villages consists of using what could be used like firewood or fish baits from organics and open burnings of burnable material at best. Some of the villagers claim that they throw everything in the river.

Figure A-2 waste accumulation in the Mahakam river and under housing in Muara Kaman subdistrict

Liquid petroleum gas (LPG) is used for cooking and electricity is provided either by PLN, the national electricity company or by privately owned diesel generators.

The villagers claim that their need of electricity are 450-1000W / household, prioritizing refrigerators, freezers and lighting. They are in need of freezing capability so they can store fish to sell later at the market.

Table A-1 Statistics from the questionnaire to the middle Mahakam villages.

Village	Population	Houses	Persons / house	Electricity available [h/day]	Percentage of houses connected
Muara Kaman Ulu	3600	700	5,14	24	98,57
Muara Kaman Kir	2730	645	4,23	24	77,52
Sedulang	2587	700	3,70	6	50,00
Sabintulung	2400	1100	2,18	24	63,64
Semayang	1450	350	4,14	14,5	100,00
Muara Siran	1364	376	3,63	14	47,87
Tubuhan	1073	240	4,47	14	62,50
Liang Buaya	1042	308	3,38	6,5	
Bukit jering	1023	265	3,86	5	60,38
Kupang Baru	950	310	3,06	6	48,39
Sang Kuliman	835	242	3,45	10	100,00
Muhuran	663	213	3,11	6	77,46
Sebelimbingan	513	157	3,27	6,5	60,51

Pela	416	124	3,35	24	80,65
Total	20230	5606			
Average	1556	431	3,66	12,35	70,57

	LPG Usage kg / pers
Total	59503
Average	2,90

As we can see in the statistics of table 1 there are about 20000 people living in the area, and their energy situation varies from having electricity 24h / day down to 6 h in some of the villages. In about 70% of the households electricity is available, and they use about 2,9 kg of liquid petroleum gas per person for hot cooking each month.

According to Pemerintah Kabupaten Kutai Kartanegara, PKKK, the average production of household waste is estimated to 0.7 kg/person. With this estimated waste production data, the villages in the survey will produce a total amount of 5275 ton of waste per year. The total amount of waste from all the villages in the Muara Kaman sub-district is approximated to 8634 ton a year.

Propositions

Several propositions by local NGOs in cooperation with the Bappeda (planning agency of the region) and the Buppati have been made. The propositions are all talking about the problems with land and forest conversion to oilpalm plantations, the links between deforestation and poverty, the problems with forest fires and large emission of greenhouse gasses. These are very relevant issues. However none of them addresses the problems with waste management in the area.

In both the report ”Combating Rural Poverty through biomass village electrification” by Buppati, Ph.D, Rita Widyasari and ”Low emission development” by NGO representative, Stepih Hakim and Bappeda, Hamly Pidie the solutions are proposed as sustainable forestry and biomass to electricity conversion.

The Buppati concludes that a 5MW powerplant in each district would give the households about 1000W, 24h/day.

Later propositions have been talking about smaller solutions with micro scale biomass gasification processes.

We would like to come up with some remarks to these suggestions;

First of all, neither of the solutions are addressing the problem with waste pollution in the river and waste dumping in the forest nor the link between open burnings of waste and increased risks for uncontrolled fire.

Secondly, we think that there might be hard to get qualified operators for the micro scale gasification units in the remote upriver villages, this could lead to problems with machinery and thus no electrification.

Last, the efficiency of a large plant always wins against a smaller, and there will always be excess heat produced. In the city this excess heat could be used for cooling government buildings, mall etc. with absorption cooling technology. In the sub district it would be harder to find use of this heat, and this would lead to a less economically viable solution.

Instead we want you to consider the possibilities to make larger scale plants. This would need to be accompanied by an investment in the electrical grid, but this type of infrastructure investments would be an investment for the future.

From our simulations we conclude that the waste of Maura Kaman has an energy value between 6-12MJ/kg,. When assuming the same composition as Samarinda it is 11.95 MJ/kg but there are reasons to believe that the waste composition might hold more organics and more moisture than Samarinda, and that would lead to a lower energy value. To get a more precise approximation of the energy value, a full analysis of the composition would be needed.

Table A-2 LHV for different types of fuel

Fuels	LHV [MJ/kg]
LPG	46,44
Diesel	43,00
Natural gas	38,16
Antracit	30,00
Bituminous coal	24,05
Biogas 62,7%	20,21
Under bitunimous coal	16,65
Woodchips 30 %	12,60
MSW Samarinda*	11,94
Lignite	9,90

Comparing the different fuel types we can see that there is a small difference in the heating value between woodchips and MSW. However, the MSW is free, and is a pollution problem if not used, while the woodchips comes at a cost and has a slight environmental impact in using.

Applying the Samarinda waste composition to the waste stream in Muara Kaman we get 924kW electricity production and 1743kW excess heat production.

If the households need 1kW each, this accounts for electricity for about 900 households. This will not cover the total demand, but this fuel is free and can easily be co-combusted with any other fuel like woodchips to satisfy a larger energy demand.

In the report by Buppati Rita Widyasari It is stated that according to Japan Renewable Energy Foundation 5GW / year needs 18-27 Ha/year.

Only looking to the heating values approximately a fifth of this, 3,6-5,4 Ha could be saved using co-combustion with MSW.

In this report we want to open your eyes for MSW as an alternative and or complement to other fuel types. By using this type of fuel we are adressing all of the above listed problems with toxic emissions, emissions of greenhouse gases and the risks with open burnings.

Appendix B - Promotional project summary for Pole to Paris

Kutai Kartanegara in East Kalimantan, Borneo, is the oldest kingdom in Indonesia and has a long history and proud cultural heritage. The Kutai region is divided into 18 districts and 2012 the population was 674 464 people, where about 15% live in the capital city Tenggarong. The region has rich natural resources, especially coal, oil, natural gas, quarry and tropical forest. Coal mining, oil, natural gas and quarry sector dominates the economy, which account for more than 85% of the region's GDP. Forestry and agriculture is the next biggest sector where palm oil planting and rubber trees are dominant.

This development has contributed to high greenhouse gas emissions and reduction of biodiversity in the area. Lack of biodiversity can be a potential threat to endangered wildlife such as orangutan and fresh water dolphins that live in the region, and the decreasing fishing stocks affect fishermen in rural districts.

Despite these rich energy resources only 62% of the electricity demand is met within the region. The lack of a fully covering transmission grid forces the villages in the sub districts to have local grids powered by diesel generators, running only a few hours a day. Even in Tenggarong where a connection to the fossil fuel powered distribution grid is available, there are several of power cuts a day.

The Kutai government with regent Ph.D Rita Widyasari in charge have recognized the problems and engaged the region into several collaboration projects towards sustainability, for example Smart City and REDD. REDD is a UN collaborate project and stands for reducing emissions from deforestation and forest degradation. It aims to create a financial value for carbon stored in the forest and offer incentives for investment in sustainable development. In Kutai Kartanegara this project currently aims to use biomass for energy in a sustainable way to increase the availability of electricity in the sub-districts.

Right now this project is in the start phase and we have had the privilege to attend several of the village councils both in the villages and in the sub district center. During these meetings we have got a unique first-hand look on decision-making and we also had the opportunity to ask the villagers a couple of questions about the waste and energy situation in the sub districts.

Figure B-1, Top left and bottom left: Waste accumulation in the Mahakam river, Top right: Remains of open burnings, Bottom right: Waste accumulation under housing in the sub district

The waste management in the villages consists of using what could be used like firewood or fishbaits from organics and open burnings of burnable material at best. Some of the villagers claim that they throw everything in the river.

Figure 0-2 Forest fire at Sebangau forest, Central Kalimantan. Photo by CIMTROP

Forest fires are listed as one of the largest threats to the biodiversity in the area and most of the causes of the fires have been man made.

As the villagers are dependent on the river for fish and the forest and peat lands for agriculture, they need to become more aware of the dangers of polluting the river and burning the waste. We are trying to provide incentives for choosing a system that could handle waste as well as biomass for electrification of the sub districts.

Our main project is a multi-collaborate project between Swedish companies and the Kutai Kartanegara region. The project originated when a Kutai delegation visited Falu Energy and Water and Borlänge Energy in Sweden and outlined their local energy systems. The delegation was impressed by these energy systems and requested similar systems in Kutai Kartanegara. To investigate the feasibility of these systems; SWECO, IVL and ÅF have together with Uppsala University and Swedish University of Agricultural Sciences provided two Master of Science students, namely us; Johan Torstensson, Sociotechnical Systems and Jon Gezelius, Energy Systems, to conduct a pre-feasibility study on waste-to-energy in the region.

We are currently in Tenggarong collecting data for the pre-feasibility study. The main objectives of the research is to recommend suitable techniques to process the local waste, to estimate potential energy output from the waste and to evaluate economical and environmental aspects of a waste-to-energy plant. What is already known is that a waste-to-energy plant in Tenggarong would decrease the amount of waste dumped at landfills and also decrease the dependence of fossil fuel generated power. This would result in a decrease of greenhouse gas emissions in the region.

Figure B-3 Left: Separation station in Tenggarong, Middle: Wastecollection in Tenggarong, Right: Landfill in Tenggarong

As we can se in figure 2, the region is striving towards a system where there is a separation of the waste, but unfortunately all of the waste still ends up in the same landfill. By creating a system where the waste actually is worth something, both in the city and in the sub district, we are hoping that this will reduce the amount of waste ending up both in the Mahakam river and the surrounding forest.

Figure B-4 Discussing with local NGO representative Stepih Hakim during a visit to the Muara Kaman sub district. Photo by Heru Abdee

We are the first two students in this collaborative project, the aim is that more students will follow and complement our research to help Kutai Kartanegara to fulfill their goal to become a more sustainable region. By fulfilling their goals Kutai Kartanegara can be a role model for other developing regions.

Figure B-5 Participating in small village council in Liang Buaya, Muara Kaman.

Appendix C - Summary ORWARE-model

ORWARE is LCA model for WTE purposes. It was developed in the early 1990's as cooperation between KTH, SLU, JTI and IVL. The model has been considered to be scientifically significant for European WTE. The model is built up by blocks in MATLAB and SIMULINK, this is an advantage that makes it easy to further develop (Frostell, 2015) (Bisaillon, Sahlin, Johansson, & Jones, 2014) .

Appendix D - Matlab codes

Main programme code

```
KOD STARTWASTE

clear
format long g
prompt = {'Organic:','Plastic:','Paper and cardboard','Textile and
Rubber','Metal','Glass','wasteflow'};

dlg_title = 'Mass fractions [%]';
num_lines = 1;
def={'0','50.2','42.9','1.8','1.6','2.4','215696.2'};%406208
% 60.4 19.9 17 0.68 0.65 0.92
% 0 50.2 42.9 1.8 1.6 2.4

q=inputdlg(prompt,dlg_title,num_lines,def);

%m=str2num(q{1}); Input for massflow, later...

mass = str2num(q{7});
tic

Other=1-
(str2num(q{1})+str2num(q{2})+str2num(q{3})+str2num(q{4})+str2num(q{5})+str2
num(q{6}))/100;

Organic=(Other/(length(def))+str2num(q{1})/100;

Plastic=(Other/(length(def))+str2num(q{2})/100;

Papercard=(Other/(length(def))+str2num(q{3})/100;

Textilerub=(Other/(length(def))+str2num(q{4})/100;

Metal=(Other/(length(def))+str2num(q{5})/100;

Glass=(Other/(length(def))+str2num(q{6})/100;


atar=(Organic+Plastic+Papercard+Textilerub+Metal+Glass);

% ÄNDRA YEARLY_FEED OM AVFALL SORTERAS

yearly_feed = mass*(1-0.604);% waste feed ton/year % OBS ÄNDRAS OM MAN INTE
SORTERAR BORT ORGANICS

feed=(yearly_feed*1000)/(8000*3600);

%Kontroll sats

if atar<0.99 |  atar>1.01

    display('The sum of fractions must be 100%')

    break
```

```
   end

%Avfallsdata (ORWARE)

genwastematrix; %Genererar WasteTSMat


%fraktioner
tabell_CO2kk=zeros(25,6,4);
%NPVtabell_mgkk=zeros(1,20,4);
%NPVtabell_askk=zeros(1,20,4);

for kk=1:4;

    reduc=0.6+kk/10;

    reduckk(kk)=reduc;

TSfrac=wasteTSMat(:,47)*reduc;  %kg TS/ Kg avfall

ffrac=1-TSfrac; %kg H20 /kg avfall

%Omvandlig från Kg/KgTs -> KgTs /Kg avfall

DOCfrac=wasteTSMat(:,1).*TSfrac; %DOC fraction / kgTS avfall

Ofrac=wasteTSMat(:,20) .*TSfrac;
Cfrac=(wasteTSMat(:,1)+wasteTSMat(:,45)).*TSfrac;
Hfrac=wasteTSMat(:,21).*TSfrac;
Nfrac=wasteTSMat(:,23).*TSfrac;
Sfrac=wasteTSMat(:,28).*TSfrac;
Cfosfrac=wasteTSMat(:,45).*TSfrac;

%fraktioner VS CONTENT INTE tagit hänsyn till.

%f = fukthalt
forganic=Organic*((ffrac(1)+ffrac(12))/2); %1=Organic households
12=restaurants and trade
fplastic=Plastic*ffrac(8);
fpapercard=Papercard*((ffrac(6)+ffrac(7))/2); %6=dry mixed paper
7=cardboard
ftextilerub=Textilerub*ffrac(5);
fmetal=Metal*ffrac(11);
fglass=Glass*ffrac(10);

fv=[forganic,fplastic,fpapercard,ftextilerub,fmetal,fglass];%,Oothers];
ftot=sum(fv);

%O
Oorganic=Organic*((Ofrac(1)+Ofrac(12))/2);%1=Organic households
12=restaurants and trade
Oplastic=Plastic*Ofrac(8);
Opapercard=Papercard*((Ofrac(6)+Ofrac(7))/2); %6=dry mixed paper
7=cardboard
Otextilerub=Textilerub*Ofrac(5);
Ometal=Metal*Ofrac(11);
Oglass=Glass*Ofrac(10);
```

```
O=[Oorganic,Oplastic,Opapercard,Otextilerub,Ometal,Oglass];
Otot=sum(O);



%DOC

DOCorganic=Organic*((DOCfrac(1)+DOCfrac(12))/2);%1=Organic households
12=restaurants and trade
DOCplastic=Plastic*DOCfrac(8);
DOCpapercard=Papercard*((DOCfrac(6)+DOCfrac(7))/2); %6=dry mixed paper
7=cardboard
DOCtextilerub=Textilerub*DOCfrac(5);
DOCmetal=Metal*DOCfrac(11);
DOCglass=Glass*DOCfrac(10);

DOC=[DOCorganic,DOCplastic,DOCpapercard,DOCtextilerub,DOCmetal,DOCglass];
DOCtot=sum(DOC);

%C
Corganic=Organic*((Cfrac(1)+Cfrac(12))/2);%1=Organic households
12=restaurants and trade
Cplastic=Plastic*Cfrac(8);
Cpapercard=Papercard*((Cfrac(6)+Cfrac(7))/2); %6=dry mixed paper
7=cardboard
Ctextilerub=Textilerub*Cfrac(5);
Cmetal=Metal*Cfrac(11);
Cglass=Glass*Cfrac(10);

C=[Corganic,Cplastic,Cpapercard,Ctextilerub,Cmetal,Cglass];
Ctot=sum(C);

%Cfos
Cfosorganic=Organic*((Cfosfrac(1)+Cfosfrac(12))/2);%1=Organic households
12=restaurants and trade
Cfosplastic=Plastic*Cfosfrac(8);
Cfospapercard=Papercard*((Cfosfrac(6)+Cfrac(7))/2); %6=dry mixed paper
7=cardboard
Cfostextilerub=Textilerub*Cfosfrac(5);
Cfosmetal=Metal*Cfosfrac(11);
Cfosglass=Glass*Cfosfrac(10);

Cfosvec=[Cfosorganic,Cfosplastic,Cfospapercard,Cfostextilerub,Cfosmetal,Cfo
sglass];
Cfostot=sum(Cfosvec);
cfos=Cfostot;

%H
Horganic=Organic*((Hfrac(1)+Hfrac(12))/2);%1=Organic households
12=restaurants and trade
Hplastic=Plastic*Hfrac(8);
Hpapercard=Papercard*((Hfrac(6)+Hfrac(7))/2); %6=dry mixed paper
7=cardboard
Htextilerub=Textilerub*Hfrac(5);
Hmetal=Metal*Hfrac(11);
Hglass=Glass*Hfrac(10);

H=[Horganic,Hplastic,Hpapercard,Htextilerub,Hmetal,Hglass];
```

```
Htot=sum(H);

%N

Norganic=Organic*((Nfrac(1)+Nfrac(12))/2);%1=Organic households
12=restaurants and trade
Nplastic=Plastic*Nfrac(8);
Npapercard=Papercard*((Nfrac(6)+Nfrac(7))/2); %6=dry mixed paper
7=cardboard
Ntextilerub=Textilerub*Nfrac(5);
Nmetal=Metal*Nfrac(11);
Nglass=Glass*Nfrac(10);

N=[Norganic,Nplastic,Npapercard,Ntextilerub,Nmetal,Nglass];
Ntot=sum(N);

%S

Sorganic=Organic*((Sfrac(1)+Sfrac(12))/2);%1=Organic households
12=restaurants and trade
Splastic=Plastic*Sfrac(8);
Spapercard=Papercard*((Sfrac(6)+Sfrac(7))/2); %6=dry mixed paper
7=cardboard
Stextilerub=Textilerub*Sfrac(5);
Smetal=Metal*Sfrac(11);
Sglass=Glass*Sfrac(10);

S=[Sorganic,Splastic,Spapercard,Stextilerub,Smetal,Sglass];
Stot=sum(S);

sammansatt=[Ctot,Htot,Stot,Ntot,Otot,ftot];

a=1-sum(sammansatt);

sammansatt=[;Ctot,Htot,Stot,Ntot,Otot,ftot,a]*100;

c=sammansatt(1);
h=sammansatt(2);
s=sammansatt(3);
n=sammansatt(4);
o=sammansatt(5);
f=sammansatt(6);
a=sammansatt(7);



% [Hi,Htot,gas_temp,ig, P_ig, P_boiler,
n_boiler]=combustion(sammansatt(1),sammansatt(2),sammansatt(3),sammansatt(4
),sammansatt(5),sammansatt(6),sammansatt(7))
%
% [P_el,P_tot,max_n_el,
nb]=boiler(sammansatt(1),sammansatt(2),sammansatt(3),sammansatt(4),sammansa
tt(5),sammansatt(6),sammansatt(7))
%

biogas;
dryer;

%combustion_dryer;
combustion;
```

```
boiler;
%boiler_dryer;
%economics;
environment;

fkk(kk)=ftot
Hivec(kk)=Hi
P_elkk(kk)=P_el(m,nn)
%electricity_demand_dryerkk(kk)=electricity_demand_dryer
net_elkk(kk)=net_el(m,nn)
prod_el_WtEkk(kk)=prod_el_WtE
el_use_biokk(kk)=el_use_bio
net_prod_el_WtEkk(kk)=net_prod_el_WtE
Vbiokk(kk)=Vbio
prod_el_biogaskk(kk)=net_prod_el_bio

DHkk(kk)=DH(m,nn)
heat_demand_dryerkk(kk)=heat_demand_dryer
cool_demandkk(kk)=cool_demand
net_DHkk(kk)=net_DH(m,nn)
thermal_generationkk(kk)=thermal_generation
%heat_usage_dryerkk(kk)=heat_usage_dryer
cool_usagekk(kk)=cool_usage
net_thermal_generationkk(kk)=net_thermal_generation

%Economy
% invest_WtE_plant_MG_kk(kk)=invest_WtE_plant_Martin_GmbH
% invest_WtE_plant_asiankk(kk)=invest_WtE_plant_asian
% construction_WtE_plant_MGkk(kk)=construction_WtE_plant_Martin_GmbH
% construction_WtE_plant_asiankk(kk)=construction_WtE_plant_asian
% invest_coolingkk(kk)=invest_cooling
% invest_biogaskk(kk)=invest_biogas
%invest_bed_dryerkk(kk)=invest_bed_dryer
% tot_investkk_MGkk(kk)=tot_invest_Martin_GmbH
% tot_invest_asiankk(kk)=tot_invest_asian
% income_el_WtEkk(kk)=income_el_WtE
% income_el_biogaskk(kk)=income_el_biogas
%  income_coolkk(kk)=income_cool
%  income_bottom_slagkk(kk)=income_bottom_slag
%  tot_income_before_taxkk(kk)=tot_income_before_tax
%  maintenance_MGkk(kk)=maintenance_Martin_GmbH
%  maintenance_asiankk(kk)=maintenance_asian
%  anual_salarykk(kk)=anual_salary
%  tot_chem_costkk(kk)=tot_chem_cost
%  support_fuel_costkk(kk)=support_fuel_cost
%
%  tot_expensesMGkk(kk)=tot_expenses_Martin_GmbH
%  tot_expenses_asiankk(kk)=tot_expenses_asian
%  anual_cash_flowMGkk(kk)=anual_cash_flow_Martin_GmbH
%  anual_cash_flow_asiankk(kk)=anual_cash_flow_asian
%  pay_back_timeMGkk(kk)=pay_back_time_Martin_GmbH
%  pay_back_time_asiankk(kk)=pay_back_time_asian
%  NPVMGkk(kk)=NPV_MG
%  NPV_asiankk(kk)=NPV_asian
%  IRRMGkk(kk)=IRR_MG
%  IRR_asiankk(kk)=IRR_asian

 %CO2_emissions_netkk(kk)=CO2_emissions_net(kk)'
%CO2_emissions_netkk(kk) = CO2_emissions_net(kk)'
```

```
% NPVtabell_mgkk(:,:,kk)=PVaccmg-tot_invest_Martin_GmbH;
% visaNPVmg1=reshape(NPVtabell_mgkk(:,:,4),[1 20]);
% visaNPVmg2=reshape(NPVtabell_mgkk(:,:,3),[1 20]);
% visaNPVmg3=reshape(NPVtabell_mgkk(:,:,2),[1 20]);
% visaNPVmg4=reshape(NPVtabell_mgkk(:,:,1),[1 20]);
%
% NPVtabell_askk(:,:,kk)=PVacc_asian-tot_invest_asian;
% visaNPVasien1=reshape(NPVtabell_askk(:,:,4),[1 20]);
% visaNPVasien2=reshape(NPVtabell_askk(:,:,3),[1 20]);
% visaNPVasien3=reshape(NPVtabell_askk(:,:,2),[1 20]);
% visaNPVasien4=reshape(NPVtabell_askk(:,:,1),[1 20]);


tabell_CO2kk(:,:,kk) =tabell_CO2;
visa1=reshape(tabell_CO2kk(:,:,4),[25 6]);
visa2=reshape(tabell_CO2kk(:,:,3),[25 6]);
visa3=reshape(tabell_CO2kk(:,:,2),[25 6]);
visa4=reshape(tabell_CO2kk(:,:,1),[25 6]);
% DOCorgkk(kk)=DOCorg
steamfeedkk(kk)=steamfeed(m,nn)
P_boilerkk(kk)=P_boiler
n_boilerkk(kk)=n_boiler
n_elkk(kk)=n_el(m,nn)
n_heatkk(kk)=n_heat(m,nn)
n_totkk(kk)=n_tot(m,nn)

%
% net_CO2kk(kk) = net_CO2;
end

%result=
[fkk',Hivec',P_elkk',net_elkk',prod_elkk',DHkk',thermal_generationkk',inves
t_WtE_plant_MG_kk',construction_WtE_plantkk',invest_coolingkk',tot_investkk
_MGkk',income_el_WtEkk',income_coolkk',income_bottom_slagkk',tot_income_bef
ore_taxkk',maintenance_MGkk',anual_salarykk',tot_chem_costkk',support_fuel_
costkk',tot_expensesMGkk',anual_cash_flowMGkk',pay_back_timeMGkk',NPVkk',IR
RMGkk']';
%resultat_power =
[P_elkk',net_elkk',prod_el_WtEkk',net_prod_el_WtEkk',Vbiokk',prod_el_biogas
kk',DHkk',net_DHkk',thermal_generationkk',net_thermal_generationkk']
%resultat_economy_MG =
%[invest_WtE_plant_MG_kk',construction_WtE_plant_MGkk',invest_coolingkk',in
vest_biogaskk',tot_investkk_MGkk',tot_income_before_taxkk',
%CO2_emissions_netkk;



%!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!%%



%
% labels={'Ctot','Htot','Stot','Ntot','Otot','ftot','a'}
% explode = [1,1,1,1,1,1,1];
%
% pie(sammansatt,explode);
%
% legend(labels);
%
% PPP=cell(2,length(sammansatt));
%
```

```
% PPP(1,:)=labels;
%
% PPP{2,1}=sammansatt(1);
% PPP{2,2}=sammansatt(2);
% PPP{2,3}=sammansatt(3);
% PPP{2,4}=sammansatt(4);
% PPP{2,5}=sammansatt(5);
% PPP{2,6}=sammansatt(6);
% PPP{2,7}=sammansatt(7);
%
% PPP;
%
 toc
%
% Hi %Kj/kg
```

Boiler code

```
Kod Boiler

% [Hi, Htot, gas_temp, ig, P_ig, P_boiler, n_boiler]=
combustion(c,h,s,nn,o,f,a);

nis1=0.85;
nis2=0.85;
ngen=0.98;

%steamfeed = 47.6888; % matarvatten kg/s

%Hi = 28*10^6; % 28 MJ/kg bränsle

Hi;
Htot;
gas_temp;
ig;

cp_H2O = 4.181; % Specifik värmekapacitet vatten kJ/kg*K

%x10=[]
%n_el=[]

avtapp_p = [1:0.1:5];

avtapp = [0:0.01:0.5];

n_el=zeros(length(avtapp_p),length(avtapp));
x10=zeros(length(avtapp_p),length(avtapp));


for k = 1:length(avtapp_p);

for i = 1:length(avtapp);
```

```
% Parametrar punkt 1
% p1 = 0.13; % Tryck efter kondensor innnan matarvatten pump, från
tabellvärde
% T1= XSteam('Tsat_p',p1); % Temp efter kondensering mot
absorptionskyla,grader C
% s1 = XSteam('sL_T',T1); % Entropi efter kondensering mot absorptionsskyla
% h1 = XSteam('hL_p',p1); %Entalpi i punkt 1, efter kondensering mot
absorptionskyla
% x1 = XSteam('x_ph',p1,h1); %Ånghalt efter kondensering mot
fjärrvärmevattnet efter punkt 6

% Parametrar punkt 2
% s2=s1; %Entropi efter matarvattenpumpen
% p2=40; % Önskat tryck efter matarvattenpump, bar
% T2 = XSteam('T_ps',p2,s2); % Temperatur efter matarvattenpump, grader C
% h2 = XSteam('h_pt',p2,T2);

% Parametrar punkt 3, överhettad ånga 40 bar
T3= 400; % Temperatur efter panna, grader C
p3= 40; % Tryck i pannan, 40 bar
s3= XSteam('s_pT',p3,T3); % Ångans entropi innan Turbin 1
h3=(XSteam('h_pt',p3,T3)); %Entalpin hos överhettad ånga

% El-effektuttag från Turbin 1

% Parametrar punkt 4, efter turbin 1
s4= s3; % Isentropisk, ingen entropi förändring
p4= 6; % Ångtryck efter Turbin 1, Detta värde ska ändras OBS!?!?
T4= XSteam('T_ps',p4,s4); % Temperatur efter Turbin 1
h4 = XSteam('h_pt',p4,T4);
h4_prim = h3-(nis1*(h3-h4));

% Parametrar punkt 5, efter mellan överhettare innan turbin 2
T5=T3; %Temperatur efter överhettning, grader C
p5=p4; %Tryck innan turbin 2 är samma som efter turbin 1 innan
mellanöverhettare
s5=XSteam('s_pT',p5,T5); % Ångans entropi innna Turbin 2
h5=XSteam('h_pt',p5,T5);

% Entalpi som krävs för att värma upp från punkt 4 till 5
H_turbin2=(h5-h4_prim);

%Avtappningspunkt, avtappning från turbin 2
p5_prim=avtapp_p(k); %Avtappningstryck 2 bar i script, avtapp_p
s5_prim=s5; %Isentropisk
T5_prim=XSteam('T_ps',p5_prim,s5_prim);
h5_avtapp=XSteam('h_ps',p5_prim,s5_prim);

h5_prim=h5-(nis2*(h5-h5_avtapp));

% punkt 6, ånga efter turbin 2
s6=s5; %Isentropisk
p6=0.05;  % TABELL VÄRDE, 95% ÅNGHALT

x6=XSteam('x_ps',p6,s6);

h6=XSteam('h_ps',p6,s6);
```

```
h6_prim=h5-nis2*(h5-h6);

T6=XSteam('T_ph',p6,h6_prim);

x6prim=XSteam('x_ph',p6,h6_prim);

% Punkt 7, avtappningsångan kondenserar mot det kondenserade
% fjärrvärmevattnet, från p5_prim och p1, som blir punkt 7 och punkt 8

p7=p5_prim; %Samma tryck som avtappningstrycket
T7(k,i)=XSteam('Tsat_p',p7); %Temperatur för kondenserat vatten vid detta
tryck, saturerat vatten
h7=XSteam('hL_p',p7); % Entalpin för det kondenserade vattnet från
avtappningsångan

% Punkt 8, vatten efter kondensering mot fjärrvärme
p8=p6;
T8= XSteam('Tsat_p',p8);
h8 = XSteam('hL_p',p8);
s8 = XSteam('sL_T',T8);

% Entalpi som överförs till fjärrvärmevattnet i kondenseringsprocess
h_dh = h6_prim-h8;

% Punkt 9, vatten efter kondensering mot fjärrvärme, efter en pump som
% höjer trycket, efter punkt 8, Isentropisk pump
p9 = avtapp_p(k); %Pump höjer trycket till avtapp_p(k)
s9= s8; % Ska ändras till s8!!!! gamla s1
T9= XSteam('T_ps',p9,s9);
h9= XSteam('h_ps',p9,s9);

% Punkt 10, vatten som förvärms av avtappningsånga efter kondesering mot
% fjärrvärme och höjning av tryck
h10=((1-avtapp(i))*h9+(avtapp(i)*h5_prim))-(avtapp(i)*h7)/(1-avtapp(i));
p10=p9;
T10(k,i)=XSteam('T_ph',p10,h10);
x10(k,i)=XSteam('x_ph',p10,h10);

% Punkt 11, Vattentank där punkt 10 och punkt 7 samlas
h11=((avtapp(i)*h7)+((1-avtapp(i))*h10));
p11=p10;
T11(k,i)=XSteam('T_ph',p11,h11);
s11 = XSteam('sL_T',T11(k,i));
x11(k,i)=XSteam('x_ph',p11,h11);

% Punkt 12, Matarvatten med högre tryck, 40 bar efter vattentank 11, pump
% isentropiskt
p12=p3;
s12=s11;
T12=XSteam('T_ps',p12,s12);
h12=XSteam('h_ps',p12,s12);
x12(k,i)=XSteam('x_ph',p12,h12);

% Entalpi som krävs för att värma matarvattnet till 400 grader, punkt 12
% till punkt 3
H_turbin1(k,i)=(h3-h12);

steamfeed(k,i)=P_boiler/(H_turbin1(k,i)+H_turbin2)*1000;
```

```
% Effekt för att förånga Matarvatten från punkt 2 till punkt 3 som sedan
% uträttar arbete i Turbin 1
%P_steam_Turbine1 = ((h3- h2)*steamfeed)/1000; % kJ/kg ånga *kg/s /1000 =
MJ/s = MW

Power1 = ((h3-h4_prim)*steamfeed(k,i))/1000; % Effektuttag från Turbin 1

% Massflöde på fjärrvärmevattnet, räknat med att tillfört vatten är 25
% grader och att vi vill få upp det till 115 grader för absorptionskylan
dh_waterfeed (k,i) = (steamfeed(k,i)*(1-avtapp(i))*h_dh)/((115-25)*cp_H2O);


% Effekt för att värma upp ångan efter Turbin 1 innan Turbin 2, punkt 4
% till punkt 5
P_steam_Turbine2 = ((h5- h4_prim)*steamfeed(k,i))/1000;

% El-effekt genererad från turbin 2 till avtappningspunkt, 2 bar
Power2_to_prim=((h5-h5_prim)*steamfeed(k,i))/1000;

% El-effekt genererad från turbin 2 efter avtappningspunkt
Power2_after_prim=((h5_prim-h6_prim)*steamfeed(k,i)*(1-avtapp(i)))/1000;

% Total el-effekt från turbin 2
Power2_tot(k,i) = (Power2_to_prim + Power2_after_prim);

% Effekt till fjärrvärme, h6-h8
DH(k,i)=(h_dh*steamfeed(k,i)*(1-avtapp(i)))/1000; % Effekt till fjärrvärme

% Total el-effekt
P_el(k,i) = (Power1+Power2_tot(k,i))*ngen; %0.98=ngen

% Totalt uttagen effekt
P_tot(k,i) = P_el(k,i)+DH(k,i);


if x10(k,i)==0

    n_el(k,i) = P_el(k,i)/P_ig;
    n_heat(k,i) = DH(k,i)/P_ig;
    n_tot(k,i)= P_tot(k,i)/P_ig;

% El verkningsgrad
else n_el(k,i)=0;

    n_heat(k,i)=0;
    n_tot(k,i)=0;

end

% % Värme verkningsgrad
% n_heat(k,i) = DH(k,i)/P_boiler;
%
% % Total verkningsgrad
% n_tot(k,i)= P_tot(k,i)/P_boiler;


end
```

```
end

[max_n_el,ind]=max(n_el(:));
max_n_el;
[m,nn]=ind2sub(size(n_el),ind);

cool_demand = 3.53; %MW  % I scenario 1 cooldemand = DH, annars 3.53 MW i
net_DH blir det 0
net_DH(m,nn) = DH(m,nn);%-cool_demand;%-heat_demand_dryer % net spill
värme, efter kylning av lokaler och torkning
thermal_generation = DH(m,nn)*8000;
cool_usage = cool_demand*8000;
net_thermal_generation=net_DH(m,nn)*8000;
net_el(m,nn) = (P_el(m,nn)*0.93);% el_biogas =
85000*(yearly_feed*Organic/1000); kWh % El genererad ut på elnätet. 7%
används internt
prod_el_WtE = net_el(m,nn)*8000; % El producerad från WtE efter att man tar
bort intern elanvändning

% Elanvändning biogasanläggning
el_use_bio = (85000*(mass*0.604/1000))/1000; %(85000 kWh per kton
biomassa)/1000 = MWh

net_prod_el_WtE=prod_el_WtE;%-el_use_bio; %MWh %OBS kom ihåg att ta bort
biogas-elanvändning.
net_prod_el_bio=Egas*0.42; %MWh
tot_net_prod_el=net_prod_el_WtE+net_prod_el_bio;



avtapp_p_opt=avtapp_p(m);
avtapp_opt=avtapp(nn);
n_boiler;



% nytt
% [max_n_tot,ind]=max(n_tot(:));
% max_n_tot;
% [m,nn]=ind2sub(size(n_tot),ind);
%
% avtapp_p_opt=avtapp_p(m);
% avtapp_opt=avtapp(nn);
```

Boiler dryer code

```
KOD BOILER_DRYER

% [Hi, Htot, gas_temp, ig, P_ig, P_boiler, n_boiler]=
combustion(c,h,s,nn,o,f,a);

nis1=0.85;
nis2=0.85;
ngen=0.98;

%steamfeed = 47.6888; % matarvatten kg/s
```

```
%Hi = 28*10^6; % 28 MJ/kg bränsle

Hi;
Htot;
gas_temp;
ig;

cp_H2O = 4.181; % Specifik värmekapacitet vatten kJ/kg*K

%x10=[]
%n_el=[]

avtapp_p = [1:0.1:5];

avtapp = [0:0.01:0.5];

n_el=zeros(length(avtapp_p),length(avtapp));
x10=zeros(length(avtapp_p),length(avtapp));


for k = 1:length(avtapp_p);

for i = 1:length(avtapp);

  cool_demand = 3.53; %MW

% Parametrar punkt 1
% p1 = 0.13; % Tryck efter kondensor innnan matarvatten pump, från
tabellvärde
% T1= XSteam('Tsat_p',p1); % Temp efter kondensering mot
absorptionskyla,grader C
% s1 = XSteam('sL_T',T1); % Entropi efter kondensering mot absorptionsskyla
% h1 = XSteam('hL_p',p1); %Entalpi i punkt 1, efter kondensering mot
absorptionskyla
% x1 = XSteam('x_ph',p1,h1); %Ånghalt efter kondensering mot
fjärrvärmevattnet efter punkt 6

% Parametrar punkt 2
% s2=s1; %Entropi efter matarvattenpumpen
% p2=40; % Önskat tryck efter matarvattenpump, bar
% T2 = XSteam('T_ps',p2,s2); % Temperatur efter matarvattenpump, grader C
% h2 = XSteam('h_pt',p2,T2);

% Parametrar punkt 3, överhettad ånga 40 bar
T3= 400; % Temperatur efter panna, grader C
p3= 40; % Tryck i pannan, 40 bar
s3= XSteam('s_pT',p3,T3); % Ångans entropi innan Turbin 1
h3=(XSteam('h_pt',p3,T3)); %Entalpin hos överhettad ånga

% El-effektuttag från Turbin 1

% Parametrar punkt 4, efter turbin 1
s4= s3; % Isentropisk, ingen entropi förändring
p4= 6; % Ångtryck efter Turbin 1, Detta värde ska ändras OBS!?!?
T4= XSteam('T_ps',p4,s4); % Temperatur efter Turbin 1
h4 = XSteam('h_pt',p4,T4);
h4_prim = h3-(nis1*(h3-h4));
```

```
% Parametrar punkt 5, efter mellan överhettare innan turbin 2
T5=T3; %Temperatur efter överhettning, grader C
p5=p4; %Tryck innan turbin 2 är samma som efter turbin 1 innan
mellanöverhettare
s5=XSteam('s_pT',p5,T5); % Ångans entropi innna Turbin 2
h5=XSteam('h_pt',p5,T5);

% Entalpi som krävs för att värma upp från punkt 4 till 5
H_turbin2=(h5-h4_prim);

%Avtappningspunkt, avtappning från turbin 2
p5_prim=avtapp_p(k); %Avtappningstryck 2 bar i script, avtapp_p
s5_prim=s5; %Isentropisk
T5_prim=XSteam('T_ps',p5_prim,s5_prim);
h5_avtapp=XSteam('h_ps',p5_prim,s5_prim);

h5_prim=h5-(nis2*(h5-h5_avtapp));

% punkt 6, ånga efter turbin 2
s6=s5; %Isentropisk
p6=0.05;  % TABELL VÄRDE, 95% ÅNGHALT

x6=XSteam('x_ps',p6,s6);

h6=XSteam('h_ps',p6,s6);

h6_prim=h5-nis2*(h5-h6);

T6=XSteam('T_ph',p6,h6_prim);

x6prim=XSteam('x_ph',p6,h6_prim);

% Punkt 7, avtappningsångan kondenserar mot det kondenserade
% fjärrvärmevattnet, från p5_prim och p1, som blir punkt 7 och punkt 8

p7=p5_prim; %Samma tryck som avtappningstrycket
T7(k,i)=XSteam('Tsat_p',p7); %Temperatur för kondenserat vatten vid detta
tryck, saturerat vatten
h7=XSteam('hL_p',p7); % Entalpin för det kondenserade vattnet från
avtappningsångan

% Punkt 8, vatten efter kondensering mot fjärrvärme
p8=p6;
T8= XSteam('Tsat_p',p8);
h8 = XSteam('hL_p',p8);
s8 = XSteam('sL_T',T8);

% Entalpi som överförs till fjärrvärmevattnet i kondenseringsprocess
h_dh = h6_prim-h8;

% Punkt 9, vatten efter kondensering mot fjärrvärme, efter en pump som
% höjer trycket, efter punkt 8, Isentropisk pump
p9 = avtapp_p(k); %Pump höjer trycket till avtapp_p(k)
s9= s8; % Ska ändras till s8!!!! gamla s1
T9= XSteam('T_ps',p9,s9);
h9= XSteam('h_ps',p9,s9);

% Punkt 10, vatten som förvärms av avtappningsånga efter kondesering mot
```

```
% fjärrvärme och höjning av tryck
h10=((1-avtapp(i))*h9+(avtapp(i)*h5_prim))-(avtapp(i)*h7)/(1-avtapp(i));
p10=p9;
T10(k,i)=XSteam('T_ph',p10,h10);
x10(k,i)=XSteam('x_ph',p10,h10);

% Punkt 11, Vattentank där punkt 10 och punkt 7 samlas
h11=((avtapp(i)*h7)+((1-avtapp(i))*h10));
p11=p10;
T11(k,i)=XSteam('T_ph',p11,h11);
s11 = XSteam('sL_T',T11(k,i));
x11(k,i)=XSteam('x_ph',p11,h11);

% Punkt 12, Matarvatten med högre tryck, 40 bar efter vattentank 11, pump
% isentropiskt
p12=p3;
s12=s11;
T12=XSteam('T_ps',p12,s12);
h12=XSteam('h_ps',p12,s12);
x12(k,i)=XSteam('x_ph',p12,h12);

% Entalpi som krävs för att värma matarvattnet till 400 grader, punkt 12
% till punkt 3
H_turbin1(k,i)=(h3-h12);

steamfeed(k,i)=P_boiler/(H_turbin1(k,i)+H_turbin2)*1000;

% Effekt för att förånga Matarvatten från punkt 2 till punkt 3 som sedan
% uträttar arbete i Turbin 1
%P_steam_Turbine1 = ((h3- h2)*steamfeed)/1000; % kJ/kg ånga *kg/s /1000 =
MJ/s = MW

Power1 = ((h3-h4_prim)*steamfeed(k,i))/1000; % Effektuttag från Turbin 1

% Massflöde på fjärrvärmevattnet, räknat med att tillfört vatten är 25
% grader och att vi vill få upp det till 115 grader för absorptionskylan
dh_waterfeed (k,i) = (steamfeed(k,i)*(1-avtapp(i))*h_dh)/((115-25)*cp_H2O);


% Effekt för att värma upp ångan efter Turbin 1 innan Turbin 2, punkt 4
% till punkt 5
P_steam_Turbine2 = ((h5- h4_prim)*steamfeed(k,i))/1000;

% El-effekt genererad från turbin 2 till avtappningspunkt, 2 bar
Power2_to_prim=((h5-h5_prim)*steamfeed(k,i))/1000;

% El-effekt genererad från turbin 2 efter avtappningspunkt
Power2_after_prim=((h5_prim-h6_prim)*steamfeed(k,i)*(1-avtapp(i)))/1000;

% Total el-effekt från turbin 2
Power2_tot(k,i) = (Power2_to_prim + Power2_after_prim);

% Effekt till fjärrvärme, h6-h8
DH(k,i)=(h_dh*steamfeed(k,i)*(1-avtapp(i)))/1000; % Effekt till fjärrvärme

% Total el-effekt
P_el(k,i) = (Power1+Power2_tot(k,i))*ngen; %0.98=ngen
```

```
% Totalt uttagen effekt
P_tot(k,i) = P_el(k,i)+DH(k,i);


if x10(k,i)==0

    n_el(k,i) = P_el(k,i)/P_boiler;
    n_heat(k,i) = DH(k,i)/P_boiler;
    n_tot(k,i)= P_tot(k,i)/P_boiler;

% El verkningsgrad
else n_el(k,i)=0;

    n_heat(k,i)=0;
    n_tot(k,i)=0;

end

% % Värme verkningsgrad
% n_heat(k,i) = DH(k,i)/P_boiler;
%
% % Total verkningsgrad
% n_tot(k,i)= P_tot(k,i)/P_boiler;


end

end

[max_n_el,ind]=max(n_el(:));
max_n_el;
[m,nn]=ind2sub(size(n_el),ind);
P_el(m,nn);
%obs! ändra för scenario 2 och 3
net_DH(m,nn) = DH(m,nn)-heat_demand_dryer;%-cool_demand; % net spill värme,
efter kylning av lokaler och torkning
net_el(m,nn) = (P_el(m,nn)*0.93)-electricity_demand_dryer;%;; % El
genererad ut på elnätet. 7% används internt
prod_el_WtE =net_el(m,nn)*8000
% Elanvändning biogasanläggning
el_use_bio = (85000*(biomassa/1000))/1000; %(85000 kWh per kton
biomassa)/1000 = MWh

net_prod_el_WtE=prod_el_WtE;%-el_use_bio; %MWh %OBS kom ihåg att ta bort
biogas-elanvändning.
net_prod_el_bio=Egas*0.42; %MWh
tot_net_prod_el=net_prod_el_WtE;

thermal_generation = DH(m,nn)*8000;
heat_usage_dryer =heat_demand_dryer*8000;
cool_usage=cool_demand*8000;
net_thermal_generation=thermal_generation-heat_usage_dryer;%-cool_usage;
avtapp_p_opt=avtapp_p(m);
avtapp_opt=avtapp(nn);
n_boiler;
```

Combustion code

```
% function [Hi,Htot,gas_temp,ig, P_ig, P_boiler, n_boiler]
=combustion(c,h,s,n,o,f,a)
%

%yearly_feed = mass; % waste feed ton/year
% yearly_feed = new_mass;
% feed kg per second = 215696*1000/(8000*3600)
%feed=(yearly_feed*1000)/(8000*3600); %kg/s %bränsle tillförsel

n_air=1.55; %luftfaktor sopor, sid 492
%feed=7.5; %kg/s %bränsle tillförsel
cpO=0.92; %kJ/kg*K %värmekapacitet för syre, enligt Moldavien, sid 68
cpN=1.04; %kJ/kg*K %värmekapacitet för kväve, sid 68, kJ/kg*K
O_andel=0.23; %viktprocentandel syre i luft, sid 495
N_andel=0.77; %viktprocentandel kväve i luft, sid 495
deltaT=900; %förändring av temperatur, DENNA ÄR OKLAR! Moldavien rapport
sid 69

Hi=(0.339*c+0.105*s+1.21*(h-(o/8))-0.0251*f)*1000; %kJ/kg bränsle %från
exempel sid 501


temp_air=82.8639; % temperatur på tillförd luft, just nu påhittat! KOLLA
RAD 87 I KOD FÖR ATT RÄKNA UT NY??
cpAir=1.00; % specifik värmekapacitet luft

a_t=((32+3.76*28)/100)*((c/12)+(h/4)+(s/32)-(o/32)); %teoretisk luftmängd,
från exempel sid 495

a_r = n_air*a_t; %kg/kg bränsle % verklig luftmängd = teoretisk luftmängd *
luftfaktor för sopor=1.55
a_sur= a_r - a_t; %kg/kg bränsle  %surplus of air

O_sur=a_sur*O_andel;
N_sur=a_sur*N_andel;

Htot=Hi-((O_sur*cpO*deltaT)+(N_sur*cpN*deltaT));%+andel n som måste värmas
upp+Residues inert, Reaching comb temp,); %kJ/kg bränsle %OBS!!!! Har inte
med %% LÄGG TILL FÖRBRÄNNINGS FÖRLUSTER 3-5% SID 820


g_t = a_t+(1-(a/100));  %kg/kg bränsle  % teoretisk rökgasmängd sid 495
g_r = g_t+(n_air-1)*a_t;    %kg/kg bränsle   %verklig rökgasmängd sid 495
fluegas = g_r * feed; %kg/kg bränsle * kg bränsle/s = kg/s avgaser
%fluegas = g_r * new_feed; %med tork


%Rökgasens teoretiska sammansättning, från exempel 6.1.1-1 sid 495

CO2=((1/12)*(c/100))*44; % kg/kg bränsle  %Vikt CO2 i avgaserna
CO2fos=((1/12)*(cfos))*44; % kg/kg bränsle  %Vikt av fossilt CO2 i
avgaserna
H2O=((0.5*(h/100)+(1/18))*(f/100))*18; % kg/kg bränsle   %Vikt H2O i
avgaserna
```

```
SO2=((1/32)*(s/100)*64); % kg/kg bränsle   %Vikt SO2 i avgaserna
N2=(((3.76/12)*(c/100)+(3.76/4)*(h/100)-
((3.76/32)*(o/100))+(1/28)*(n/100)+(3.76/32)*(s/100))*28)+N_sur; %kg/kg
bränsle %Vikt N2 i avgaserna + överskottskväve
O2=O_sur; % kg/kg bränsle överskottssyre från överskottsluften
CO2_emissions_WtE = CO2*yearly_feed*1000; % Vikt CO2 i kg/kg bränlse * kg
bränsle på ett år

roksammansatt=[CO2,H2O,SO2,N2,O2];

Gas_tot_weight=CO2+H2O+SO2+N2+O2;   % total fluegas vikt i kg/kg bränsle

% viktandel av fluegas

share_CO2=CO2/Gas_tot_weight;
share_H2O=H2O/Gas_tot_weight;
share_SO2=SO2/Gas_tot_weight;
share_N2=N2/Gas_tot_weight;
share_O2=O2/Gas_tot_weight;

% Värden från tabellsamling värmdö gymnasium, kan eventuellt byta om jag
% hittar en bättre, samtliga i kJ/kg * K
cpCO2= 0.82;
cpH2O=1.93;
cpSO2=0.61;
cpN2=1.04;
cpO2=0.92;

% specifik värmekapacitet på fluegas
cpGas=share_CO2*cpCO2+share_H2O*cpH2O+share_SO2*cpSO2+share_N2*cpN2+share_O
2*cpO2;

% teoretisk förbränningstemperatur, sid 507
gas_temp = ((Htot+a_r*cpAir*temp_air)/(g_r*cpGas));     % enhet på a_r och
gv???

%entalpi från fluegas
ig=(cpGas*gas_temp);
P_ig=((cpGas*gas_temp)*fluegas)/1000;     % kJ/kg avgaser * kg avgaser/s
/1000 = MJ/s = MW)

%Total Entalpi från fluegas till boiler innan avgasrening
% Avgaserna antas renas vid 155 grader

h155=((140.273*share_CO2)+(144.266*share_O2)+(291.778*share_H2O)+(101.699*s
hare_SO2)+(161.518*share_N2));%kJ/kg avgas entalpi för avgaser vid 155
grader
h_boiler=ig-h155;
P_boiler=(h_boiler*fluegas)/1000; %  MW till boiler


% Entalpiförlust vid avgasrening
% Vid rening förloras energin mellan h155 och h130 eftersom avgastemp efter
% rening är 130 grader

h130=((113.455*share_CO2)+(119.844*share_O2)+(242.667*share_H2O)+(82.773*sh
are_SO2)+(134.643*share_N2));

h_cleaning_fluegas=h155-h130;
```

```
P_cleaning_fluegas=(h_cleaning_fluegas*fluegas)/1000;  % Effekt som
förloras vid rening av avgas

% Förvärmning av tillluft i förbränning och entalpi förlust i detta steg
t_out=27; % Medel lufttemperatur utomhus på Borneo
t_gas_after_cleaning=130; % Gas temperatur efter avgasrening

new_temp_air=((a_r*cpAir*t_out+g_r*cpGas*t_gas_after_cleaning)/(a_r*cpAir+g
_r*cpGas)); % Temp_air = 80.3056 grader
h_temp_air=((69.818*share_CO2)+(73.7495*share_O2)+(149.335*share_H2O)+(50.9
375*share_SO2)+(82.857*share_N2));
P_heat_exchange=((h130*fluegas)-(h_temp_air*fluegas))/1000;

% Effektförust i avgaser som släpps ut

P_exhaust = ((h_temp_air*fluegas))/1000;
n_boiler=(P_heat_exchange+P_boiler)/P_ig;

%få ut entalpi för respektive temperatur på fluegasen genom tabell sid 509*
%1/M (M=molmassa för respektive molekyl)



% pie(roksammansatt);
% legend('CO2','H2O','SO2','N2','O2');
```

Combustion dryer code

```
% function [Hi,Htot,gas_temp,ig, P_ig, P_boiler, n_boiler]
=combustion(c,h,s,n,o,f,a)
%
%yearly_feed = mass;
% yearly_feed = new_mass; % waste feed ton/year
% % feed kg per second = 215696*1000/(8000*3600)
% feed=(yearly_feed*1000)/(8000*3600); %kg/s %bränsle tillförsel

n_air=1.55; %luftfaktor sopor, sid 492
%feed=7.5; %kg/s %bränsle tillförsel
cpO=0.92; %kJ/kg*K %värmekapacitet för syre, enligt Moldavien, sid 68
cpN=1.04; %kJ/kg*K %värmekapacitet för kväve, sid 68, kJ/kg*K
O_andel=0.23; %viktprocentandel syre i luft, sid 495
N_andel=0.77; %viktprocentandel kväve i luft, sid 495
deltaT=900; %förändring av temperatur, DENNA ÄR OKLAR! Moldavien rapport
sid 69

Hi=(0.339*new_c+0.105*new_s+1.21*(new_h-(new_o/8))-0.0251*new_f)*1000;
%kJ/kg bränsle %från exempel sid 501


temp_air=82.8639; % temperatur på tillförd luft, just nu påhittat! KOLLA
RAD 87 I KOD FÖR ATT RÄKNA UT NY??
cpAir=1.00; % specifik värmekapacitet luft

a_t=((32+3.76*28)/100)*((new_c/12)+(new_h/4)+(new_s/32)-(new_o/32));
%teoretisk luftmängd, från exempel sid 495

a_r = n_air*a_t; %kg/kg bränsle % verklig luftmängd = teoretisk luftmängd *
luftfaktor för sopor=1.55
a_sur= a_r - a_t; %kg/kg bränsle  %surplus of air

O_sur=a_sur*O_andel;
N_sur=a_sur*N_andel;

Htot=Hi-((O_sur*cpO*deltaT)+(N_sur*cpN*deltaT));%+andel n som måste värmas
upp+Residues inert, Reaching comb temp,); %kJ/kg bränsle %OBS!!!! Har inte
med %% LÄGG TILL FÖRBRÄNNINGS FÖRLUSTER 3-5% SID 820



g_t = a_t+(1-(new_a/100));  %kg/kg bränsle  % teoretisk rökgasmängd sid 495
g_r = g_t+(n_air-1)*a_t;    %kg/kg bränsle   %verklig rökgasmängd sid 495
%fluegas = g_r * feed; %kg/kg bränsle * kg bränsle/s = kg/s avgaser
fluegas = g_r * new_feed; %med tork



%Rökgasens teoretiska sammansättning, från exempel 6.1.1-1 sid 495

CO2=((1/12)*(new_c/100))*44; % kg/kg bränsle  %Vikt CO2 i avgaserna
CO2fos=((1/12)*(cfos))*44; % kg/kg bränsle  %Vikt av fossilt CO2 i
avgaserna
H2O=((0.5*(new_h/100)+(1/18))*(new_f/100))*18; % kg/kg bränsle   %Vikt H2O
i avgaserna
SO2=((1/32)*(new_s/100)*64); % kg/kg bränsle   %Vikt SO2 i avgaserna
```

```
N2=(((3.76/12)*(new_c/100)+(3.76/4)*(new_h/100)-
((3.76/32)*(new_o/100))+(1/28)*(new_n/100)+(3.76/32)*(new_s/100))*28)+N_sur
; %kg/kg bränsle %Vikt N2 i avgaserna + överskottskväve
O2=O_sur; % kg/kg bränsle överskottssyre från överskottsluften

roksammansatt=[CO2,H2O,SO2,N2,O2];

Gas_tot_weight=CO2+H2O+SO2+N2+O2;   % total fluegas vikt i kg/kg bränsle

% viktandel av fluegas

share_CO2=CO2/Gas_tot_weight;
share_H2O=H2O/Gas_tot_weight;
share_SO2=SO2/Gas_tot_weight;
share_N2=N2/Gas_tot_weight;
share_O2=O2/Gas_tot_weight;

% Värden från tabellsamling värmdö gymnasium, kan eventuellt byta om jag
% hittar en bättre, samtliga i kJ/kg * K
cpCO2= 0.82;
cpH2O=1.93;
cpSO2=0.61;
cpN2=1.04;
cpO2=0.92;

% specifik värmekapacitet på fluegas
cpGas=share_CO2*cpCO2+share_H2O*cpH2O+share_SO2*cpSO2+share_N2*cpN2+share_O
2*cpO2;

% teoretisk förbränningstemperatur, sid 507
gas_temp = ((Htot+a_r*cpAir*temp_air)/(g_r*cpGas));     % enhet på a_r och
gv???

%entalpi från fluegas
ig=(cpGas*gas_temp);
P_ig=((cpGas*gas_temp)*fluegas)/1000;     % kJ/kg avgaser * kg avgaser/s
/1000 = MJ/s = MW)

%Total Entalpi från fluegas till boiler innan avgasrening
% Avgaserna antas renas vid 155 grader

h155=((140.273*share_CO2)+(144.266*share_O2)+(291.778*share_H2O)+(101.699*s
hare_SO2)+(161.518*share_N2));%kJ/kg avgas entalpi för avgaser vid 155
grader
h_boiler=ig-h155;
P_boiler=(h_boiler*fluegas)/1000; %  MW till boiler



% Entalpiförlust vid avgasrening
% Vid rening förloras energin mellan h155 och h130 eftersom avgastemp efter
% rening är 130 grader

h130=((113.455*share_CO2)+(119.844*share_O2)+(242.667*share_H2O)+(82.773*sh
are_SO2)+(134.643*share_N2));

h_cleaning_fluegas=h155-h130;
P_cleaning_fluegas=(h_cleaning_fluegas*fluegas)/1000;  % Effekt som
förloras vid rening av avgas
```

```
% Förvärmning av tillluft i förbränning och entalpi förlust i detta steg
t_out=27; % Medel lufttemperatur utomhus på Borneo
t_gas_after_cleaning=130; % Gas temperatur efter avgasrening

new_temp_air=((a_r*cpAir*t_out+g_r*cpGas*t_gas_after_cleaning)/(a_r*cpAir+g
_r*cpGas)); % Temp_air = 80.3056 grader
h_temp_air=((69.818*share_CO2)+(73.7495*share_O2)+(149.335*share_H2O)+(50.9
375*share_SO2)+(82.857*share_N2));
P_heat_exchange=((h130*fluegas)-(h_temp_air*fluegas))/1000;

% Effektförust i avgaser som släpps ut

P_exhaust = ((h_temp_air*fluegas))/1000;
n_boiler=(P_heat_exchange+P_boiler)/P_ig;

%få ut entalpi för respektive temperatur på fluegasen genom tabell sid 509*
%1/M (M=molmassa för respektive molekyl)



% pie(roksammansatt);
% legend('CO2','H2O','SO2','N2','O2');
```

Dryer code

```
% Bed dryer

input_moist = f/100;
output_moist = 0.4;

evaporated_moist = (input_moist*feed-output_moist*feed)/(1-output_moist);
%Evaporated moist kg moist/ s

moist_heat_energy = 3.9; % 3.9 MJ / kg evaporated moist
moist_electricity_energy = 0.15; % 0.15 MJ / kg evaporated moist

heat_demand_dryer = evaporated_moist*moist_heat_energy; % MW = MJ/kg * kg/s
= MJ/s
electricity_demand_dryer = moist_electricity_energy*evaporated_moist; % MW

% Updated elemental composition
new_feed = feed-evaporated_moist;
new_f = output_moist*100;
new_c = ((c)*feed)/new_feed;
new_h = ((h)*feed)/new_feed;
new_s = ((s)*feed)/new_feed;
new_n = ((n)*feed)/new_feed;
new_o = ((o)*feed)/new_feed;
new_a = ((a)*feed)/new_feed;

new = [new_f new_c new_h new_s new_n new_o new_a];
old = [f c h s n o a];

comp = [new; old];

dry_air_flow = 65*evaporated_moist*3.6*1000; % m^3 air per hour

%Price
invest_bed_dryer = (0.2*(dry_air_flow/1000)^0.8)*1000000; % Swedish Kr
maintenance_bed_dryer = 0.02*invest_bed_dryer; % Swedish Kr

%Size
surface_bed_dryer = 2*(dry_air_flow/3600); %m^2
```

Economics code

```
% Ekonomiska modeller


%COST ESTIMATES

% China = 70000*8.38*ton per dag
% Europa = 470*9.5*yearly_feed

%WtE Martin GmbH
invest_WtE_plant_Martin_GmbH = 470*9.5*yearly_feed*1.2; % tekniska
komponenter WtE plant
construction_WtE_plant_Martin_GmbH = 0.2*invest_WtE_plant_Martin_GmbH;

%WtE Chinese
invest_WtE_plant_asian = 70000*8.38*(yearly_feed/365)*1.2;
construction_WtE_plant_asian = 0.2*invest_WtE_plant_asian;

%Absorption-cooling
cool_demand_for_invest = 3.53; %MW
invest_sub_station_absoprtion_cooling = 550*cool_demand_for_invest*1000; %
550 SEK/kW * 3.5 MW kylbehov * 1000 =kW
invest_absorption_cooling_machine = 4000*cool_demand_for_invest*1000;% 4000
SEK/kW * 3.5 MW kylbehov * 1000 =kW
invest_cooling =
invest_absorption_cooling_machine+invest_sub_station_absoprtion_cooling;

%Pris bed_dryer
%invest_bed_dryer; % SEK från dryer;

% Invest Biogas
invest_biogas = 161*8.38*(mass*0.604); % 161 dollar * exchange rate
(8.38)SEK /year organic wet weight

%total investering
tot_invest_Martin_GmbH =
invest_WtE_plant_Martin_GmbH+construction_WtE_plant_Martin_GmbH+invest_cool
ing+invest_biogas;%+invest_bed_dryer;%+invest_biogas;%+invest_bed_dryer;%
+invest_biogas ;
tot_invest_asian = invest_WtE_plant_asian + construction_WtE_plant_asian +
invest_cooling+invest_biogas;%+invest_bed_dryer;%+invest_biogas;

% ANNUAL INCOME

% Income waste tipping fee
yearly_feed; % Årlig sophantering i ton, GEMENSAM INPUT!!!
gate_fee = 0; % Gate fee inkomst per ton avfall, kr/ton
income_gate_fee = yearly_feed*gate_fee; % Årlig inkomst gate fee,
ton*kr/ton = kr

operational_time = 8000; % Årliga drifttimmar

% Income electricity from incineration
sold_el_WtE = net_prod_el_WtE*1000; % Årlig producerad el, MWh*1000 = kWh
price_el = 0.81; % Pris kr/kWh el;
```

```
income_el_WtE = sold_el_WtE*price_el; % Årlig inkomst av elförsäljning,
kWh*kr/kWh = kr

% Income electricity from biogas
prod_el_biogas = Egas*0.42;% = MWh * dieselverkningsgrad * 1000
income_el_biogas = price_el*prod_el_biogas*1000; % kr = kr/kWh*MWh*1000

% Income cooling %%%%%!!!!!!!!!!!!!!!!!!!%%%%%%%%%%%%%%%%%%
net_DH(m,nn);
cool_demand_usage=net_DH(m,nn)*0.7; % cool_demand i scenario 2 och 3!
income_cool = ((cool_demand_usage*8760*1000)/3)*price_el; % Årlig inkomst
från absorbtion cooling, kWh*kr/kWh = kr

% Income by-products
anual_bottom_slag = yearly_feed*0.15; % Årlig vikt av botten aska, m^3,
kanske kan hämta en färdig parameter från combustion
price_bottom_slag = 41.874 ; % Pris försljning av bottenaska, kr/m^3, källa
Syarief
income_bottom_slag = anual_bottom_slag*price_bottom_slag; % Årlig inkomst
försäljning av bottenaska, m^3*kr/m^3 = kr

%Income emission rights
%anual_emission_right = 2; % Årlig tilldelning av elcertifikat, st
%price_emission_right = 4; % Pris per elcert kr/st
%income_emission_right = anual_emission_right*price_emission_right; % Årlig
inkomst från elcert st*kr/st = kr

%ÅRLIG INTÄKT
tot_income_before_tax = income_gate_fee + income_el_WtE +
income_bottom_slag + income_cool+ income_el_biogas; % Total årliginkomst
innan skatt

%income_tax_rate = 0.20;
%tot_income_after_tax = tot_income_before_tax*(1-income_tax_rate) % Total
årlig inkomst efter skatt

% % Anual expenses
% own_cap = 3; % Eget kapital vid grundinvestering
%
% loan = tot_invest-own_cap; % Lån som tas för grundinvestering
%
% rate_loan = 0.04; % Lånadsränta

salary_WtE_1 = 1460245;
salary_WtE_2 = 3438404;
salary_WtE_3 = 3780000;
salary_biogas = 214969;

anual_salary = salary_WtE_1; % + salary_biogas ;Totala årliga lönekostnader

maintenance_Martin_GmbH =
(invest_WtE_plant_Martin_GmbH+invest_cooling+invest_biogas)*0.02;%+invest_b
ed_dryer +invest_biogas + och biogas % Årliga underhållskostnader, Källa
Erich Bauer%maintenance_bed_dryer = maintenance_bed_dryer; % Årliga
avgifter bed dryer i M SEK
maintenance_asian =
(invest_WtE_plant_asian+invest_cooling+invest_biogas)*0.02;%+invest_biogas
+invest_bed_dryer
```

```
anual_lime = 20*yearly_feed; % Årlig användning av lime, i kg
anual_carbon = 1.2*yearly_feed; % Årlig använding av aktivtkol, i kg
anual_ammonium = 4*yearly_feed; % Årlig användning av ammonium, i kg
price_lime = 0.92; % Pris för 1 kg lime
price_carbon = 6.7; % Pris för 1 kg aktivtkol
price_ammonium = 1.8; % Pris för 1 liter ammonium

anual_price_lime = anual_lime*price_lime; % Årligt pris för lime
anual_price_carbon = anual_carbon*price_carbon; % Årligt prs för aktivtkol
anual_price_ammonium = anual_ammonium*price_ammonium; % Årligt pris för
ammonium
tot_chem_cost = anual_price_lime+anual_price_carbon+anual_price_ammonium; %
Total årlig kostand för kemikalier

ammount_support_fuel = 1250*P_boiler; % 1250 m^3 naturgas per MW kapacitet
* Boiler MW kapacitet
price_support_fuel = 0.35*9.64; % Pris på support fuel Euro/m^3 * SEK/Euro
support_fuel_cost = ammount_support_fuel*price_support_fuel;

anual_flyash = yearly_feed*0.05; % Årlig vikt av flygaska, kanske kan hämta
en färdig parameter från combustion
cost_landfill_flyash = 0; % Kostand för att deponera flyash per kg;
tot_flyash_cost = anual_flyash*cost_landfill_flyash; % Total årlig kostnad
för att deponera flygaska

amount_CO2 = CO2*yearly_feed; % Årlig mängd CO2 utsläpp i ton, SKA FINNAS
SOM ANNAN PARAMETER i tex GHG_landfill och combustion
CO2_tax = 0; % avgigt per ton CO2 utsläpp, kr/ton
tot_CO2_cost = amount_CO2*CO2_tax; % Årlig kostnad för CO2 utsläpp

% Transport costs
transport_cost_scen1 = 0;
transport_cost_scen2 = 58203*365; % Transport kostnad Samarinda etc per
dag; scen 2
transport_cost_scen3 = 101553*365; % Scen 3


% Waste handling costs
waste_handling_scen1 = 1415.98*365; % Hanteringskostnad av sopor inne i
staden per dag SEK, scenario 1
waste_handling_scen2 = 20219.5*365;
waste_handling_scen3 = 37441*365;

% TOTALT ÅRLIGA KOSTNADER
tot_expenses_Martin_GmbH = anual_salary + maintenance_Martin_GmbH +
tot_chem_cost + tot_flyash_cost + support_fuel_cost + transport_cost_scen1;
% Total årlig kostnad
tot_expenses_asian = anual_salary + maintenance_asian + tot_chem_cost +
tot_flyash_cost + support_fuel_cost + transport_cost_scen1;

% ANNUAL CASH FLOW
anual_cash_flow_Martin_GmbH = tot_income_before_tax -
tot_expenses_Martin_GmbH;
anual_cash_flow_asian = tot_income_before_tax - tot_expenses_asian;

% Pay-Back Method
pay_back_time_Martin_GmbH =
tot_invest_Martin_GmbH/anual_cash_flow_Martin_GmbH;
pay_back_time_asian = tot_invest_asian/anual_cash_flow_asian;
```

```
% Net profit value
economic_life_time = 20; % Ekonomisk livstid på grundinvestering
disc_rate = 0.08; % Estimerad discount rate


% Martin GmbH
PVmg = [];
PVaccmg = [];
PVmg(1) = anual_cash_flow_Martin_GmbH/((1+disc_rate)^1);
PVaccmg(1) = PVmg(1);
for j=2:economic_life_time
    PVmg(j) = (anual_cash_flow_Martin_GmbH)/((1+disc_rate)^j);
    PVaccmg(j) = PVaccmg(j-1)+PVmg(j);
end

PVmg; % Nu värde för varje år
PVaccmg; % Ackumulerat nuvärde för varje år, (ger summan av alla nuvärden
för respektive år)
PVaccmg(economic_life_time); % Summan av alla nuvärden för det sista året
PVtot_mg = sum(PVmg); % Summan av alla nuvärden

NPV_MG = -tot_invest_Martin_GmbH+PVtot_mg; % NPV värdet



% Testar matlabs inbyggda funktion
cash_in_vector_mg = ones(1,economic_life_time)*anual_cash_flow_Martin_GmbH;
investment_vector_mg = [-tot_invest_Martin_GmbH];
tot_vector_mg = [investment_vector_mg cash_in_vector_mg];

matlab_npv_mg = pvvar(tot_vector_mg,disc_rate);
IRR_MG = irr(tot_vector_mg);



% Asian supplier
PV_asian = [];
PVacc_asian = [];
PV_asian(1) = anual_cash_flow_asian/((1+disc_rate)^1);
PVacc_asian(1) = PV_asian(1);
for e=2:economic_life_time
    PV_asian(e) = (anual_cash_flow_asian)/((1+disc_rate)^e);
    PVacc_asian(e) = PVacc_asian(e-1)+PV_asian(e);
end

PV_asian; % Nu värde för varje år
PVacc_asian; % Ackumulerat nuvärde för varje år, (ger summan av alla
nuvärden för respektive år)
PVacc_asian(economic_life_time); % Summan av alla nuvärden för det sista
året
PVtot_asian = sum(PV_asian); % Summan av alla nuvärden

NPV_asian = -tot_invest_asian+PVtot_asian; % NPV värdet

% Testar matlabs inbyggda funktion
cash_in_vector_asian = ones(1,economic_life_time)*anual_cash_flow_asian;
investment_vector_asian = [-tot_invest_asian];
```

```
tot_vector_asian = [investment_vector_asian cash_in_vector_asian];

matlab_npv_asian = pvvar(tot_vector_asian,disc_rate);
IRR_asian = irr(tot_vector_asian);
```

Environment code

```
KOD ENVIRONMENT


% Beräkning av växthusgas utsläpp från landfill, med IPCC metoden

S = 0; % Startår för investering
Stop = 25; %Slutår för investering
t = Stop-S; %Livslängd för investering
w = yearly_feed; %Årligt avfall till landfill i Mg = ton
MCF = 0.6; %CH4 korrektionsfaktor, Obemannat och mycket vatten, enligt IPCC
tabell 3.1
DOCf= 0.5; %Fraktion av dekomposterat DOC, vanligtvis 0.5, kan göra
känslighetsanalys
F = 0.5; %Fraktion i volym av CH4 gas i landfill, antas vara 0.5
(vanligtvis)
rat = 16/12; % ratio mellan MCH4/MC
OX = 0.05; % Oxideringsfaktor av CH4 i landfill mellan 0-0.1

DOCorg = DOCorganic; % kg C-organiskt från organiskt avfall /kg avfall
(60%*DOC värde), 0.2851
DOCpap = DOCpapercard; % Andel papper i avfall (15ish%*DOC värde(0.4))
0.0548
%DOC = 0.433523; % DOC för textil och papper Moldavien

k_org = 0.4; % Från IPCC, fuktigt och varmt klimat, sid 17, 0.4
k_pap = 0.07; % Från IPCC fuktigt och varmt klimat, sid 17, 0.07
%k = 0.04; % dekomposterings konstant per år
%tp = 0.088; % andel textil och papper i avfall Moldavien

DDOCmorg = [];
DDOCmaorg = [];
DDOCmdecomporg = [];
CH4genorg = [];

DDOCmpap = [];
DDOCmapap = [];
DDOCmdecomppap = [];
CH4genpap = [];

DDOCm = [];
DDOCma = [];
DDOCmdecomp = [];
CH4gen = [];

years = [2015:1:2015+t]';

DDOCmorg = w*DOCorg*DOCf*MCF;
DDOCmaorg(1)=DDOCmorg;
DDOCmdecomporg(1)=0;

DDOCmpap = w*DOCpap*DOCf*MCF;
```

```
DDOCmapap(1)=DDOCmpap;
DDOCmdecomppap(1)=0;

DDOCm = DDOCmorg + DDOCmpap;
DDOCma(1)=DDOCm;
DDOCmdecomp(1)=0;

CH4genorg = [];
CH4genpap = [];
CH4gentot = [];

CH4genorg(1)=0;
CH4genpap(1)=0;
CH4gentot(1)=0;

for x=2:t

    % tar bort DDOCmdecomporg(x-1)+ DDO....

    DDOCmaorg(x) = DDOCmorg + (DDOCmaorg(x-1)*exp(-k_org));
    DDOCmdecomporg(x) = DDOCmaorg(x-1)*(1-(exp(-k_org))); %Ackumulerad
summa eller inte?? Kolla på IPCC, där är det inte ackumulerad! i så fall
borde allt avta med -k??
    CH4genorg(x) = DDOCmdecomporg(x)*F*(16/12)*(1-OX);



    DDOCmapap(x) = DDOCmpap + (DDOCmapap(x-1)*exp(-k_pap));
    DDOCmdecomppap(x) = DDOCmapap(x-1)*(1-(exp(-k_pap))); %Ackumulerad
summa eller inte?? Kolla på IPCC, där är det inte ackumulerad!
    CH4genpap(x) = DDOCmdecomppap(x)*F*(16/12)*(1-OX);

    DDOCma(x) = (DDOCmorg + (DDOCmaorg(x-1)*exp(-k_org)))+DDOCmpap +
(DDOCmapap(x-1)*exp(-k_pap));
    DDOCmdecomp(x) = (DDOCmaorg(x-1)*(1-(exp(-k_org))))+DDOCmapap(x-1)*(1-
(exp(-k_pap))); %Ackumulerad summa eller inte?? Kolla på IPCC, där är det
inte ackumulerad!
    %DDOCmdecomp(x) = (DDOCmdecomporg(x-1)+ DDOCmaorg(x-1)*(1-(exp(-
k_org))))+DDOCmdecomppap(x-1)+ DDOCmapap(x-1)*(1-(exp(-k_pap)));
    CH4gen = DDOCmdecomp*F*(16/12)*(1-OX);

    CH4gentot(x) = CH4genorg(x) + CH4genpap(x);

end

DDOCmaorg;
DDOCmdecomporg;
CH4genorg;

DDOCmapap;
DDOCmdecomppap;
CH4genpap;

DDOCma;
DDOCmdecomp;
CH4gen;

CH4gentot;
```

```
org=[DDOCmaorg',DDOCmdecomporg',CH4genorg'];
pap=[DDOCmapap',DDOCmdecomppap',CH4genpap'];
gen=[CH4genorg',CH4genpap',CH4gen',CH4gentot'];
%plot(years,DDOCma,years,DDOCmdecomp,years,CH4gen);

%  Orginal
%  DDOCma(x) = DDOCm + (DDOCma(x-1)*exp(-k));
%  DDOCmdecomp(x) = DDOCmdecomp(x-1)+ DDOCma(x-1)*(1-(exp(-k)));
%Ackumulerad summa eller inte?? Kolla på IPCC, där är det inte ackumulerad!
%  CH4gen = DDOCmdecomp*F*(16/12)*(1-OX);

% Om vi ska ta med CO2 utsläpp
% CO2 = CH4gen*(((1-F)/F)+OX)*(44/16);
% Från
http://www.epa.gov/ttnchie1/efpac/ghg/GHG_Biogenic_Report_draft_Dec1410.pdf

% Utsläpp från WtE

CO2fos_emissions_WtE = CO2fos*yearly_feed*1000; % CO2 finns i combustion
rad 43 och yearly_feed i startwaste rad 175 = kg CO2 per year
CO2_WtE = ones(1,25).*CO2fos_emissions_WtE;



% Utsläpp från ersatt dieselkraftverk

diesel_CO2 = 0.764; % kg CO2 utsläpp / genererad kWh
operational_time = 8000;
prod_el = net_el(m,nn)*operational_time*1000; % Producerad el,
%MW*drifttimmar*1000 = kWh Utan biogas

% Med biogas

CO2_emissions_diesel = diesel_CO2*tot_net_prod_el*1000;%*prod_el; %OBS
BIOGAS
CO2_diesel = ones(1,25).*CO2_emissions_diesel;

% Utsläpp från transporter
CO2_waste_handling_scen1 = 0; % kg CO2 per dag
CO2_waste_handling_scen2 = 193*365;
CO2_waste_handling_scen3 = 357*365;
CO2_waste_handling = ones(1,25).*CO2_waste_handling_scen3;

CO2_transport_scen1 = 0;    % kg CO2 utsläpp från transport av avfall till
Tenggarong
CO2_transport_scen2 = 1463*365;
CO2_transport_scen3 = 3390.2*365;
CO2_transport = ones(1,25).*CO2_transport_scen3;

% Jämförelse
CO2_emissions_net = (((CH4gen*1000)*25)+CO2_diesel-CO2_WtE-CO2_transport-
CO2_waste_handling)';
tabell_CO2 =
[((CH4gen*1000)*25)',CO2_diesel',CO2_WtE',CO2_transport',CO2_waste_handling
',CO2_emissions_net];
net_CO2 = sum(CO2_emissions_net);
```

Biogas code

```
biomassa=mass; %ton/Âr

Vbio=biomassa*204 %Nm3/ton WW Substrathandboken

VCH4=biomassa*128 %Nm3/ton WW Substrathandboken

Egas=biomassa*1.26%MWh/ton WW Substrathandboken

RateCH4=VCH4/Vbio % Andel metan i gasen Substrathandboken

Evardegas=1000*Egas/Vbio %kWh/Nm3 Substrathandboken

Viktgas=Vbio/1.1 %ca 1.1kg/nm3 SGC rapport
```

Waste data matrix from orware

```
% 1 organic waste, households
% 2 non burnable rest waste
% 3 Burnable rest fraction
% 4 Diapers
% 5 Rubber, fabric etc.
% 6 Dry (mixed) paper
% 7 Cardboard
% 8 mixed plastic
% 9 laminate
% 10 Glass
% 11 Metals
% 12 organic waste, restaurants and trade


wasteTSMat=[ ;% kg/kg TS (alla utom 47)
 %  1       2       3        4       5        6           7       8
9         10      11       12
 0.434    ,0      ,0.48     ,0.21   ,0        ,0.47     ,0.4     ,0
,0.24    ,0       ,0       ,0.452    ;% 1=C-tot
 0.029    ,0      ,0.16     ,0     ,0        ,0.033    ,0.059   ,0
,0.036   ,0       ,0     ,0.026    ;% 2=C-kolhyd, lignin
 0.097    ,0      ,0        ,0     ,0        ,0        ,0       ,0
,0        ,0       ,0      ,0.083  ;% 3=C-kolhyd, l„tt
 0.135    ,0      ,0        ,0     ,0        ,0        ,0     ,0         ,0
,0        ,0      ,0.182    ;% 4=C-fett
 0.066    ,0      ,0        ,0     ,0        ,0        ,0     ,0         ,0
,0        ,0      ,0.068    ;% 5=C-protein
 0        ,0      ,0        ,0     ,0        ,0        ,0     ,0         ,0
,0        ,0      ,0        ;% 6=BOD
 0.80     ,0.09     ,0.85     ,0.89   ,0.87     ,0.87     ,0.94    ,0.97
,0.85    ,0       ,0     ,0.80 ;% 7=VS
 1        ,1      ,1        ,1     ,1        ,1        ,1     ,1         ,1
,1        ,1      ,1        ;% 8=TS
 0        ,0      ,0        ,0     ,0        ,0        ,0     ,0         ,0
,0        ,0      ,0        ;% 9=CO2-f
 0        ,0      ,0        ,0     ,0        ,0        ,0     ,0         ,0
,0        ,0      ,0        ;% 10=CO2-b
 0        ,0      ,0        ,0     ,0        ,0        ,0     ,0         ,0
,0        ,0      ,0        ;% 11=CH4
 2e-6     ,0      ,0        ,0     ,0        ,0        ,0     ,0         ,0
,0        ,0      ,1.1e-6   ;% 12=VOC
 0.01e-6  ,0      ,0        ,0     ,0        ,0        ,0     ,0         ,0
,0        ,0      ,5e-9     ;% 13=CHX
```

```
 0         ,0       ,0         ,0    ,0         ,0         ,0      ,0          ,0
,0        ,0       ,0         ;% 14=AOX
 0.86e-6  ,0       ,0         ,0    ,0         ,0         ,0      ,0          ,0
,0        ,0       ,1e-6 ;% 15=PAH  Jönköping
 0         ,0       ,0         ,0    ,0         ,0         ,0      ,0          ,0
,0        ,0       ,0         ;% 16=CO
 27.5e-6  ,0       ,0         ,0    ,0         ,0         ,0      ,0          ,0
,0        ,0       ,2.7e-5   ;% 17=Fenoler
 8.32e-8  ,0       ,0         ,0    ,0         ,0         ,0      ,0          ,0
,0        ,0       ,5.5e-9   ;% 18=PCB  Jönköping
 0.09e-12 ,0       ,0         ,0    ,0         ,0         ,0      ,0          ,0
,0        ,0       ,1.1e-13  ;% 19=Dioxiner
 0.287    ,0       ,0.38      ,0    ,0.11      ,0.47      ,0      ,0.048      ,0
,0        ,0       ,0.263    ;% 20=O
 0.058    ,0       ,0.06      ,0.079 ,0.089    ,0.064     ,0.069   ,0.12
,0.069    ,0       ,0       ,0.031    ;% 21=H
 0         ,0       ,0         ,0    ,0         ,0      ,0   ,0          ,0
,0        ,0       ,0         ;% 22=H2O
 0.02     ,0       ,0.002     ,0.013  ,0.087    ,2.8e-3   ,2.6e-3  ,3e-3
,3e-3     ,0       ,0       ,0.022    ;% 23=N-Tot
 0         ,0       ,0         ,8.4e-3 ,0         ,0         ,0   ,0          ,0
,0        ,0       ,0         ;% 24=NH3/NH4-N
 0         ,0       ,0         ,0    ,0         ,0      ,0   ,0          ,0
,0        ,0       ,0         ;% 25=N-NOx
 0         ,0       ,0         ,0    ,0         ,0      ,0   ,0          ,0
,0        ,0       ,0         ;% 26=N-NO3
 0         ,0       ,0         ,0    ,0         ,0      ,0   ,0          ,0
,0        ,0       ,0         ;% 27=N-N2O
 0.0024   ,0       ,0.001     ,0    ,0.011     ,1.2e-3   ,1.2e-3  ,1.5e-3
,7e-4     ,0       ,0    ,0.002    ;% 28=S-tot
 0         ,0       ,0         ,0    ,0         ,0      ,0   ,0          ,0
,0        ,0    ,0         ;% 29=S-SOx
 0.0038   ,0       ,0         ,9.9e-4 ,0         ,2e-4     ,4.7e-4  ,8.2e-4
,4.2e-4   ,0       ,0       ,0.0011   ;% 30=P-tot
 0.0039   ,0       ,0.002     ,0    ,0.022     ,8.5e-4   ,1.7e-3  ,3.8e-2
,3.6e-3   ,0       ,0    ,0.0039   ;% 31=Cl
 0.0093   ,0       ,0         ,3.3e-3 ,0         ,1.4e-3   ,1.2e-3  ,1.5e-3
,1.2e-3   ,0       ,0       ,0.0119   ;% 32=K
 0.028    ,0       ,0         ,9.1e-4 ,0         ,1.9e-2   ,1.4e-2  ,4.9e-3
,9.8e-3   ,0       ,0       ,0.028    ;% 33=Ca
 3.00E-6  ,5e-6     ,19e-6  ,5e-6     ,2.1e-6   ,1.3e-5   ,8.3e-6  ,2.1e-4
,1.8e-5   ,0        ,1.8e-4 ,4e-8    ;% 34=Pb  Jönköping
 0.06E-6  ,1e-7     ,5e-7   ,3e-7     ,2.1e-7   ,1.8e-7   ,1.4e-7  ,3.7e-7
,5.1e-7   ,0        ,0    ,2e-8 ;% 35=Cd  Jönköping
 2.29E-8  ,5e-8     ,2.8e-8   ,5e-8   ,3.4e-8   ,2.1e-8   ,4e-8  ,6e-8
,3e-8     ,0       ,0       ,5e-9 ;% 36=Hg  Jönköping
 8.63E-6  ,1.5e-5   ,53e-6  ,5e-6     ,8.8e-6   ,4.1e-5   ,1.9e-5  ,1.5e-4
,1.5e-4   ,0       ,4.7e-3 ,1.3e-6 ;% 37=Cu  Jönköping
 2.50E-6  ,5.8e-5   ,21e-6  ,5e-6     ,2.9e-5   ,7.3e-6   ,7.3e-6  ,1.6e-5
,8.6e-6   ,1.8e-5  ,1.1e-3 ,2e-8   ;% 38=Cr  Jönköping
 1.21E-6  ,1.9e-5   ,31e-6  ,2e-6     ,3.1e-6   ,5.4e-6   ,5.3e-6  ,7.6e-6
,4.8e-6   ,0       ,5.3e-4 ,1.3e-7 ;% 39=Ni  Jönköping
 24.57E-6 ,1.3e-4   ,3.5e-4   ,4.7e-5 ,1.1e-4   ,5.6e-5   ,3.4e-5  ,3.3e-4
,1.2e-4   ,0       ,2e-4     ,10.5e-6  ;% 40=Zn  Jönköping
 0.107    ,0       ,0.34 ,0.21      ,0         ,0.31      ,0.34  ,0
,0.2       ,0         ,0    ,0.093    ;% 41=C-Kolh.Cellulosa
 0         ,0       ,0         ,0    ,0         ,0      ,0   ,0          ,0
,0         ,0    ,0         ;% 42=Partiklar/Suspenderat mtrl
 0         ,0       ,0         ,0    ,0         ,0      ,0   ,0          ,0
,0         ,0    ,0         ;% 43=COD
```

```
 0         ,0       ,0         ,0     ,0         ,0       ,0    ,0          ,0
,0         ,0     ,0         ;% 44=empty
 0         ,0       ,0         ,0.38     ,0.58 ,0       ,0.085   ,0.73  ,0.24
,0         ,0     ,0         ;% 45=Ctot, f
 0       ,0     ,0        ,0.45   ,0         ,0         ,0.1       ,0
,0.28     ,0         ,0     ,0        ;% 46=PE
 0.3    ,0.76 ,0.92      ,0.28   ,0.92     ,0.88     ,0.79     ,0.95
,0.84     ,1         ,1     ,0.25 ;% 47=TS/kg avfall]';
```

Appendix E - Extended method transportation cost

River transport

Box E-1 Calculation for river transport

The loading capacity of a normal size coal barge on the Mahakam river is 7000-8000 ton of coal. Density of coal of 800kg/m^3 (hardcoal) This gives a loading capacity of 10000m^3/barge The density of Samarinda waste is 260kg/m^3. So each barge can carry 10000m^3 waste = 2600ton The cost for transportation of coal on the Mahakam river is 0,02USD/ton/mile The cost for reloading of goods in harbour is 3,9USD/ton =33,18 SEK (54160 IDR)/ton (Fixed prices, government standard) One mile =1.609344km This gives a transportation costs of 0,1055 SEK (172 IDR) ton^{-1} km^{-1}

(Fahlberg & Johansson, 2007) (Bappeda technical department, 2015)

Road transport

The fuel consumptions for waste transportation vehicles vary depending on the size, model and generation of the vehicle. Our experience from our visit to the region is that the vehicles are rather old model of a smaller size and the vehicle data we gathered from the planning agency of Kutai Kartanegara also supports this.

Indications from both our visit and the literature study are that a higher number should be used.

0,159l/ton km (vehicle with a loading capacity up to 16-ton without trailer)

(Hammarström & Yahya, 2000)

The type of waste vehicle data we got from Kutai Kartanegara is for a loading capacity of 8m^3 and no trailer, with this in mind our calculations will use the with the number 0,159l/ton km.

Scenario 2

The distances from the main cities in the subdistricts are shown in Table 4-4 Distance to Tenggarong from the different subdistricts in scenario 2.

The amount of drivers needed is based on measurements of average driving speed between the cities Tenggarong and Samarinda and the fact that each truck can carry 8m^3 of waste. The used drivingspeed is 1,96min/km (measurement)**,** this collaborates very well with the google maps estimated driving speed between the cities.

The driver's salary is based on the driver salary for a waste truck driver in Tenggarong that is also used to calculate the waste handling cost.

Scenario 3

In Scenario 3 we are including both of the major cities Kota Bontang and Balikpapan. The distances to Tenggarong by road is obtained with google maps and information from the local government.

The distances by boat has been estimated using a map program called Map Pedometer.

(Map Pedometer, 2009)

When estimating the distances by boat from Sanga Sanga and Samboja, the closest point to the river or the sea has been used.

The assumption that the river barges are able to travel close to shore in open water has also been made.

Appendix F - Extended method waste handling cost

Box F-1 Calculation for the quantified waste handling cost

There are 21 cars currently operating. These cars consume 250 l of fuel / week

12 l /car/week

The cost for fuel is 7500 IDR/l.

Total = 90,000 IDR/week/car.

The salary for a driver of a waste-collecting car in Tenggarong is 2,9 MIDR/month.

This gives a total monthly cost of between 41,962 and 42,478 SEK/month

The waste production in Tenggarong with a collection rate of 57 % is 41.5 ton/day.

This gives a total cost of 33.7 and 34.12 SEK / ton of collected waste.

(Bappeda technical department, 2015)

Appendix G - Extended method electricity need biogasplant

The calculations of electricity need for a biogas plant are based on numbers from Biosystems AB, and their prestudy for a biogasplant in Vansbro.

Box G-1 Calculation of electricityneed for a biogasplant

The biogasplant in Vansbro uses 2 818 256kWh of electricity annually. The capacity of organic waste is 33 kton WW /yr. 85401kWhyr /kton WW

(Lindow, 2012)

shows the calculation of electricityneed for a biogasplant. This value will be used to estimate the consumed electricity in the model.

Appendix H - Extended method GHG emissions from transport

River transport

Transport on river is calculated from Samarinda and Sebulu, with addition to the waste from Tenggarong sebarang that is transported by car to Sebulu.

The emission factors are shown in Table 4-25 Emission factors for river transportation, with respect to upstream and downstream transport.

The distance from Samarinda is upstream and the distance from Sebulu is downstream.

TEU (twenty foot equivalent unit) is a unit used in freight overseas for measuring volume of standard containers, 2TEU = 77m^3.

The data gathered from Tenggarong with 10000m^3/barge = 260TEU which corresponds closest to a medium size barge of 208 TEU (The Europeean Chemical Industry Council, 2011).

Road transport

Box H-1 Calculation of emissions from combustion of diesel

1 liter of diesel weighs 835g

Diesel consists for 86,2% of carbon

This is 720g of carbon / l diesel

$C + O_2 = CO_2$

Molar weights of C respectively O are 12 and 16.

To burn one unit of carbon, $\frac{32}{12}$ times as much oxygen is needed

In order to combust this carbon to CO_2, 1920g of oxygen is needed

Summation:

$$720 + 1920 \ = \ 2640g \, \frac{CO_2}{l(diesel)}$$

Box H-1 Calculation of emissions from combustion of diesel the calculated emission of CO_2 / l diesel, this value will be used in the environmental model.

Waste handling

The climate cost for waste handling is calculated from the amount of fuel used in the trucks. In the section about cost for waste handling it is mentioned that the waste trucks in Tenggarong consumes about 250l of diesel/week. We know the amount of waste handled in Tenggarong and can thus determine the amount of diesel used/ton waste handled. When the amount of used diesel is known, the same procedure as for road transport is used.

Appendix I - Extended simulation results

Energy and economics

Scenario 1 System inc

Moisture in%	0.48	0.53	0.58	0.63
Hi (MJ/kg)	11.95	10.5	9.1	7.6
P el (MW)	1.62	1.41	1.2	0.98
Net P El (MW)	1.51	1.31	1.11	0.92
Electrical output (MWh)	1.206e4	1.048e4	0.89e4	0.73e4
P DH (MW)	3.06	2.66	2.26	1.86
Thermal output (MW)	2.45e4	2.13e4	1.81e4	1.49e4
Investment WtE plant (SEK)				
Martin GmbH China	81184416 29212680	81184416 29212680	81184416 29212680	81184416 29212680
Investment construction (SEK)				
Martin GmbH China	16236883 5842536	16236883 5842536	16236883 5842536	16236883 5842536
Investment cooling (SEK)	15925000	15925000	15925000	15925000
Total investment cost (SEK)				
Martin GmbH China	112250000 50980216	112250000 50980216	112250000 50980216	112250000 50980216
Income electicity (SEK)	9769568	8489554	7210144	5931331
Income cooling (SEK)	5064691	4.4011e6	3.7378e6	3.0749e6
Income residues (SEK)	95171	95171	95171	95171
Annual income (SEK)	14929430	12985838	11043162	9101393
Maintenance (SEK)				
Martin GmbH China	1.9422e6 9.03e5	1.9422e6 9.03e5	1.9422e6 9.03e5	1.9422e6 9.03e5
Salaries (SEK)	1460245	1460245	1460245	1460245
Chemical cost (SEK)	509713	509713	509713	509713
Support fuel (SEK)	20202	17555	14909	12265
Annual expense (SEK)				
Martin GmbH China	3935078 2895817	3932431 2893170	3929786 2890525	3927141 2887880
Annual cash flow (years)				
Martin GmbH China	10994351 12033613	9053406 10092667	7113376 8152637	5174252 6213513

Payback time (years)				
Martin GmbH China	10.32 4.2	12.5 5.1	16.0 6.3	21.9 8.2
NPV				
Martin GmbH China	-5538630 67020657	-24595121 47964166	-43642624 28916663	-62681229 9878059
IRR (%)				
Martin GmbH China	0.073 0.23	0.049 0.19	0.022 0.15	-0.0086 0.10

Scenario 1 System inc + dryer

Moisture in%	0.48	0.53	0.58	0.63
Moisture out%	0.4	0.4	0.4	0.4
Hi (MJ/kg)	14.08	14.08	14.08	14.08
P el (MW)	1.69	1.52	1.35	1.18
P dryer (MW)	0,01	0,02	0,02	0,03
Net P El (MW)	1.56	1.39	1.23	1.07
Electrical output (MWh)	12462	11152	9843	8533
P DH (MW)	3.18	2.86	2.54	3.06
Heat demand dryer (MW)	0.26	0.44	0.62	0.8
Net thermal (MW)	2.92	2.42	1.92	1.43
Thermal output (MWh)	25450	22905	20360	17814
Thermal use dryer (MWh)	2109	3538	4966	6395
Investment WtE plant (SEK)				
Martin GmbH China	81184416 29212680	81184416 29212680	81184416 29212680	81184416 29212680
Investment construction (SEK)				
Martin GmbH China	16236883 5842536	16236883 5842536	16236883 5842536	16236883 5842536
Investment dryer (SEK)	1821318	2754805	3613623	4423693
Total investment cost (SEK)				
Martin GmbH China	115304117 52948448	116237604 53881935	117096423 54740754	117906492 55550823
Income electicity (SEK)	10094507	9033844	7973181	6912518
Income cooling (SEK)	4830685	4008204	3185722	2363241
Income residues (SEK)	95171	95171	95171	95171

Annual income (SEK)	15020363	13137219	11254075	9370931
Maintenance (SEK)				
Martin GmbH China	1981344 942083	2000014 960753	2017190 977929	2033392 994131
Salaries (SEK)	1460245	1460245	1460245	1460245
Chemical cost (SEK)	509713	509713	509713	509713
Support fuel (SEK)	21009	18908	16807	14706
Annual expense (SEK)				
Martin GmbH China	3972312 2933051	3988881 2949620	4003956 2964695	4018056 2978795
Annual cash flow (years)				
Martin GmbH China	11048051 12087312	9148338 10187599	7250119 8289380	5352874 6392136
Payback time (years)				
Martin GmbH China	10.44 4.38	12.71 5.29	16.15 6.6	22.03 8.7
NPV				
Martin GmbH China	-6832724 37525686	-26417869 26015782	-45913684 14595208	-65351177 3232956
IRR (%)				
Martin GmbH China	0.072 0.224	0.048 0.182	0.021 0.141	-0.009 0.097

Scenario 1 System inc + bio

Moisture in%	0,1	0.19	0.28	0.37
Hi (MJ/kg)	26,01	23,22	20,37	17,51
P el (MW)	1,46	1,29	1,13	0,96
P bed dryer (MW)	-	-	-	-
Net P El (MW)	1,36	1,2	1,05	0,9
Electrical output WtE (MWh)	10874	9635	8397	7161
El use biogas plant (MWh)	778	778	778	778
Net el WtE	10096	8858	7620	6383
Volume biogas (Nm^3)	1715964	1544367	1372771	1201174
Electrical output biogas (MWh)	4428	3985	3542	3099
P DH (MW)	2,75	2,44	2,13	1,82
Heat demand cooling (MW)	2,75	2,44	2,13	1,82
Heat demand dryer (MW)	-	-	-	-
Net P thermal (MW)	0	0	0	0
Thermal output	22065	19551	17039	14530

(MW)				
Thermal use cooling (MWh)	22065	19551	17039	14530
Net thermal output (MWh)	0	0	0	0
Investment WtE plant (SEK)				
Martin GmbH China	32149028 11571657	32149028 11571657	32149028 11571657	32149028 11571657
Investment construction (SEK)				
Martin GmbH China	6429805 2314331	6429805 2314331	6429805 2314331	6429805 2314331
Investment cooling (SEK)	16061500	16061500	16061500	16061500
Investment dryer (SEK)	-	-	-	-
Investment biogas (SEK)	12347436	12347436	12347436	12347436
Total investment cost (SEK)				
Martin GmbH China	66987770 42294925	66987770 42294925	66987770 42294925	66987770 42294925
Income electicity WtE (SEK)	8178451	7174907	6172252	5170474
Income electricity from biogas (SEK)	3586688	3228019	2869350	2510682
Income cooling (SEK)	4566486	4046233	3526442	3007106
Income residues (SEK)	37687	37687	37687	37687
Annual income (SEK)	16369315	14486848	12605734	10725950
Maintenance (SEK)				
Martin GmbH China	1211159 799611	1211159 799611	1211159 799611	1211159 799611
Salaries (SEK)	1460245	1460245	1460245	1460245
Chemical cost (SEK)	201846	201846	201846	201846
Support fuel (SEK)	11994	11994	11994	11994
Annual expense (SEK)				
Martin GmbH China	2891465 2479918	2889390 2477843	2887317 2475769	2885245 2473698
Annual cash flow (years)				
Martin GmbH China	13477849 13889396	11597458 12009005	9718417 10129964	7840704 8252252
Payback time (years)				
Martin GmbH China	5,0 3,1	5,8 3,5	6,9 4,2	8,5 5,1

NPV				
Martin GmbH China	65339741 94073219	46877783 75611261	28429082 57162561	9993424 38726902
IRR (%)				
Martin GmbH China	0,2 0,33	0,165 0,28	0,133 0,236	0,099 0,1889
Steamfeed	1,3	1,2	1	0,9
P boiler	4,3	3,8	3,3	2,8
n_boiler	0.934	0.932	0.930	0.926
n_el	0.338	0.338	0.338	0.338
n_heat	0.639	0.639	0.639	0.639
n_tot	0.977	0.977	0.977	0.977

Scenario 2 System inc

Moisture in%	0.48	0.53	0.58	0.63
Hi (MJ/kg)	11.95	10.5	9.1	7.6
P el (MW)	23,1	20,05	17	14
Net P El (MW)	21,5	18,7	15,8	13
Electrical output (MWh)	171696	149201	126715	104241
P DH (MW)	43,55	37,84	32,14	26,44
Heat demand cooling (MW)	3,53	3,53	3,53	3,53
Thermal output (MW)	348376	302732	257109	211507
Investment WtE plant (SEK)				
Martin GmbH China	963082640 346621940	963082640 346621940	963082640 346621940	963082640 346621940
Investment construction (SEK)				
Martin GmbH China	192616528 69324388	192616528 69324388	192616528 69324388	192616528 69324388
Investment cooling (SEK)	15925000	15925000	15925000	15925000
Total investment cost (SEK)				
Martin GmbH China	1171624168 431871328	1171624168 431871328	1171624168 431871328	1171624168 431871328
Income electicity (SEK)	139074500	120852885	102639864	84435351
Income cooling (SEK)	5794740	5794740	5794740	5794740
Income residues (SEK)	1354808	1354808	1354808	1354808
Annual income (SEK)	146224048	128002433	109789412	91584900
Maintenance (SEK)				
Martin GmbH China	19580153 7250939	19580153 7250939	19580153 7250939	19580153 7250939
Salaries (SEK)	3438404	3438404	3438404	3438404

Chemical cost (SEK)	7256013	7256013	7256013	7256013
Support fuel (SEK)	287587	249907	212245	174601
Annual expense (SEK)				
Martin GmbH China	51806252 39477038	51768572 39439358	51730910 39401696	51693266 39364052
Annual cash flow (years)				
Martin GmbH China	94417795 106747009	76233860 88563074	58058501 70387715	39891633 52220847
Payback time (years)				
Martin GmbH China	12,4 4.05	15,4 4.9	20,2 6.1	29,4 8.3
NPV				
Martin GmbH China	-244616330 +616186549	-423148889 +437653990	-601597241 +259205638	-779962227 +80840653
IRR (%)				
Martin GmbH China	0.05 0.24	0.026 0.20	-0.0008 0.15	-0.034 0.104

Scenario 2 System inc + dryer

Moisture in%	0.48	0.53	0.58	0.63
Moisture out%	0.4	0.4	0.4	0.4
Hi (MJ/kg)	14.08	14.08	14.08	14.08
P el (MW)	24	21,6	19,2	16,8
Net P El (MW)	22,2	19,8	1.23	1.07
P bed dryer (MW)	0.14	0.24	0.34	0.44
Electrical output (MWh)	177408	158767	140126	121485
P DH (MW)	45,3	40,8	36,2	31,7
Heat demand dryer (MW)	3,75	6,3	8,8	11,4
Heat demand cooling (MW)	3,53	3,53	3,53	3,53
Net DH (MW) (måste kylas bort)	38,01	30,93	23,86	16,79
Thermal output (Mwh) (tot)	362307	326071	289836	253601
Thermal use dryer (MWh)	30026	50366	70706	91045
Thermal use cooling (MWh)	28240	28240	28240	28240
Investment WtE plant (SEK)				
Martin GmbH China	963082640 346621940	963082640 346621940	963082640 346621940	963082640 346621940
Investment construction (SEK)				

Martin GmbH China	192616528 69324388	192616528 69324388	192616528 69324388	192616528 69324388
Investment dryer (SEK)	15243460	23056245	30244099	37023946
Investment cooling (SEK)	15925000	15925000	15925000	15925000
Total investment cost (SEK)				
Martin GmbH China	1186867628 447114788	1194680413 454927573	1201868267 462115427	1208648114 468895274
Income electicity (SEK)	143700165	128601118	113502070	98403023
Income cooling (SEK)	5844409	5844409	5844409	5844409
Income residues (SEK)	1354808	1354808	1354808	1354808
Annual income (SEK)	150899382	135800335	120701288	105602240
Maintenance (SEK)				
Martin GmbH China	19885022 7555808	20041277 7712063	20185034 7855820	20320631 7991417
Salaries (SEK)	3438404	3438404	3438404	3438404
Chemical cost (SEK)	7256013	7256013	7256013	7256013
Support fuel (SEK)	299087	269174	239262	209349
Annual expense (SEK)				
Martin GmbH China	52122621 39793407	52248964 39919750	52362809 40033595	52468493 40139279
Annual cash flow (years)				
Martin GmbH China	98776761 111105975	83551370 95880584	68338478 80667692	53133747 65462961
Payback time (years)				
Martin GmbH China	12.1 4	14.3 4,7	17.6 5.7	22.7 7.2
NPV				
Martin GmbH China	-217062828 643740052	-374360739 486442140	-530911008 329891871	-686973151 173829728
IRR (%)				
Martin GmbH China	0.054 0.24	0.034 0.21	0.013 0.17	-0.012 0.13

Scenario 2 System inc + bio

Moisture in%	0,1	0.19	0.28	0.37
Hi (MJ/kg)	26,01	23,22	20,37	17,51
P el (MW)	20.81	18.44	16,07	13.70
P bed dryer (MW)	-	-	-	-
Net P El (MW)	19.35	17.15	14.94	12.74

Electrical output WtE (MWh)	154807	137170	119549	101943
El use biogas plant (MWh)	11074	11074	11074	11074
Net el WtE	143733	126096	108475	90869
Volume biogas (Nm^3)	24427594	21984835	19542075	17099316
Electrical output biogas (MWh)	63034	56731	50427	44124
P DH (MW)	39.26	34.79	30.32	25.86
Heat demand cooling (MW)	3.53	3.53	3.53	3.53
Heat demand dryer (MW)	-	-	-	-
Net P thermal (MW)	35.73	31.26	26.79	22.32
Thermal output (MW)	314107	278321	242567	206844
Thermal use cooling (MWh)	28240	28240	28240	28240
Net thermal output (MWh)	285867	250081	214327	178604
Investment WtE plant (SEK)				
Martin GmbH China	381380725 137273425	381380725 137273425	381380725 137273425	381380725 137273425
Investment construction (SEK)				
Martin GmbH China	76276145 27454685	76276145 27454685	76276145 27454685	76276145 27454685
Investment cooling (SEK)	16061500	16061500	16061500	16061500
Investment dryer (SEK)	-	-	-	-
Investment biogas (SEK)	175771688	175771688	175771688	175771688
Total investment cost (SEK)				
Martin GmbH China	649490059 356561299	649490059 356561299	649490059 356561299	649490059 356561299
Income electicity WtE (SEK)	116424191	102138248	87864983	73604188
Income electricity from biogas (SEK)	51058284	45952456	40846627	35740799
Income cooling (SEK)	5844409	5844409	5844409	5844409
Income residues (SEK)	536504	536504	536504	536504
Annual income (SEK)	173863497	154471713	135092606	115725969
Maintenance (SEK)				
Martin GmbH	11464278	11464278	11464278	11464278

China	6582132	6582132	6582132	6582132
Salaries (SEK)	3438404	3438404	3438404	3438404
Chemical cost (SEK)	2873381	2873381	2873381	2873381
Support fuel (SEK)	259298	229756	200241	170752
Annual expense (SEK)				
Martin GmbH China	39279456 34397310	39249915 34367769	39220400 34338254	39190910 34308764
Annual cash flow (years)				
Martin GmbH China	134584028 139466178	115221785 120103935	95872192 100754343	76535045 81417196
Payback time (years)				
Martin GmbH China	4,8 2,6	5,6 3,0	6,8 3,5	8,5 4,4
NPV				
Martin GmbH China	671875179 1012737884	481773823 822636528	291796675 632659380	101941713 442804418
IRR (%)				
Martin GmbH China	0,202 0.39	0,169 0.336	0.136 0.28	0.100 0.224
Steamfeed	19	16,8	14,65	12,5
P boiler	61,5	54,5	47,5	40,5
n_boiler	0.934	0.932	0.930	0.926
n_el	0.338	0.338	0.338	0.338
n_heat	0.639	0.639	0.639	0.639
n_tot	0.977	0.977	0.977	0.977

Scenario 3 System inc

Moisture	0.48	0.53	0.58	0.63
Hi (MJ/kg)	11.95	10.5	9.1	7.6
P el (MW)	43,46	37,76	32,07	26,39
P bed dryer (MW)	-	-	-	-
Net P El (MW)	40,42	35,12	29,83	24,54
Electrical output (MWh)	323347	280982	238637	196311
P DH (MW)	82,01	71,26	60,52	49,79
Heat demand cooling (MW)	3,53	3,53	3,53	3,53
Heat demand dryer (MW)	-	-	-	-
Net P thermal (MW)	78,51	67,76	57,02	46,29
Thermal output (MW)	656078	570119	484199	398320
Net thermal output (MWh)	628078	542119	456199	370320
Investment WtE plant (SEK)				

Martin GmbH China	1813720952 652827140	1813720952 652827140	1813720952 652827140	1813720952 652827140
Investment construction (SEK)				
Martin GmbH China	362744190 130565428	362744190 130565428	362744190 130565428	362744190 130565428
Investment cooling (SEK)	16061500	16061500	16061500	16061500
Investment dryer (SEK)	- -	- -	- -	- -
Total investment cost (SEK)				
Martin GmbH China	2192526643 799454068	2192526643 799454068	2192526643 799454068	2192526643 799454068
Income electicity (SEK)	261911413	227595640	193296052	159012488
Income cooling (SEK)	5794740	5794740	5794740	5794740
Income residues (SEK)	2551436	2551436	2551436	2551436
Annual income (SEK)	270257589	235941816	201642228	167358664
Maintenance (SEK)				
Martin GmbH China	36595649 13377772	36595649 13377772	36595649 13377772	36595649 13377772
Salaries (SEK)	3780000	3780000	3780000	3780000
Chemical cost (SEK)	13664853	13664853	13664853	13664853
Support fuel (SEK)	541597	470637	399710	328816
Annual expense (SEK)				
Martin GmbH China	91648945 68431069	91577985 68360109	91507058 68289182	91436164 68218288
Annual cash flow (years)				
Martin GmbH China	178608643 201826519	144363830 167581707	110135169 133353046	75922499 99140376
Payback time (years)				
Martin GmbH China	12,3 4,0	15,2 4,77	19,9 6,00	28,9 8,06
NPV				
Martin GmbH China	-438920651 1182108455	-775141271 845887835	-1111203310 509825796	-1447108348 173920758
IRR (%)				
Martin GmbH China	0.05 0.25	0.03 0.204	0.0004 0.16	-0.03 0.11

Scenario 3 System inc + dryer

Moisture in%	0.48	0.53	0.58	0.63
Hi (MJ/kg)	14,08	14,08	14,08	14,08

P el (MW)	45,2	40,7	36,2	31,6
P bed dryer (MW)	0,27	0,46	0,64	0,82
Net P El (MW)	41,76	37,37	32,99	28,6
Electrical output (MWh)	334102	298996	263891	228786
P DH (MW)	85,3	76,8	68,2	59,7
Heat demand cooling (MW)	3,53	3,53	3,53	3,53
Heat demand dryer (MW)	7,07	11,85	16,6	21,4
Net P thermal (MW)	74,7	61,4	48,05	34,74
Net thermal output (MWh)	597525	490981	384437	277893
Investment WtE plant (SEK)				
Martin GmbH China	1813720952 652827140	1813720952 652827140	1813720952 652827140	1813720952 652827140
Investment construction (SEK)				
Martin GmbH China	362744190 130565428	362744190 130565428	362744190 130565428	362744190 130565428
Investment cooling (SEK)	15925000	15925000	15925000	15925000
Investment dryer (SEK)	25293510	38257282	50184106	61433921
Total investment cost (SEK)				
Martin GmbH China	2217683653 824611078	2230647425 837574850	2242574249 849501674	2253824064 860751489
Income electicity (SEK)	270622675	242187464	213752253	185317041
Income cooling (SEK)	5844409	5844409	5844409	5844409
Income residues (SEK)	2551436	2551436	2551436	2551436
Annual income (SEK)	279018521	250583309	222148098	193712887
Maintenance (SEK)				
Martin GmbH China	37098789 13880913	37358064 14140188	37596601 14378724	37821597 14603721
Salaries (SEK)	3780000	3780000	3780000	3780000
Chemical cost (SEK)	13664853	13664853	13664853	13664853
Support fuel (SEK)	563254	506921	450589	394256
Annual expense (SEK)				
Martin GmbH China	92173742 68955866	92376685 69158809	92558889 69341013	92727553 69509676
Annual cash flow (years)				
Martin GmbH	186842048	158203894	129586478	100982603

China	210059924	181421770	152804355	124200480
Payback time (years)				
Martin GmbH China	11,9 3.9	14,1 4.6	17,3 5.6	22,32 6.9
NPV				
Martin GmbH China	-383377382 +1237651724	-677514772 +943514334	-970411597 +650617509	-1262498472 +358530633
IRR (%)				
Martin GmbH China	0.056 0.252	0.036 0.22	0.014 0.17	-0.01 0.13

Scenario 3 System inc + bio

Moisture in%	0,1	0.19	0.28	0.37
Hi (MJ/kg)	26,01	23,22	20,37	17,51
P el (MW)	39.18	34.72	30.26	25.80
P bed dryer (MW)	-	-	-	-
Net P El (MW)	36.44	32.29	28.14	23.99
Electrical output WtE (MWh)	291539	258325	225140	191983
El use biogas plant (MWh)	20854	20854	20854	20854
Net el WtE	270685	237470	204285	171129
Volume biogas (Nm^3)	46003056	41402750	36802444	32202139
Electrical output biogas (MWh)	118709	106838	94967	83096
P DH (MW)	73.94	65.52	57,1	48.69
Heat demand cooling (MW)	3.53	3.53	3.53	3.53
Heat demand dryer (MW)	-	-	-	-
Net P thermal (MW)	70.41	61.99	53.57	45.16
Thermal output (MW)	591540	524147	456814	389539
Thermal use cooling (MWh)	28240	28240	28240	28240
Net thermal output (MWh)	563300	495907	428574	361299
Investment WtE plant (SEK)				
Martin GmbH China	718232613 258519229	718232613 258519229	718232613 258519229	718232613 258519229
Investment construction (SEK)				
Martin GmbH China	143646522 51703845	143646522 51703845	143646522 51703845	143646522 51703845
Investment cooling (SEK)	16061500	16061500	16061500	16061500

Investment dryer (SEK)	-	-	-	-
Investment biogas (SEK)	331020816	331020816	331020816	331020816
Total investment cost (SEK)				
Martin GmbH China	1208961452 657305391	1208961452 657305391	1208961452 657305391	1208961452 657305391
Income electicity WtE (SEK)	219255053	192351150	165471121	138614578
Income electricity from biogas (SEK)	96155072	86539565	76924057	67308550
Income cooling (SEK)	5844409	5844409	5844409	5844409
Income residues (SEK)	1010367	1010367	1010367	1010367
Annual income (SEK)	322264902	285745492	249249956	212777905
Maintenance (SEK)				
Martin GmbH China	21306298 12112030	21306298 12112030	21306298 12112030	21306298 12112030
Salaries (SEK)	3780000	3780000	3780000	3780000
Chemical cost (SEK)	5411275	5411275	5411275	5411275
Support fuel (SEK)	488321	432687	377103	321567
Annual expense (SEK)				
Martin GmbH China	68052740 58858472	67997106 58802839	67941522 58747254	67885986 58691719
Annual cash flow (years)				
Martin GmbH China	254212162 263406429	217748385 226942653	181308433 190502701	144891918 154086186
Payback time (years)				
Martin GmbH China	4.7 2.5	5,55 2.9	6,7 3,5	8,3 4,3
NPV				
Martin GmbH China	1286931027 1928857763	928924296 1570851032	571151478 1213078214	213608765 855535501
IRR (%)				
Martin GmbH China	0.205 0.40	0.173 0.344	0.138 0.288	0.103 0.23
Steamfeed kg/s	35,11	31.66	27.59	23.53
P_boiler	115,7	102,6	89,4	76,24

Environmental

Scenario 1 System inc

	48% fukt					
Scenario 1 utan tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste handling	CO2 net
2015	0	9214753,429	9728907,724	0	0	-514154,295
2016	2047466,423	9214753,429	9728907,724	0	0	1533312,129
2017	3499305,194	9214753,429	9728907,724	0	0	2985150,899
2018	4546516,164	9214753,429	9728907,724	0	0	4032361,869
2019	5317493,181	9214753,429	9728907,724	0	0	4803338,886
2020	5898639,506	9214753,429	9728907,724	0	0	5384485,211
2021	6348188,393	9214753,429	9728907,724	0	0	5834034,099
2022	6705468,858	9214753,429	9728907,724	0	0	6191314,563
2023	6997118,138	9214753,429	9728907,724	0	0	6482963,844
2024	7241247,383	9214753,429	9728907,724	0	0	6727093,089
2025	7450235,247	9214753,429	9728907,724	0	0	6936080,953
2026	7632601,663	9214753,429	9728907,724	0	0	7118447,368
2027	7794264,957	9214753,429	9728907,724	0	0	7280110,662
2028	7939385,536	9214753,429	9728907,724	0	0	7425231,241
2029	8070932,375	9214753,429	9728907,724	0	0	7556778,081
2030	8191063,628	9214753,429	9728907,724	0	0	7676909,333
2031	8301382,578	9214753,429	9728907,724	0	0	7787228,284
2032	8403109,985	9214753,429	9728907,724	0	0	7888955,69
2033	8497200,316	9214753,429	9728907,724	0	0	7983046,021
2034	8584420,334	9214753,429	9728907,724	0	0	8070266,04
2035	8665402,396	9214753,429	9728907,724	0	0	8151248,102
2036	8740680,761	9214753,429	9728907,724	0	0	8226526,467
2037	8810716,468	9214753,429	9728907,724	0	0	8296562,173
2038	8875914,517	9214753,429	9728907,724	0	0	8361760,222
2039	8936635,859	9214753,429	9728907,724	0	0	8422481,564

	53% fukt					
Scenario 1 utan tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	8007431,514	8756016,951	0	0	-748585,438
2016	1842719,781	8007431,514	8756016,951	0	0	1094134,343
2017	3149374,674	8007431,514	8756016,951	0	0	2400789,237
2018	4091864,547	8007431,514	8756016,951	0	0	3343279,11
2019	4785743,863	8007431,514	8756016,951	0	0	4037158,425
2020	5308775,555	8007431,514	8756016,951	0	0	4560190,118
2021	5713369,554	8007431,514	8756016,951	0	0	4964784,116
2022	6034921,972	8007431,514	8756016,951	0	0	5286336,535
2023	6297406,325	8007431,514	8756016,951	0	0	5548820,887
2024	6517122,645	8007431,514	8756016,951	0	0	5768537,207
2025	6705211,722	8007431,514	8756016,951	0	0	5956626,285
2026	6869341,496	8007431,514	8756016,951	0	0	6120756,059
2027	7014838,461	8007431,514	8756016,951	0	0	6266253,023
2028	7145446,982	8007431,514	8756016,951	0	0	6396861,545
2029	7263839,138	8007431,514	8756016,951	0	0	6515253,7
2030	7371957,265	8007431,514	8756016,951	0	0	6623371,827
2031	7471244,32	8007431,514	8756016,951	0	0	6722658,883
2032	7562798,987	8007431,514	8756016,951	0	0	6814213,549
2033	7647480,284	8007431,514	8756016,951	0	0	6898894,847
2034	7725978,301	8007431,514	8756016,951	0	0	6977392,863
2035	7798862,157	8007431,514	8756016,951	0	0	7050276,719
2036	7866612,685	8007431,514	8756016,951	0	0	7118027,248
2037	7929644,821	8007431,514	8756016,951	0	0	7181059,383
2038	7988323,065	8007431,514	8756016,951	0	0	7239737,628
2039	8042972,273	8007431,514	8756016,951	0	0	7294386,836

	58% fukt					
Scenario 1 utan tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	6800679,042	7783126,179	0	0	-982447,137
2016	1637973,139	6800679,042	7783126,179	0	0	655526,0014
2017	2799444,155	6800679,042	7783126,179	0	0	1816997,018
2018	3637212,931	6800679,042	7783126,179	0	0	2654765,794
2019	4253994,545	6800679,042	7783126,179	0	0	3271547,408
2020	4718911,604	6800679,042	7783126,179	0	0	3736464,467
2021	5078550,715	6800679,042	7783126,179	0	0	4096103,577
2022	5364375,086	6800679,042	7783126,179	0	0	4381927,949
2023	5597694,511	6800679,042	7783126,179	0	0	4615247,374
2024	5792997,907	6800679,042	7783126,179	0	0	4810550,769
2025	5960188,198	6800679,042	7783126,179	0	0	4977741,061
2026	6106081,33	6800679,042	7783126,179	0	0	5123634,193
2027	6235411,965	6800679,042	7783126,179	0	0	5252964,828
2028	6351508,429	6800679,042	7783126,179	0	0	5369061,292
2029	6456745,9	6800679,042	7783126,179	0	0	5474298,763
2030	6552850,902	6800679,042	7783126,179	0	0	5570403,765
2031	6641106,063	6800679,042	7783126,179	0	0	5658658,925
2032	6722487,988	6800679,042	7783126,179	0	0	5740040,851
2033	6797760,253	6800679,042	7783126,179	0	0	5815313,116
2034	6867536,267	6800679,042	7783126,179	0	0	5885089,13
2035	6932321,917	6800679,042	7783126,179	0	0	5949874,78
2036	6992544,609	6800679,042	7783126,179	0	0	6010097,472
2037	7048573,174	6800679,042	7783126,179	0	0	6066126,037
2038	7100731,614	6800679,042	7783126,179	0	0	6118284,476
2039	7149308,687	6800679,042	7783126,179	0	0	6166861,55

	63% fukt					
Scenario 1 utan tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	5594490,338	6810235,407	0	0	-1215745,07
2016	1433226,496	5594490,338	6810235,407	0	0	217481,4273
2017	2449513,636	5594490,338	6810235,407	0	0	1233768,567
2018	3182561,315	5594490,338	6810235,407	0	0	1966816,246
2019	3722245,227	5594490,338	6810235,407	0	0	2506500,158
2020	4129047,654	5594490,338	6810235,407	0	0	2913302,585
2021	4443731,875	5594490,338	6810235,407	0	0	3227986,806
2022	4693828,201	5594490,338	6810235,407	0	0	3478083,132
2023	4897982,697	5594490,338	6810235,407	0	0	3682237,628
2024	5068873,168	5594490,338	6810235,407	0	0	3853128,099
2025	5215164,673	5594490,338	6810235,407	0	0	3999419,604
2026	5342821,164	5594490,338	6810235,407	0	0	4127076,095
2027	5455985,47	5594490,338	6810235,407	0	0	4240240,401
2028	5557569,875	5594490,338	6810235,407	0	0	4341824,806
2029	5649652,663	5594490,338	6810235,407	0	0	4433907,594
2030	5733744,539	5594490,338	6810235,407	0	0	4517999,47
2031	5810967,805	5594490,338	6810235,407	0	0	4595222,736
2032	5882176,99	5594490,338	6810235,407	0	0	4666431,921
2033	5948040,221	5594490,338	6810235,407	0	0	4732295,152
2034	6009094,234	5594490,338	6810235,407	0	0	4793349,165
2035	6065781,678	5594490,338	6810235,407	0	0	4850036,609
2036	6118476,533	5594490,338	6810235,407	0	0	4902731,464
2037	6167501,527	5594490,338	6810235,407	0	0	4951756,459
2038	6213140,162	5594490,338	6810235,407	0	0	4997395,093
2039	6255645,101	5594490,338	6810235,407	0	0	5039900,032

Scenario 1 System inc + dryer

	58% fukt					
Scenario 1 med tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	7520383,632	7783126,179	0	0	-262742,547
2016	1637973,139	7520383,632	7783126,179	0	0	1375230,592
2017	2799444,155	7520383,632	7783126,179	0	0	2536701,608
2018	3637212,931	7520383,632	7783126,179	0	0	3374470,384
2019	4253994,545	7520383,632	7783126,179	0	0	3991251,998
2020	4718911,604	7520383,632	7783126,179	0	0	4456169,058
2021	5078550,715	7520383,632	7783126,179	0	0	4815808,168
2022	5364375,086	7520383,632	7783126,179	0	0	5101632,54
2023	5597694,511	7520383,632	7783126,179	0	0	5334951,964
2024	5792997,907	7520383,632	7783126,179	0	0	5530255,36
2025	5960188,198	7520383,632	7783126,179	0	0	5697445,651
2026	6106081,33	7520383,632	7783126,179	0	0	5843338,783
2027	6235411,965	7520383,632	7783126,179	0	0	5972669,418
2028	6351508,429	7520383,632	7783126,179	0	0	6088765,882
2029	6456745,9	7520383,632	7783126,179	0	0	6194003,353
2030	6552850,902	7520383,632	7783126,179	0	0	6290108,355
2031	6641106,063	7520383,632	7783126,179	0	0	6378363,516
2032	6722487,988	7520383,632	7783126,179	0	0	6459745,441
2033	6797760,253	7520383,632	7783126,179	0	0	6535017,706
2034	6867536,267	7520383,632	7783126,179	0	0	6604793,721
2035	6932321,917	7520383,632	7783126,179	0	0	6669579,37
2036	6992544,609	7520383,632	7783126,179	0	0	6729802,062
2037	7048573,174	7520383,632	7783126,179	0	0	6785830,627
2038	7100731,614	7520383,632	7783126,179	0	0	6837989,067
2039	7149308,687	7520383,632	7783126,179	0	0	6886566,14

	63% fukt					
Scenario 1 med tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	6519955,826	6810235,407	0	0	-290279,581
2016	1433226,496	6519955,826	6810235,407	0	0	1142946,915
2017	2449513,636	6519955,826	6810235,407	0	0	2159234,055
2018	3182561,315	6519955,826	6810235,407	0	0	2892281,734
2019	3722245,227	6519955,826	6810235,407	0	0	3431965,646
2020	4129047,654	6519955,826	6810235,407	0	0	3838768,073
2021	4443731,875	6519955,826	6810235,407	0	0	4153452,295
2022	4693828,201	6519955,826	6810235,407	0	0	4403548,62
2023	4897982,697	6519955,826	6810235,407	0	0	4607703,116
2024	5068873,168	6519955,826	6810235,407	0	0	4778593,587
2025	5215164,673	6519955,826	6810235,407	0	0	4924885,092
2026	5342821,164	6519955,826	6810235,407	0	0	5052541,583
2027	5455985,47	6519955,826	6810235,407	0	0	5165705,889
2028	5557569,875	6519955,826	6810235,407	0	0	5267290,294
2029	5649652,663	6519955,826	6810235,407	0	0	5359373,082
2030	5733744,539	6519955,826	6810235,407	0	0	5443464,958
2031	5810967,805	6519955,826	6810235,407	0	0	5520688,224
2032	5882176,99	6519955,826	6810235,407	0	0	5591897,409
2033	5948040,221	6519955,826	6810235,407	0	0	5657760,64
2034	6009094,234	6519955,826	6810235,407	0	0	5718814,653
2035	6065781,678	6519955,826	6810235,407	0	0	5775502,097
2036	6118476,533	6519955,826	6810235,407	0	0	5828196,952
2037	6167501,527	6519955,826	6810235,407	0	0	5877221,947
2038	6213140,162	6519955,826	6810235,407	0	0	5922860,581
2039	6255645,101	6519955,826	6810235,407	0	0	5965365,52

Scenario 1 System inc + bio

	48% fukt					
Scenario 1 med bio	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	11096996,8	9727761,35	0	0	1369235,448
2016	2047466,423	11096996,8	9727761,35	0	0	3416701,871
2017	3499305,194	11096996,8	9727761,35	0	0	4868540,642
2018	4546516,164	11096996,8	9727761,35	0	0	5915751,612
2019	5317493,181	11096996,8	9727761,35	0	0	6686728,629
2020	5898639,506	11096996,8	9727761,35	0	0	7267874,954
2021	6348188,393	11096996,8	9727761,35	0	0	7717423,841
2022	6705468,858	11096996,8	9727761,35	0	0	8074704,306
2023	6997118,138	11096996,8	9727761,35	0	0	8366353,587
2024	7241247,383	11096996,8	9727761,35	0	0	8610482,831
2025	7450235,247	11096996,8	9727761,35	0	0	8819470,695
2026	7632601,663	11096996,8	9727761,35	0	0	9001837,111
2027	7794264,957	11096996,8	9727761,35	0	0	9163500,405
2028	7939385,536	11096996,8	9727761,35	0	0	9308620,984
2029	8070932,375	11096996,8	9727761,35	0	0	9440167,823
2030	8191063,628	11096996,8	9727761,35	0	0	9560299,076
2031	8301382,578	11096996,8	9727761,35	0	0	9670618,026
2032	8403109,985	11096996,8	9727761,35	0	0	9772345,433
2033	8497200,316	11096996,8	9727761,35	0	0	9866435,764
2034	8584420,334	11096996,8	9727761,35	0	0	9953655,782
2035	8665402,396	11096996,8	9727761,35	0	0	10034637,84
2036	8740680,761	11096996,8	9727761,35	0	0	10109916,21
2037	8810716,468	11096996,8	9727761,35	0	0	10179951,92
2038	8875914,517	11096996,8	9727761,35	0	0	10245149,97
2039	8936635,859	11096996,8	9727761,35	0	0	10305871,31

	53% fukt					
Scenario 1 med bio	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	9812143,387	8754985,215	0	0	1057158,172
2016	1842719,781	9812143,387	8754985,215	0	0	2899877,953
2017	3149374,674	9812143,387	8754985,215	0	0	4206532,847
2018	4091864,547	9812143,387	8754985,215	0	0	5149022,72
2019	4785743,863	9812143,387	8754985,215	0	0	5842902,035
2020	5308775,555	9812143,387	8754985,215	0	0	6365933,727
2021	5713369,554	9812143,387	8754985,215	0	0	6770527,726
2022	6034921,972	9812143,387	8754985,215	0	0	7092080,145
2023	6297406,325	9812143,387	8754985,215	0	0	7354564,497
2024	6517122,645	9812143,387	8754985,215	0	0	7574280,817
2025	6705211,722	9812143,387	8754985,215	0	0	7762369,895
2026	6869341,496	9812143,387	8754985,215	0	0	7926499,669
2027	7014838,461	9812143,387	8754985,215	0	0	8071996,633
2028	7145446,982	9812143,387	8754985,215	0	0	8202605,155
2029	7263839,138	9812143,387	8754985,215	0	0	8320997,31
2030	7371957,265	9812143,387	8754985,215	0	0	8429115,437
2031	7471244,32	9812143,387	8754985,215	0	0	8528402,493
2032	7562798,987	9812143,387	8754985,215	0	0	8619957,159
2033	7647480,284	9812143,387	8754985,215	0	0	8704638,457
2034	7725978,301	9812143,387	8754985,215	0	0	8783136,473
2035	7798862,157	9812143,387	8754985,215	0	0	8856020,329
2036	7866612,685	9812143,387	8754985,215	0	0	8923770,858
2037	7929644,821	9812143,387	8754985,215	0	0	8986802,993
2038	7988323,065	9812143,387	8754985,215	0	0	9045481,238
2039	8042972,273	9812143,387	8754985,215	0	0	9100130,445

	58% fukt					
Scenario 1 med bio	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	8528129,926	7782209,08	0	0	745920,8461
2016	1637973,139	8528129,926	7782209,08	0	0	2383893,985
2017	2799444,155	8528129,926	7782209,08	0	0	3545365,001
2018	3637212,931	8528129,926	7782209,08	0	0	4383133,777
2019	4253994,545	8528129,926	7782209,08	0	0	4999915,391
2020	4718911,604	8528129,926	7782209,08	0	0	5464832,451
2021	5078550,715	8528129,926	7782209,08	0	0	5824471,561
2022	5364375,086	8528129,926	7782209,08	0	0	6110295,933
2023	5597694,511	8528129,926	7782209,08	0	0	6343615,357
2024	5792997,907	8528129,926	7782209,08	0	0	6538918,753
2025	5960188,198	8528129,926	7782209,08	0	0	6706109,044
2026	6106081,33	8528129,926	7782209,08	0	0	6852002,176
2027	6235411,965	8528129,926	7782209,08	0	0	6981332,811
2028	6351508,429	8528129,926	7782209,08	0	0	7097429,275
2029	6456745,9	8528129,926	7782209,08	0	0	7202666,746
2030	6552850,902	8528129,926	7782209,08	0	0	7298771,748
2031	6641106,063	8528129,926	7782209,08	0	0	7387026,909
2032	6722487,988	8528129,926	7782209,08	0	0	7468408,834
2033	6797760,253	8528129,926	7782209,08	0	0	7543681,099
2034	6867536,267	8528129,926	7782209,08	0	0	7613457,114
2035	6932321,917	8528129,926	7782209,08	0	0	7678242,763
2036	6992544,609	8528129,926	7782209,08	0	0	7738465,455
2037	7048573,174	8528129,926	7782209,08	0	0	7794494,02
2038	7100731,614	8528129,926	7782209,08	0	0	7846652,46
2039	7149308,687	8528129,926	7782209,08	0	0	7895229,533

	63% fukt					
Scenario 1 med biogas	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	7244942,742	6809432,945	0	0	435509,7973
2016	1433226,496	7244942,742	6809432,945	0	0	1868736,294
2017	2449513,636	7244942,742	6809432,945	0	0	2885023,433
2018	3182561,315	7244942,742	6809432,945	0	0	3618071,112
2019	3722245,227	7244942,742	6809432,945	0	0	4157755,024
2020	4129047,654	7244942,742	6809432,945	0	0	4564557,451
2021	4443731,875	7244942,742	6809432,945	0	0	4879241,673
2022	4693828,201	7244942,742	6809432,945	0	0	5129337,998
2023	4897982,697	7244942,742	6809432,945	0	0	5333492,494
2024	5068873,168	7244942,742	6809432,945	0	0	5504382,966
2025	5215164,673	7244942,742	6809432,945	0	0	5650674,47
2026	5342821,164	7244942,742	6809432,945	0	0	5778330,961
2027	5455985,47	7244942,742	6809432,945	0	0	5891495,267
2028	5557569,875	7244942,742	6809432,945	0	0	5993079,672
2029	5649652,663	7244942,742	6809432,945	0	0	6085162,46
2030	5733744,539	7244942,742	6809432,945	0	0	6169254,337
2031	5810967,805	7244942,742	6809432,945	0	0	6246477,602
2032	5882176,99	7244942,742	6809432,945	0	0	6317686,787
2033	5948040,221	7244942,742	6809432,945	0	0	6383550,019
2034	6009094,234	7244942,742	6809432,945	0	0	6444604,031
2035	6065781,678	7244942,742	6809432,945	0	0	6501291,475
2036	6118476,533	7244942,742	6809432,945	0	0	6553986,33
2037	6167501,527	7244942,742	6809432,945	0	0	6603011,325
2038	6213140,162	7244942,742	6809432,945	0	0	6648649,959
2039	6255645,101	7244942,742	6809432,945	0	0	6691154,899

Scenario 2 System inc

	48% fukt					
Scenario 2 utan tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste handling	CO2 net
2015	0	131176564,1	138495804,3	533995	70445	-7923680,2
2016	29146695,29	131176564,1	138495804,3	533995	70445	21223015,09
2017	49814336,91	131176564,1	138495804,3	533995	70445	41890656,71
2018	64721902,04	131176564,1	138495804,3	533995	70445	56798221,84
2019	75697140,49	131176564,1	138495804,3	533995	70445	67773460,29
2020	83970045,31	131176564,1	138495804,3	533995	70445	76046365,11
2021	90369595,65	131176564,1	138495804,3	533995	70445	82445915,45
2022	95455659,44	131176564,1	138495804,3	533995	70445	87531979,24
2023	99607430,93	131176564,1	138495804,3	533995	70445	91683750,72
2024	103082731,2	131176564,1	138495804,3	533995	70445	95159051,04
2025	106057776,7	131176564,1	138495804,3	533995	70445	98134096,45
2026	108653852,6	131176564,1	138495804,3	533995	70445	100730172,4
2027	110955209,4	131176564,1	138495804,3	533995	70445	103031529,2
2028	113021072,5	131176564,1	138495804,3	533995	70445	105097392,3
2029	114893706,7	131176564,1	138495804,3	533995	70445	106970026,5
2030	116603834,4	131176564,1	138495804,3	533995	70445	108680154,2
2031	118174279,1	131176564,1	138495804,3	533995	70445	110250598,9
2032	119622419	131176564,1	138495804,3	533995	70445	111698738,7
2033	120961841,3	131176564,1	138495804,3	533995	70445	113038161,1
2034	122203461,3	131176564,1	138495804,3	533995	70445	114279781,1
2035	123356280,9	131176564,1	138495804,3	533995	70445	115432600,7
2036	124427905,6	131176564,1	138495804,3	533995	70445	116504225,4
2037	125424898,5	131176564,1	138495804,3	533995	70445	117501218,3
2038	126353024,9	131176564,1	138495804,3	533995	70445	118429344,7
2039	127217423,1	131176564,1	138495804,3	533995	70445	119293742,9

	53% fukt					
Scenario 2 utan tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	113989740,6	124646223,8	533995	70445	-11260923,3
2016	26232025,76	113989740,6	124646223,8	533995	70445	14971102,51
2017	44832903,22	113989740,6	124646223,8	533995	70445	33571979,97
2018	58249711,84	113989740,6	124646223,8	533995	70445	46988788,59
2019	68127426,44	113989740,6	124646223,8	533995	70445	56866503,19
2020	75573040,78	113989740,6	124646223,8	533995	70445	64312117,53
2021	81332636,09	113989740,6	124646223,8	533995	70445	70071712,83
2022	85910093,5	113989740,6	124646223,8	533995	70445	74649170,25
2023	89646687,84	113989740,6	124646223,8	533995	70445	78385764,58
2024	92774458,12	113989740,6	124646223,8	533995	70445	81513534,87
2025	95451998,99	113989740,6	124646223,8	533995	70445	84191075,74
2026	97788467,35	113989740,6	124646223,8	533995	70445	86527544,1
2027	99859688,47	113989740,6	124646223,8	533995	70445	88598765,21
2028	101718965,2	113989740,6	124646223,8	533995	70445	90458041,99
2029	103404336	113989740,6	124646223,8	533995	70445	92143412,77
2030	104943450,9	113989740,6	124646223,8	533995	70445	93682527,68
2031	106356851,2	113989740,6	124646223,8	533995	70445	95095927,93
2032	107660177,1	113989740,6	124646223,8	533995	70445	96399253,8
2033	108865657,1	113989740,6	124646223,8	533995	70445	97604733,88
2034	109983115,2	113989740,6	124646223,8	533995	70445	98722191,9
2035	111020652,8	113989740,6	124646223,8	533995	70445	99759729,57
2036	111985115	113989740,6	124646223,8	533995	70445	100724191,8
2037	112882408,6	113989740,6	124646223,8	533995	70445	101621485,4
2038	113717722,4	113989740,6	124646223,8	533995	70445	102456799,1
2039	114495680,8	113989740,6	124646223,8	533995	70445	103234757,6

	58% fukt					
Scenario 2 utan tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	96811023,41	110796643,4	533995	70445	-14590060
2016	23317356,24	96811023,41	110796643,4	533995	70445	8727296,239
2017	39851469,53	96811023,41	110796643,4	533995	70445	25261409,53
2018	51777521,63	96811023,41	110796643,4	533995	70445	37187461,64
2019	60557712,39	96811023,41	110796643,4	533995	70445	45967652,39
2020	67176036,25	96811023,41	110796643,4	533995	70445	52585976,25
2021	72295676,52	96811023,41	110796643,4	533995	70445	57705616,53
2022	76364527,56	96811023,41	110796643,4	533995	70445	61774467,56
2023	79685944,74	96811023,41	110796643,4	533995	70445	65095884,75
2024	82466185	96811023,41	110796643,4	533995	70445	67876125
2025	84846221,33	96811023,41	110796643,4	533995	70445	70256161,33
2026	86923082,09	96811023,41	110796643,4	533995	70445	72333022,09
2027	88764167,52	96811023,41	110796643,4	533995	70445	74174107,53
2028	90416858	96811023,41	110796643,4	533995	70445	75826798
2029	91914965,35	96811023,41	110796643,4	533995	70445	77324905,36
2030	93283067,5	96811023,41	110796643,4	533995	70445	78693007,5
2031	94539423,28	96811023,41	110796643,4	533995	70445	79949363,28
2032	95697935,16	96811023,41	110796643,4	533995	70445	81107875,16
2033	96769473,01	96811023,41	110796643,4	533995	70445	82179413,01
2034	97762769,02	96811023,41	110796643,4	533995	70445	83172709,03
2035	98685024,73	96811023,41	110796643,4	533995	70445	84094964,73
2036	99542324,48	96811023,41	110796643,4	533995	70445	84952264,48
2037	100339918,8	96811023,41	110796643,4	533995	70445	85749858,77
2038	101082419,9	96811023,41	110796643,4	533995	70445	86492359,9
2039	101773938,5	96811023,41	110796643,4	533995	70445	87183878,52

	63% fukt					
Scenario 2 utan tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	79640331,76	96947062,98	533995	70445	-17911171,2
2016	20402686,71	79640331,76	96947062,98	533995	70445	2491515,481
2017	34870035,84	79640331,76	96947062,98	533995	70445	16958864,61
2018	45305331,43	79640331,76	96947062,98	533995	70445	27394160,2
2019	52987998,34	79640331,76	96947062,98	533995	70445	35076827,12
2020	58779031,72	79640331,76	96947062,98	533995	70445	40867860,49
2021	63258716,96	79640331,76	96947062,98	533995	70445	45347545,73
2022	66818961,61	79640331,76	96947062,98	533995	70445	48907790,39
2023	69725201,65	79640331,76	96947062,98	533995	70445	51814030,42
2024	72157911,87	79640331,76	96947062,98	533995	70445	54246740,65
2025	74240443,66	79640331,76	96947062,98	533995	70445	56329272,44
2026	76057696,83	79640331,76	96947062,98	533995	70445	58146525,6
2027	77668646,58	79640331,76	96947062,98	533995	70445	59757475,36
2028	79114750,75	79640331,76	96947062,98	533995	70445	61203579,52
2029	80425594,68	79640331,76	96947062,98	533995	70445	62514423,46
2030	81622684,06	79640331,76	96947062,98	533995	70445	63711512,84
2031	82721995,37	79640331,76	96947062,98	533995	70445	64810824,14
2032	83735693,27	79640331,76	96947062,98	533995	70445	65824522,04
2033	84673288,88	79640331,76	96947062,98	533995	70445	66762117,66
2034	85542422,9	79640331,76	96947062,98	533995	70445	67631251,67
2035	86349396,64	79640331,76	96947062,98	533995	70445	68438225,41
2036	87099533,92	79640331,76	96947062,98	533995	70445	69188362,69
2037	87797428,92	79640331,76	96947062,98	533995	70445	69886257,69
2038	88447117,41	79640331,76	96947062,98	533995	70445	70535946,18
2039	89052196,2	79640331,76	96947062,98	533995	70445	71141024,98

Scenario 2 System inc + dryer

	48% fukt					
Scenario 2 med tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	135539540,9	138495804,3	533995	70445	-3560703,31
2016	29146695,29	135539540,9	138495804,3	533995	70445	25585991,98
2017	49814336,91	135539540,9	138495804,3	533995	70445	46253633,6
2018	64721902,04	135539540,9	138495804,3	533995	70445	61161198,73
2019	75697140,49	135539540,9	138495804,3	533995	70445	72136437,18
2020	83970045,31	135539540,9	138495804,3	533995	70445	80409342
2021	90369595,65	135539540,9	138495804,3	533995	70445	86808892,34
2022	95455659,44	135539540,9	138495804,3	533995	70445	91894956,13
2023	99607430,93	135539540,9	138495804,3	533995	70445	96046727,62
2024	103082731,2	135539540,9	138495804,3	533995	70445	99522027,93
2025	106057776,7	135539540,9	138495804,3	533995	70445	102497073,3
2026	108653852,6	135539540,9	138495804,3	533995	70445	105093149,3
2027	110955209,4	135539540,9	138495804,3	533995	70445	107394506,1
2028	113021072,5	135539540,9	138495804,3	533995	70445	109460369,2
2029	114893706,7	135539540,9	138495804,3	533995	70445	111333003,4
2030	116603834,4	135539540,9	138495804,3	533995	70445	113043131,1
2031	118174279,1	135539540,9	138495804,3	533995	70445	114613575,8
2032	119622419	135539540,9	138495804,3	533995	70445	116061715,6
2033	120961841,3	135539540,9	138495804,3	533995	70445	117401138
2034	122203461,3	135539540,9	138495804,3	533995	70445	118642758
2035	123356280,9	135539540,9	138495804,3	533995	70445	119795577,6
2036	124427905,6	135539540,9	138495804,3	533995	70445	120867202,3
2037	125424898,5	135539540,9	138495804,3	533995	70445	121864195,1
2038	126353024,9	135539540,9	138495804,3	533995	70445	122792321,6
2039	127217423,1	135539540,9	138495804,3	533995	70445	123656719,8

	53% fukt					
Scenario 2 med tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	121297957,2	124646223,8	533995	70445	-3952706,59
2016	26232025,76	121297957,2	124646223,8	533995	70445	22279319,18
2017	44832903,22	121297957,2	124646223,8	533995	70445	40880196,64
2018	58249711,84	121297957,2	124646223,8	533995	70445	54297005,25
2019	68127426,44	121297957,2	124646223,8	533995	70445	64174719,85
2020	75573040,78	121297957,2	124646223,8	533995	70445	71620334,19
2021	81332636,09	121297957,2	124646223,8	533995	70445	77379929,5
2022	85910093,5	121297957,2	124646223,8	533995	70445	81957386,91
2023	89646687,84	121297957,2	124646223,8	533995	70445	85693981,25
2024	92774458,12	121297957,2	124646223,8	533995	70445	88821751,53
2025	95451998,99	121297957,2	124646223,8	533995	70445	91499292,41
2026	97788467,35	121297957,2	124646223,8	533995	70445	93835760,76
2027	99859688,47	121297957,2	124646223,8	533995	70445	95906981,88
2028	101718965,2	121297957,2	124646223,8	533995	70445	97766258,66
2029	103404336	121297957,2	124646223,8	533995	70445	99451629,44
2030	104943450,9	121297957,2	124646223,8	533995	70445	100990744,3
2031	106356851,2	121297957,2	124646223,8	533995	70445	102404144,6
2032	107660177,1	121297957,2	124646223,8	533995	70445	103707470,5
2033	108865657,1	121297957,2	124646223,8	533995	70445	104912950,6
2034	109983115,2	121297957,2	124646223,8	533995	70445	106030408,6
2035	111020652,8	121297957,2	124646223,8	533995	70445	107067946,2
2036	111985115	121297957,2	124646223,8	533995	70445	108032408,5
2037	112882408,6	121297957,2	124646223,8	533995	70445	108929702
2038	113717722,4	121297957,2	124646223,8	533995	70445	109765015,8
2039	114495680,8	121297957,2	124646223,8	533995	70445	110542974,2

	58% fukt					
Scenario 2 med tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	107056373,5	110796643,4	533995	70445	-4344709,86
2016	23317356,24	107056373,5	110796643,4	533995	70445	18972646,38
2017	39851469,53	107056373,5	110796643,4	533995	70445	35506759,67
2018	51777521,63	107056373,5	110796643,4	533995	70445	47432811,77
2019	60557712,39	107056373,5	110796643,4	533995	70445	56213002,53
2020	67176036,25	107056373,5	110796643,4	533995	70445	62831326,39
2021	72295676,52	107056373,5	110796643,4	533995	70445	67950966,66
2022	76364527,56	107056373,5	110796643,4	533995	70445	72019817,7
2023	79685944,74	107056373,5	110796643,4	533995	70445	75341234,88
2024	82466185	107056373,5	110796643,4	533995	70445	78121475,14
2025	84846221,33	107056373,5	110796643,4	533995	70445	80501511,47
2026	86923082,09	107056373,5	110796643,4	533995	70445	82578372,23
2027	88764167,52	107056373,5	110796643,4	533995	70445	84419457,67
2028	90416858	107056373,5	110796643,4	533995	70445	86072148,14
2029	91914965,35	107056373,5	110796643,4	533995	70445	87570255,49
2030	93283067,5	107056373,5	110796643,4	533995	70445	88938357,64
2031	94539423,28	107056373,5	110796643,4	533995	70445	90194713,42
2032	95697935,16	107056373,5	110796643,4	533995	70445	91353225,3
2033	96769473,01	107056373,5	110796643,4	533995	70445	92424763,15
2034	97762769,02	107056373,5	110796643,4	533995	70445	93418059,16
2035	98685024,73	107056373,5	110796643,4	533995	70445	94340314,87
2036	99542324,48	107056373,5	110796643,4	533995	70445	95197614,62
2037	100339918,8	107056373,5	110796643,4	533995	70445	95995208,9
2038	101082419,9	107056373,5	110796643,4	533995	70445	96737710,04
2039	101773938,5	107056373,5	110796643,4	533995	70445	97429228,66

	63% fukt					
Scenario 2 med tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	92814789,85	96947062,98	533995	70445	-4736713,13
2016	20402686,71	92814789,85	96947062,98	533995	70445	15665973,57
2017	34870035,84	92814789,85	96947062,98	533995	70445	30133322,71
2018	45305331,43	92814789,85	96947062,98	533995	70445	40568618,3
2019	52987998,34	92814789,85	96947062,98	533995	70445	48251285,21
2020	58779031,72	92814789,85	96947062,98	533995	70445	54042318,58
2021	63258716,96	92814789,85	96947062,98	533995	70445	58522003,82
2022	66818961,61	92814789,85	96947062,98	533995	70445	62082248,48
2023	69725201,65	92814789,85	96947062,98	533995	70445	64988488,52
2024	72157911,87	92814789,85	96947062,98	533995	70445	67421198,74
2025	74240443,66	92814789,85	96947062,98	533995	70445	69503730,53
2026	76057696,83	92814789,85	96947062,98	533995	70445	71320983,69
2027	77668646,58	92814789,85	96947062,98	533995	70445	72931933,45
2028	79114750,75	92814789,85	96947062,98	533995	70445	74378037,61
2029	80425594,68	92814789,85	96947062,98	533995	70445	75688881,55
2030	81622684,06	92814789,85	96947062,98	533995	70445	76885970,93
2031	82721995,37	92814789,85	96947062,98	533995	70445	77985282,23
2032	83735693,27	92814789,85	96947062,98	533995	70445	78998980,13
2033	84673288,88	92814789,85	96947062,98	533995	70445	79936575,75
2034	85542422,9	92814789,85	96947062,98	533995	70445	80805709,76
2035	86349396,64	92814789,85	96947062,98	533995	70445	81612683,51
2036	87099533,92	92814789,85	96947062,98	533995	70445	82362820,79
2037	87797428,92	92814789,85	96947062,98	533995	70445	83060715,78
2038	88447117,41	92814789,85	96947062,98	533995	70445	83710404,28
2039	89052196,2	92814789,85	96947062,98	533995	70445	84315483,07

Scenario 2 System inc + bio

	48% fukt					
Scenario 2 med bio	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste handling	
2015	0	157971227,6	138479485,1	533995	70445	18887302,55
2016	29146695,29	157971227,6	138479485,1	533995	70445	48033997,84
2017	49814336,91	157971227,6	138479485,1	533995	70445	68701639,46
2018	64721902,04	157971227,6	138479485,1	533995	70445	83609204,59
2019	75697140,49	157971227,6	138479485,1	533995	70445	94584443,04
2020	83970045,31	157971227,6	138479485,1	533995	70445	102857347,9
2021	90369595,65	157971227,6	138479485,1	533995	70445	109256898,2
2022	95455659,44	157971227,6	138479485,1	533995	70445	114342962
2023	99607430,93	157971227,6	138479485,1	533995	70445	118494733,5
2024	103082731,2	157971227,6	138479485,1	533995	70445	121970033,8
2025	106057776,7	157971227,6	138479485,1	533995	70445	124945079,2
2026	108653852,6	157971227,6	138479485,1	533995	70445	127541155,2
2027	110955209,4	157971227,6	138479485,1	533995	70445	129842512
2028	113021072,5	157971227,6	138479485,1	533995	70445	131908375
2029	114893706,7	157971227,6	138479485,1	533995	70445	133781009,2
2030	116603834,4	157971227,6	138479485,1	533995	70445	135491136,9
2031	118174279,1	157971227,6	138479485,1	533995	70445	137061581,6
2032	119622419	157971227,6	138479485,1	533995	70445	138509721,5
2033	120961841,3	157971227,6	138479485,1	533995	70445	139849143,8
2034	122203461,3	157971227,6	138479485,1	533995	70445	141090763,8
2035	123356280,9	157971227,6	138479485,1	533995	70445	142243583,5
2036	124427905,6	157971227,6	138479485,1	533995	70445	143315208,1
2037	125424898,5	157971227,6	138479485,1	533995	70445	144312201
2038	126353024,9	157971227,6	138479485,1	533995	70445	145240327,4
2039	127217423,1	157971227,6	138479485,1	533995	70445	146104725,7

	53% fukt					
Scenario 2 med bio	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste handling	
2015	0	139680705	124631536,6	533995	70445	14444728,47
2016	26232025,76	139680705	124631536,6	533995	70445	40676754,23
2017	44832903,22	139680705	124631536,6	533995	70445	59277631,69
2018	58249711,84	139680705	124631536,6	533995	70445	72694440,3
2019	68127426,44	139680705	124631536,6	533995	70445	82572154,91
2020	75573040,78	139680705	124631536,6	533995	70445	90017769,24
2021	81332636,09	139680705	124631536,6	533995	70445	95777364,55
2022	85910093,5	139680705	124631536,6	533995	70445	100354822
2023	89646687,84	139680705	124631536,6	533995	70445	104091416,3
2024	92774458,12	139680705	124631536,6	533995	70445	107219186,6
2025	95451998,99	139680705	124631536,6	533995	70445	109896727,5
2026	97788467,35	139680705	124631536,6	533995	70445	112233195,8
2027	99859688,47	139680705	124631536,6	533995	70445	114304416,9
2028	101718965,2	139680705	124631536,6	533995	70445	116163693,7
2029	103404336	139680705	124631536,6	533995	70445	117849064,5
2030	104943450,9	139680705	124631536,6	533995	70445	119388179,4
2031	106356851,2	139680705	124631536,6	533995	70445	120801579,7
2032	107660177,1	139680705	124631536,6	533995	70445	122104905,5
2033	108865657,1	139680705	124631536,6	533995	70445	123310385,6
2034	109983115,2	139680705	124631536,6	533995	70445	124427843,6
2035	111020652,8	139680705	124631536,6	533995	70445	125465381,3
2036	111985115	139680705	124631536,6	533995	70445	126429843,5
2037	112882408,6	139680705	124631536,6	533995	70445	127327137,1
2038	113717722,4	139680705	124631536,6	533995	70445	128162450,8
2039	114495680,8	139680705	124631536,6	533995	70445	128940409,3

	58% fukt					
Scenario 2 med bio	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste handling	
2015	0	121402139,5	110783588	533995	70445	10014111,48
2016	23317356,24	121402139,5	110783588	533995	70445	33331467,71
2017	39851469,53	121402139,5	110783588	533995	70445	49865581,01
2018	51777521,63	121402139,5	110783588	533995	70445	61791633,11
2019	60557712,39	121402139,5	110783588	533995	70445	70571823,87
2020	67176036,25	121402139,5	110783588	533995	70445	77190147,73
2021	72295676,52	121402139,5	110783588	533995	70445	82309788
2022	76364527,56	121402139,5	110783588	533995	70445	86378639,03
2023	79685944,74	121402139,5	110783588	533995	70445	89700056,22
2024	82466185	121402139,5	110783588	533995	70445	92480296,47
2025	84846221,33	121402139,5	110783588	533995	70445	94860332,8
2026	86923082,09	121402139,5	110783588	533995	70445	96937193,57
2027	88764167,52	121402139,5	110783588	533995	70445	98778279
2028	90416858	121402139,5	110783588	533995	70445	100430969,5
2029	91914965,35	121402139,5	110783588	533995	70445	101929076,8
2030	93283067,5	121402139,5	110783588	533995	70445	103297179
2031	94539423,28	121402139,5	110783588	533995	70445	104553534,8
2032	95697935,16	121402139,5	110783588	533995	70445	105712046,6
2033	96769473,01	121402139,5	110783588	533995	70445	106783584,5
2034	97762769,02	121402139,5	110783588	533995	70445	107776880,5
2035	98685024,73	121402139,5	110783588	533995	70445	108699136,2
2036	99542324,48	121402139,5	110783588	533995	70445	109556436
2037	100339918,8	121402139,5	110783588	533995	70445	110354030,2
2038	101082419,9	121402139,5	110783588	533995	70445	111096531,4
2039	101773938,5	121402139,5	110783588	533995	70445	111788050

	63% fukt					
Scenario 2 med bio	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste handling	
2015	0	103135336,5	96935639,54	533995	70445	5595256,961
2016	20402686,71	103135336,5	96935639,54	533995	70445	25997943,67
2017	34870035,84	103135336,5	96935639,54	533995	70445	40465292,8
2018	45305331,43	103135336,5	96935639,54	533995	70445	50900588,39
2019	52987998,34	103135336,5	96935639,54	533995	70445	58583255,3
2020	58779031,72	103135336,5	96935639,54	533995	70445	64374288,68
2021	63258716,96	103135336,5	96935639,54	533995	70445	68853973,92
2022	66818961,61	103135336,5	96935639,54	533995	70445	72414218,57
2023	69725201,65	103135336,5	96935639,54	533995	70445	75320458,61
2024	72157911,87	103135336,5	96935639,54	533995	70445	77753168,83
2025	74240443,66	103135336,5	96935639,54	533995	70445	79835700,62
2026	76057696,83	103135336,5	96935639,54	533995	70445	81652953,79
2027	77668646,58	103135336,5	96935639,54	533995	70445	83263903,55
2028	79114750,75	103135336,5	96935639,54	533995	70445	84710007,71
2029	80425594,68	103135336,5	96935639,54	533995	70445	86020851,65
2030	81622684,06	103135336,5	96935639,54	533995	70445	87217941,02
2031	82721995,37	103135336,5	96935639,54	533995	70445	88317252,33
2032	83735693,27	103135336,5	96935639,54	533995	70445	89330950,23
2033	84673288,88	103135336,5	96935639,54	533995	70445	90268545,84
2034	85542422,9	103135336,5	96935639,54	533995	70445	91137679,86
2035	86349396,64	103135336,5	96935639,54	533995	70445	91944653,6
2036	87099533,92	103135336,5	96935639,54	533995	70445	92694790,88
2037	87797428,92	103135336,5	96935639,54	533995	70445	93392685,88
2038	88447117,41	103135336,5	96935639,54	533995	70445	94042374,37
2039	89052196,2	103135336,5	96935639,54	533995	70445	94647453,17

Scenario 3 System inc

	48% fukt					
Scenario 3 utan tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste handling	CO2 net
2015	0	247037127,8	260821023,5	1237423	130305	-15151623,7
2016	54890261,41	247037127,8	260821023,5	1237423	130305	39738637,7
2017	93812418,44	247037127,8	260821023,5	1237423	130305	78660794,73
2018	121886961,3	247037127,8	260821023,5	1237423	130305	106735337,6
2019	142555984	247037127,8	260821023,5	1237423	130305	127404360,3
2020	158135860,4	247037127,8	260821023,5	1237423	130305	142984236,7
2021	170187758,1	247037127,8	260821023,5	1237423	130305	155036134,4
2022	179766043,7	247037127,8	260821023,5	1237423	130305	164614420
2023	187584831,4	247037127,8	260821023,5	1237423	130305	172433207,7
2024	194129660,6	247037127,8	260821023,5	1237423	130305	178978036,9
2025	199732389,1	247037127,8	260821023,5	1237423	130305	184580765,4
2026	204621426,6	247037127,8	260821023,5	1237423	130305	189469802,9
2027	208955436,9	247037127,8	260821023,5	1237423	130305	193803813,2
2028	212845955,6	247037127,8	260821023,5	1237423	130305	197694331,9
2029	216372577,8	247037127,8	260821023,5	1237423	130305	201220954,1
2030	219593160,9	247037127,8	260821023,5	1237423	130305	204441537,2
2031	222550687,3	247037127,8	260821023,5	1237423	130305	207399063,6
2032	225277884,2	247037127,8	260821023,5	1237423	130305	210126260,5
2033	227800339,6	247037127,8	260821023,5	1237423	130305	212648715,9
2034	230138609,8	247037127,8	260821023,5	1237423	130305	214986986,1
2035	232309647,4	247037127,8	260821023,5	1237423	130305	217158023,6
2036	234327775,3	247037127,8	260821023,5	1237423	130305	219176151,6
2037	236205353,4	247037127,8	260821023,5	1237423	130305	221053729,7
2038	237953239,4	247037127,8	260821023,5	1237423	130305	222801615,7
2039	239581110	247037127,8	260821023,5	1237423	130305	224429486,3

	53% fukt					
Scenario 3 utan tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	214670191,4	234738921,2	1237423	130305	-21436457,8
2016	49401235,26	214670191,4	234738921,2	1237423	130305	27964777,5
2017	84431176,59	214670191,4	234738921,2	1237423	130305	62994718,83
2018	109698265,2	214670191,4	234738921,2	1237423	130305	88261807,42
2019	128300385,6	214670191,4	234738921,2	1237423	130305	106863927,9
2020	142322274,3	214670191,4	234738921,2	1237423	130305	120885816,6
2021	153168982,3	214670191,4	234738921,2	1237423	130305	131732524,5
2022	161789439,3	214670191,4	234738921,2	1237423	130305	140352981,6
2023	168826348,2	214670191,4	234738921,2	1237423	130305	147389890,5
2024	174716694,5	214670191,4	234738921,2	1237423	130305	153280236,8
2025	179759150,2	214670191,4	234738921,2	1237423	130305	158322692,4
2026	184159284	214670191,4	234738921,2	1237423	130305	162722826,2
2027	188059893,2	214670191,4	234738921,2	1237423	130305	166623435,4
2028	191561360,1	214670191,4	234738921,2	1237423	130305	170124902,3
2029	194735320	214670191,4	234738921,2	1237423	130305	173298862,2
2030	197633844,8	214670191,4	234738921,2	1237423	130305	176197387
2031	200295618,6	214670191,4	234738921,2	1237423	130305	178859160,8
2032	202750095,7	214670191,4	234738921,2	1237423	130305	181313638
2033	205020305,7	214670191,4	234738921,2	1237423	130305	183583847,9
2034	207124748,8	214670191,4	234738921,2	1237423	130305	185688291
2035	209078682,6	214670191,4	234738921,2	1237423	130305	187642224,9
2036	210894997,7	214670191,4	234738921,2	1237423	130305	189458540
2037	212584818,1	214670191,4	234738921,2	1237423	130305	191148360,3
2038	214157915,5	214670191,4	234738921,2	1237423	130305	192721457,7
2039	215622999	214670191,4	234738921,2	1237423	130305	194186541,3

	58% fukt					
Scenario 3 utan tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	182318521,1	208656818,8	1237423	130305	-27706025,7
2016	43912209,12	182318521,1	208656818,8	1237423	130305	16206183,43
2017	75049934,75	182318521,1	208656818,8	1237423	130305	47343909,05
2018	97509569,05	182318521,1	208656818,8	1237423	130305	69803543,35
2019	114044787,2	182318521,1	208656818,8	1237423	130305	86338761,53
2020	126508688,3	182318521,1	208656818,8	1237423	130305	98802662,6
2021	136150206,5	182318521,1	208656818,8	1237423	130305	108444180,8
2022	143812834,9	182318521,1	208656818,8	1237423	130305	116106809,3
2023	150067865,1	182318521,1	208656818,8	1237423	130305	122361839,4
2024	155303728,5	182318521,1	208656818,8	1237423	130305	127597702,8
2025	159785911,3	182318521,1	208656818,8	1237423	130305	132079885,6
2026	163697141,3	182318521,1	208656818,8	1237423	130305	135991115,6
2027	167164349,5	182318521,1	208656818,8	1237423	130305	139458323,8
2028	170276764,5	182318521,1	208656818,8	1237423	130305	142570738,8
2029	173098062,2	182318521,1	208656818,8	1237423	130305	145392036,5
2030	175674528,7	182318521,1	208656818,8	1237423	130305	147968503
2031	178040549,9	182318521,1	208656818,8	1237423	130305	150334524,2
2032	180222307,3	182318521,1	208656818,8	1237423	130305	152516281,6
2033	182240271,7	182318521,1	208656818,8	1237423	130305	154534246
2034	184110887,8	182318521,1	208656818,8	1237423	130305	156404862,1
2035	185847717,9	182318521,1	208656818,8	1237423	130305	158141692,2
2036	187462220,2	182318521,1	208656818,8	1237423	130305	159756194,5
2037	188964282,7	182318521,1	208656818,8	1237423	130305	161258257
2038	190362591,6	182318521,1	208656818,8	1237423	130305	162656565,9
2039	191664888	182318521,1	208656818,8	1237423	130305	163958862,3

	63% fukt					
Scenario 3 utan tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	149981964,8	182574716,5	1237423	130305	-33960479,6
2016	38423182,98	149981964,8	182574716,5	1237423	130305	4462703,338
2017	65668692,9	149981964,8	182574716,5	1237423	130305	31708213,26
2018	85320872,92	149981964,8	182574716,5	1237423	130305	51360393,27
2019	99789188,83	149981964,8	182574716,5	1237423	130305	65828709,18
2020	110695102,3	149981964,8	182574716,5	1237423	130305	76734622,61
2021	119131430,7	149981964,8	182574716,5	1237423	130305	85170951,03
2022	125836230,6	149981964,8	182574716,5	1237423	130305	91875750,93
2023	131309382	149981964,8	182574716,5	1237423	130305	97348902,31
2024	135890762,4	149981964,8	182574716,5	1237423	130305	101930282,8
2025	139812672,4	149981964,8	182574716,5	1237423	130305	105852192,7
2026	143234998,6	149981964,8	182574716,5	1237423	130305	109274519
2027	146268805,8	149981964,8	182574716,5	1237423	130305	112308326,2
2028	148992168,9	149981964,8	182574716,5	1237423	130305	115031689,3
2029	151460804,4	149981964,8	182574716,5	1237423	130305	117500324,8
2030	153715212,6	149981964,8	182574716,5	1237423	130305	119754733
2031	155785481,1	149981964,8	182574716,5	1237423	130305	121825001,5
2032	157694518,9	149981964,8	182574716,5	1237423	130305	123734039,3
2033	159460237,7	149981964,8	182574716,5	1237423	130305	125499758,1
2034	161097026,8	149981964,8	182574716,5	1237423	130305	127136547,2
2035	162616753,1	149981964,8	182574716,5	1237423	130305	128656273,5
2036	164029442,7	149981964,8	182574716,5	1237423	130305	130068963
2037	165343747,4	149981964,8	182574716,5	1237423	130305	131383267,7
2038	166567267,6	149981964,8	182574716,5	1237423	130305	132606788
2039	167706777	149981964,8	182574716,5	1237423	130305	133746297,4

Scenario 3 System inc + dryer

	48% fukt					
Scenario 3 med tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	255253666,3	260821023,5	1237423	130305	-6935085,27
2016	54890261,41	255253666,3	260821023,5	1237423	130305	47955176,13
2017	93812418,44	255253666,3	260821023,5	1237423	130305	86877333,16
2018	121886961,3	255253666,3	260821023,5	1237423	130305	114951876
2019	142555984	255253666,3	260821023,5	1237423	130305	135620898,8
2020	158135860,4	255253666,3	260821023,5	1237423	130305	151200775,1
2021	170187758,1	255253666,3	260821023,5	1237423	130305	163252672,8
2022	179766043,7	255253666,3	260821023,5	1237423	130305	172830958,4
2023	187584831,4	255253666,3	260821023,5	1237423	130305	180649746,1
2024	194129660,6	255253666,3	260821023,5	1237423	130305	187194575,3
2025	199732389,1	255253666,3	260821023,5	1237423	130305	192797303,8
2026	204621426,6	255253666,3	260821023,5	1237423	130305	197686341,4
2027	208955436,9	255253666,3	260821023,5	1237423	130305	202020351,6
2028	212845955,6	255253666,3	260821023,5	1237423	130305	205910870,4
2029	216372577,8	255253666,3	260821023,5	1237423	130305	209437492,5
2030	219593160,9	255253666,3	260821023,5	1237423	130305	212658075,6
2031	222550687,3	255253666,3	260821023,5	1237423	130305	215615602,1
2032	225277884,2	255253666,3	260821023,5	1237423	130305	218342798,9
2033	227800339,6	255253666,3	260821023,5	1237423	130305	220865254,4
2034	230138609,8	255253666,3	260821023,5	1237423	130305	223203524,5
2035	232309647,4	255253666,3	260821023,5	1237423	130305	225374562,1
2036	234327775,3	255253666,3	260821023,5	1237423	130305	227392690
2037	236205353,4	255253666,3	260821023,5	1237423	130305	229270268,1
2038	237953239,4	255253666,3	260821023,5	1237423	130305	231018154,2
2039	239581110	255253666,3	260821023,5	1237423	130305	232646024,7

	53% fukt					
Scenario 3 med tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	228433327,1	234738921,2	1237423	130305	-7673322,04
2016	49401235,26	228433327,1	234738921,2	1237423	130305	41727913,22
2017	84431176,59	228433327,1	234738921,2	1237423	130305	76757854,55
2018	109698265,2	228433327,1	234738921,2	1237423	130305	102024943,1
2019	128300385,6	228433327,1	234738921,2	1237423	130305	120627063,6
2020	142322274,3	228433327,1	234738921,2	1237423	130305	134648952,3
2021	153168982,3	228433327,1	234738921,2	1237423	130305	145495660,3
2022	161789439,3	228433327,1	234738921,2	1237423	130305	154116117,3
2023	168826348,2	228433327,1	234738921,2	1237423	130305	161153026,2
2024	174716694,5	228433327,1	234738921,2	1237423	130305	167043372,5
2025	179759150,2	228433327,1	234738921,2	1237423	130305	172085828,1
2026	184159284	228433327,1	234738921,2	1237423	130305	176485961,9
2027	188059893,2	228433327,1	234738921,2	1237423	130305	180386571,1
2028	191561360,1	228433327,1	234738921,2	1237423	130305	183888038
2029	194735320	228433327,1	234738921,2	1237423	130305	187061997,9
2030	197633844,8	228433327,1	234738921,2	1237423	130305	189960522,8
2031	200295618,6	228433327,1	234738921,2	1237423	130305	192622296,6
2032	202750095,7	228433327,1	234738921,2	1237423	130305	195076773,7
2033	205020305,7	228433327,1	234738921,2	1237423	130305	197346983,6
2034	207124748,8	228433327,1	234738921,2	1237423	130305	199451426,7
2035	209078682,6	228433327,1	234738921,2	1237423	130305	201405360,6
2036	210894997,7	228433327,1	234738921,2	1237423	130305	203221675,7
2037	212584818,1	228433327,1	234738921,2	1237423	130305	204911496
2038	214157915,5	228433327,1	234738921,2	1237423	130305	206484593,5
2039	215622999	228433327,1	234738921,2	1237423	130305	207949677

	58% fukt					
Scenario 3 med tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	201612988	208656818,8	1237423	130305	-8411558,81
2016	43912209,12	201612988	208656818,8	1237423	130305	35500650,31
2017	75049934,75	201612988	208656818,8	1237423	130305	66638375,94
2018	97509569,05	201612988	208656818,8	1237423	130305	89098010,24
2019	114044787,2	201612988	208656818,8	1237423	130305	105633228,4
2020	126508688,3	201612988	208656818,8	1237423	130305	118097129,5
2021	136150206,5	201612988	208656818,8	1237423	130305	127738647,7
2022	143812834,9	201612988	208656818,8	1237423	130305	135401276,1
2023	150067865,1	201612988	208656818,8	1237423	130305	141656306,3
2024	155303728,5	201612988	208656818,8	1237423	130305	146892169,7
2025	159785911,3	201612988	208656818,8	1237423	130305	151374352,5
2026	163697141,3	201612988	208656818,8	1237423	130305	155285582,5
2027	167164349,5	201612988	208656818,8	1237423	130305	158752790,7
2028	170276764,5	201612988	208656818,8	1237423	130305	161865205,7
2029	173098062,2	201612988	208656818,8	1237423	130305	164686503,4
2030	175674528,7	201612988	208656818,8	1237423	130305	167262969,9
2031	178040549,9	201612988	208656818,8	1237423	130305	169628991
2032	180222307,3	201612988	208656818,8	1237423	130305	171810748,5
2033	182240271,7	201612988	208656818,8	1237423	130305	173828712,9
2034	184110887,8	201612988	208656818,8	1237423	130305	175699329
2035	185847717,9	201612988	208656818,8	1237423	130305	177436159,1
2036	187462220,2	201612988	208656818,8	1237423	130305	179050661,4
2037	188964282,7	201612988	208656818,8	1237423	130305	180552723,9
2038	190362591,6	201612988	208656818,8	1237423	130305	181951032,7
2039	191664888	201612988	208656818,8	1237423	130305	183253329,2

	63% fukt					
Scenario 3 med tork	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste ha	CO2 net
2015	0	174792648,9	182574716,5	1237423	130305	-9149795,58
2016	38423182,98	174792648,9	182574716,5	1237423	130305	29273387,4
2017	65668692,9	174792648,9	182574716,5	1237423	130305	56518897,33
2018	85320872,92	174792648,9	182574716,5	1237423	130305	76171077,34
2019	99789188,83	174792648,9	182574716,5	1237423	130305	90639393,25
2020	110695102,3	174792648,9	182574716,5	1237423	130305	101545306,7
2021	119131430,7	174792648,9	182574716,5	1237423	130305	109981635,1
2022	125836230,6	174792648,9	182574716,5	1237423	130305	116686435
2023	131309382	174792648,9	182574716,5	1237423	130305	122159586,4
2024	135890762,4	174792648,9	182574716,5	1237423	130305	126740966,8
2025	139812672,4	174792648,9	182574716,5	1237423	130305	130662876,8
2026	143234998,6	174792648,9	182574716,5	1237423	130305	134085203,1
2027	146268805,8	174792648,9	182574716,5	1237423	130305	137119010,2
2028	148992168,9	174792648,9	182574716,5	1237423	130305	139842373,4
2029	151460804,4	174792648,9	182574716,5	1237423	130305	142311008,9
2030	153715212,6	174792648,9	182574716,5	1237423	130305	144565417,1
2031	155785481,1	174792648,9	182574716,5	1237423	130305	146635685,5
2032	157694518,9	174792648,9	182574716,5	1237423	130305	148544723,3
2033	159460237,7	174792648,9	182574716,5	1237423	130305	150310442,2
2034	161097026,8	174792648,9	182574716,5	1237423	130305	151947231,3
2035	162616753,1	174792648,9	182574716,5	1237423	130305	153466957,6
2036	164029442,7	174792648,9	182574716,5	1237423	130305	154879647,1
2037	165343747,4	174792648,9	182574716,5	1237423	130305	156193951,8
2038	166567267,6	174792648,9	182574716,5	1237423	130305	157417472
2039	167706777	174792648,9	182574716,5	1237423	130305	158556981,4

Scenario 3 System inc + bio

	48% fukt					
Scenario 3 med bio	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste handling	
2015	0	297497945,8	260790290,5	1237423	130305	35339927,29
2016	29146695,29	297497945,8	260790290,5	1237423	130305	64486622,58
2017	49814336,91	297497945,8	260790290,5	1237423	130305	85154264,2
2018	64721902,04	297497945,8	260790290,5	1237423	130305	100061829,3
2019	75697140,49	297497945,8	260790290,5	1237423	130305	111037067,8
2020	83970045,31	297497945,8	260790290,5	1237423	130305	119309972,6
2021	90369595,65	297497945,8	260790290,5	1237423	130305	125709522,9
2022	95455659,44	297497945,8	260790290,5	1237423	130305	130795586,7
2023	99607430,93	297497945,8	260790290,5	1237423	130305	134947358,2
2024	103082731,2	297497945,8	260790290,5	1237423	130305	138422658,5
2025	106057776,7	297497945,8	260790290,5	1237423	130305	141397703,9
2026	108653852,6	297497945,8	260790290,5	1237423	130305	143993779,9
2027	110955209,4	297497945,8	260790290,5	1237423	130305	146295136,7
2028	113021072,5	297497945,8	260790290,5	1237423	130305	148360999,8
2029	114893706,7	297497945,8	260790290,5	1237423	130305	150233634
2030	116603834,4	297497945,8	260790290,5	1237423	130305	151943761,7
2031	118174279,1	297497945,8	260790290,5	1237423	130305	153514206,4
2032	119622419	297497945,8	260790290,5	1237423	130305	154962346,2
2033	120961841,3	297497945,8	260790290,5	1237423	130305	156301768,6
2034	122203461,3	297497945,8	260790290,5	1237423	130305	157543388,6
2035	123356280,9	297497945,8	260790290,5	1237423	130305	158696208,2
2036	124427905,6	297497945,8	260790290,5	1237423	130305	159767832,9
2037	125424898,5	297497945,8	260790290,5	1237423	130305	160764825,7
2038	126353024,9	297497945,8	260790290,5	1237423	130305	161692952,2
2039	127217423,1	297497945,8	260790290,5	1237423	130305	162557350,4

	53% fukt					
Scenario 3 med bio	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste handling	
2015	0	263052477,6	234711261,5	1237423	130305	26973488,14
2016	26232025,76	263052477,6	234711261,5	1237423	130305	53205513,9
2017	44832903,22	263052477,6	234711261,5	1237423	130305	71806391,36
2018	58249711,84	263052477,6	234711261,5	1237423	130305	85223199,98
2019	68127426,44	263052477,6	234711261,5	1237423	130305	95100914,58
2020	75573040,78	263052477,6	234711261,5	1237423	130305	102546528,9
2021	81332636,09	263052477,6	234711261,5	1237423	130305	108306124,2
2022	85910093,5	263052477,6	234711261,5	1237423	130305	112883581,6
2023	89646687,84	263052477,6	234711261,5	1237423	130305	116620176
2024	92774458,12	263052477,6	234711261,5	1237423	130305	119747946,3
2025	95451998,99	263052477,6	234711261,5	1237423	130305	122425487,1
2026	97788467,35	263052477,6	234711261,5	1237423	130305	124761955,5
2027	99859688,47	263052477,6	234711261,5	1237423	130305	126833176,6
2028	101718965,2	263052477,6	234711261,5	1237423	130305	128692453,4
2029	103404336	263052477,6	234711261,5	1237423	130305	130377824,2
2030	104943450,9	263052477,6	234711261,5	1237423	130305	131916939,1
2031	106356851,2	263052477,6	234711261,5	1237423	130305	133330339,3
2032	107660177,1	263052477,6	234711261,5	1237423	130305	134633665,2
2033	108865657,1	263052477,6	234711261,5	1237423	130305	135839145,3
2034	109983115,2	263052477,6	234711261,5	1237423	130305	136956603,3
2035	111020652,8	263052477,6	234711261,5	1237423	130305	137994141
2036	111985115	263052477,6	234711261,5	1237423	130305	138958603,2
2037	112882408,6	263052477,6	234711261,5	1237423	130305	139855896,7
2038	113717722,4	263052477,6	234711261,5	1237423	130305	140691210,5
2039	114495680,8	263052477,6	234711261,5	1237423	130305	141469169

	58% fukt					
Scenario 3 med bio	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste handling	
2015	0	228629527,5	208632232,4	1237423	130305	18629567,08
2016	23317356,24	228629527,5	208632232,4	1237423	130305	41946923,32
2017	39851469,53	228629527,5	208632232,4	1237423	130305	58481036,61
2018	51777521,63	228629527,5	208632232,4	1237423	130305	70407088,71
2019	60557712,39	228629527,5	208632232,4	1237423	130305	79187279,47
2020	67176036,25	228629527,5	208632232,4	1237423	130305	85805603,33
2021	72295676,52	228629527,5	208632232,4	1237423	130305	90925243,6
2022	76364527,56	228629527,5	208632232,4	1237423	130305	94994094,64
2023	79685944,74	228629527,5	208632232,4	1237423	130305	98315511,82
2024	82466185	228629527,5	208632232,4	1237423	130305	101095752,1
2025	84846221,33	228629527,5	208632232,4	1237423	130305	103475788,4
2026	86923082,09	228629527,5	208632232,4	1237423	130305	105552649,2
2027	88764167,52	228629527,5	208632232,4	1237423	130305	107393734,6
2028	90416858	228629527,5	208632232,4	1237423	130305	109046425,1
2029	91914965,35	228629527,5	208632232,4	1237423	130305	110544532,4
2030	93283067,5	228629527,5	208632232,4	1237423	130305	111912634,6
2031	94539423,28	228629527,5	208632232,4	1237423	130305	113168990,4
2032	95697935,16	228629527,5	208632232,4	1237423	130305	114327502,2
2033	96769473,01	228629527,5	208632232,4	1237423	130305	115399040,1
2034	97762769,02	228629527,5	208632232,4	1237423	130305	116392336,1
2035	98685024,73	228629527,5	208632232,4	1237423	130305	117314591,8
2036	99542324,48	228629527,5	208632232,4	1237423	130305	118171891,6
2037	100339918,8	228629527,5	208632232,4	1237423	130305	118969485,8
2038	101082419,9	228629527,5	208632232,4	1237423	130305	119711987
2039	101773938,5	228629527,5	208632232,4	1237423	130305	120403505,6

	63% fukt					
Scenario 3 med bio	CO2 landfill	CO 2 diesel	CO2 wte	CO2 transport	CO2 waste handling	
2015	0	194228729	182553203,4	1237423	130305	10307797,59
2016	20402686,71	194228729	182553203,4	1237423	130305	30710484,3
2017	34870035,84	194228729	182553203,4	1237423	130305	45177833,43
2018	45305331,43	194228729	182553203,4	1237423	130305	55613129,02
2019	52987998,34	194228729	182553203,4	1237423	130305	63295795,93
2020	58779031,72	194228729	182553203,4	1237423	130305	69086829,31
2021	63258716,96	194228729	182553203,4	1237423	130305	73566514,55
2022	66818961,61	194228729	182553203,4	1237423	130305	77126759,2
2023	69725201,65	194228729	182553203,4	1237423	130305	80032999,24
2024	72157911,87	194228729	182553203,4	1237423	130305	82465709,46
2025	74240443,66	194228729	182553203,4	1237423	130305	84548241,25
2026	76057696,83	194228729	182553203,4	1237423	130305	86365494,42
2027	77668646,58	194228729	182553203,4	1237423	130305	87976444,18
2028	79114750,75	194228729	182553203,4	1237423	130305	89422548,34
2029	80425594,68	194228729	182553203,4	1237423	130305	90733392,28
2030	81622684,06	194228729	182553203,4	1237423	130305	91930481,65
2031	82721995,37	194228729	182553203,4	1237423	130305	93029792,96
2032	83735693,27	194228729	182553203,4	1237423	130305	94043490,86
2033	84673288,88	194228729	182553203,4	1237423	130305	94981086,48
2034	85542422,9	194228729	182553203,4	1237423	130305	95850220,49
2035	86349396,64	194228729	182553203,4	1237423	130305	96657194,23
2036	87099533,92	194228729	182553203,4	1237423	130305	97407331,51
2037	87797428,92	194228729	182553203,4	1237423	130305	98105226,51
2038	88447117,41	194228729	182553203,4	1237423	130305	98754915
2039	89052196,2	194228729	182553203,4	1237423	130305	99359993,8

Appendix J - Extended results waste handling cost

To be able to use the waste as energy in the proposed plant, it has to be collected first. Many of the districts in scenario 2 and 3 do not have a system for waste collection. The results in this section show estimations of waste handling costs in Kutai Kartanegara regency. The results will be presented according to the different scenarios described in section 4.1.

Scenario 1

The cost for waste handling in Tenggarong is presented in, this is the amount that the local government pays for personal and fuel in the local waste management system.

Table J-1 Estimation of waste handling cost for Scenario 1

Scenario 1	Waste collection [ton/day]	Cost waste handling [sek/day]	[IDR/day]
Tenggarong	41,5	1415,98	231434,0582

Scenario 2

In scenario 2, all the districts within a radius of 30km from Tenggarong are included. The results are based on the cost for waste handling in Tenggarong. Most of these districts do not yet have a system for waste handling. Instead they sell and recycle what is useful and the rest, a large fraction of the waste ends up either in the forest, in the river or is burned in open fires. An estimation of how much the local governments would have to pay to collect the waste in these districts shown in Table J-2.

Table J-2 Estimation of waste handling costs for scenario 2

Scenario 2	Waste collection [ton/day]	Cost waste handling [sek/day]	[IDR/day]
Tenggarong	41,5	1415,98	231434,0582
Samarinda	466	15899,92	2598753,52
Sebulu	15,15	516,918	84487,37304
Tenggarong sebarang	25,94	885,0728	144660,2282
Loa Kulu	17,36	592,3232	96811,93372
Loa Janan	26,65	909,298	148619,7024
Sum:	592,6	20219,512	3304766,816

Scenario 3

In scenario 3 Balikpapan and Kota Bontang already have a functional waste management system and the collected waste is put on landfill. However the rest of the districts do not, as in scenario 2 Table J-3 shows an estimation of the cost for waste collection in the districts.

Table J-3 Estimated waste handling cost for the add-ons in Scenario 3

Scenario 3	Cost waste handling [sek/day]
Balikpapan	12453,8
Kota Bontang	2393,518
Marang Kayu (Santan)	344,612

Anggana	474,268
Muara Jawa (Handil)	501,564
Sanga Sanga	262,724
Samboja	791,584
Muara Badak (Saliki)	585,158
Sum:	17807,228

Total

Table J-4 shows the accumulated cost for waste handling in the different scenarios.

Table J-4 Estimated cost for waste handling in the different scenarios

Waste handling	Cost [sek/day]	Cost [IDR/day]
Scenario 1	1,416	2,237,280
Scenario 2	20,220	31,947,600
Scenario 3	38,027	60,082,660

Appendix K - Extended result waste transport

The location for the considered plant has been chosen as Tenggarong, when the waste have been collected in the different subdistricts described in section 5.2 it has to be transported to the location of the plant before it could be used for energy production.

The transport modes considered have been car or by barge on the Mahakam river. Only the cheapest route and mode of transport will be presented in this section.

Scenario 1

In the first scenario there is no transportation of waste from other subdistricts than Tengarrong, thus only the waste handling costs will be considered in that case.

Scenario 2

Most of the districts considered in Scenario 2 are situated along the Mahakam River. As transport with river barge is less expensive and more environmental friendly considering emissions, transport by boat has been considered first hand. The only legs of transport put on road are from Loa Kulu and Loa Janan. Table K-1 shows the distances to Tenggarong from the different subdistricts. The costs for the chosen mode of transport are presented in Table K-2 and Table K-3.

Table K-1 Distance to Tenggarong from the different subdistricts in Scenario 2

Scenario 2	Distance road [km]	Distance river [km]
Tenggarong	0	0
Samarinda	25	44
Sebulu	89	34
Tenggarong sebarang (Sepali)	75,6	12
Loa Kulu	55	0
Loa Janan	42	0
Sum:	234	112

Table K-2 Estimated cost for river transport

Scenario 2	Cost boat [sek/day]	Reload cost boat [sek/day]
Samarinda	2163,172	30923,76
Sebulu	54,34305	1005,354
Tenggarong sebarang (Separi)	32,84004	1721,3784
Sum:	2250,35509	33650,4924

Table K-3 Estimation of driver capacity needed

Scenario 2	Amount of trips	Return trip [min]	Amount drivers
Loa Kulu	8,346153846	215,6	4
Loa Janan	12,8125	164,64	5
Sum:	21,158	380,24	9

Table K-4 Estimated cost for fuel and driver salary

Scenario 2	Cost fuel car [Sek/day]	Salary [Sek/day]

Loa Kulu	697,9085356	237,0087863
Loa Janan	818,1493757	296,2609829
Sum:	1516,057911	533,2697692

Table K-5 Estimated total cost for transport

Scenario 2	River [sek/day]	Road [sek/day]	Total [sek/day]
Sum:	35900,84	2049,32768	37950,1733

Scenario 3

In scenario 3 all of the districts considered are available for barge transport, thus no road transport is considered. The distances to Tenggarong by boat or car are presented in Table K-6 and the estimated costs are presented in Table K-7.

Table K-6 Distances to Tenggarong from the different subdistricts in Scenario 3

Scenario 3	Distance road [km]	Distance boat [km]
Balikpapan	145	171
Kota Bontang	129	163
Marang Kayu (Santan)	114	144
Anggana	0	74
Muara Jawa (Handil)	147	82
Sanga Sanga	72,2	75
Samboja	97	123
Muara Badak (Saliki)	79,5	96,5
Sum:	783,7	928,5

Table K-7 Estimated transport costs for boat transport in the add-ons for scenario 3

Scenario 3	Cost boat [sek/day]	Reload cost boat [sek/day]
Balikpapan	6584,7825	24221,4
Kota Bontang	1206,334475	4655,154
Marang Kayu (Santan)	153,4392	670,236
Anggana	108,5173	922,404
Muara Jawa (Handil)	127,1697	975,492
Sanga Sanga	60,92625	510,972
Samboja	301,0548	1539,552
Muara Badak (Saliki)	174,5998625	1138,074
Sum:	8716,824088	34633,284
Scenario 3	Cost	
Total	43350,10809	

Total

Table K-8 shows the total cost for transport of MSW in the different scenarios.

Table K-8 Estimated cost for waste transportation in the different Scenarios

Transport	Cost [sek/day]
Scenario 1	0
Scenario 2	58203,37098
Scenario 3	101553,4791

Appendix L - Extended results for GHG emissions from waste handling and transportation

The GHG emissions emitted from transporting and collecting the waste in Tenggarong and the different sub districts in Scenario 2 and 3 is presented in this section. The only emission considered is CO_2 from fuel to the cars or river barge. The calculated results are based on interviews in Tenggarong and literature data from CEFIC (The Europeean Chemical Industry Council, 2011).

Scenario 1

In scenario 1 there are no additional waste transportations, hence only the emissions from waste handling will be shown. shows the estimated emissions from waste handling in Tenggarong.

Table K-1 Estimated emissions from waste handling in Scenario 1

Scenario 1	Diesel waste handling [l/day]	CO2 emission [kg/day]
Tenggarong	35,71428571	94,28571429

Scenario 2

The emissions and diesel usage from waste handling and transportation in Scenario 2 are presented in and .

Table K-2 Estimated emissions from waste transportation Scenario 2

Emissions from transport	Boat [kg CO2/day]	Car [kg CO2/day]	Tot: [kg/day]
CO2 emissions:	592,410986	870,624216	1463,035202

Table K-3 CO_2 emissions from waste handling Scenario 2

Scenario 2	Diesel waste handling [l/day]	CO2 emission [kg/day]
Tenggarong	35,71428571	94,28571429
Samarinda	401,0327022	1058,726334
Sebulu	13,03786575	34,41996558
Tenggarong sebarang	22,32358003	58,93425129
Loa Kulu	14,93975904	39,44096386
Loa Janan	22,93459552	60,54733219
Sum:	509,9827883	1346,354561

Scenario 3

The emissions and dieselusage from wastehandling and transportation in Scenario 3 are presented in and .

Table K-4 Estimated CO2 emissions from waste handling Scenario 3

Scenario 3	Fuel waste handling [l/day]	CO2 emissions waste handling
Balikpapan	314,1135972	829,2598967
Kota Bontang	60,37005164	159,3769363
Marang Kayu (Santan)	8,691910499	22,94664372
Anggana	11,96213425	31,58003442

Muara Jawa (Handil)	12,65060241	33,39759036
Sanga Sanga	6,626506024	17,4939759
Samboja	19,96557659	52,7091222
Muara Badak (Saliki)	14,75903614	38,96385542
Sum:	449,1394148	1185,728055

Table K-5 Estimated emissions from transport Scenario 3

Scenario 3	Boat Upstream [kg CO2/day]	Boat Sea [kg CO2/day]	Total [kg CO2/day]
CO2 emissions:	1392,403158	581,54976	1973,952918

Total

The total emissions from waste handling and transportation in the different scenarios are presented in .

Table K-6 Estimated emissions in the different Scenarios

Emissions	Waste handling [kg CO2/day]	Transport [kg CO2/day]
Scenario 1	94,28571429	0
Scenario 2	1346,354561	1463,035202
Scenario 3	2532,082616	3436,98812
Total:	5969,070736	

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