Producing energy from cardboard factory waste

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Finding sustainable solutions for handling non-recyclable waste
Responsibility

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Producing energy from cardboard factory waste
Prolusion

This master thesis has been written within the framework of the final year of my study at the Center for Energy and Environmental Studies (IVEM) at the University of Groningen (IVEM). The thesis has been written at Tauw bv in Assen under the supervision of Jacob Klaas Star in combination with the supervision of Anne Jelle Schilstra and Henk Moll of the IVEM.

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Thijs Dijkstra
Assen, July 2008
Producing energy from cardboard factory waste
Summary

Eska Graphic Board is a cardboard factory which requires large amounts of energy in the form of heat for the production of graphical cardboard. Currently, Eska has on-site gas powered boilers to produce heat and a combined-heat-and-power (CHP) system to produce a combination of heat and electricity.

To make these installations more sustainable, a plan was made to use the waste of the factory left over from recycled paper, to be used in producing energy. This waste consists mainly of plastics and non-recyclable organic matter and is known as ‘rejects’. These rejects can be used as a fuel source for several power plants.

Using rejects as a fuel can be the best sustainable option in handling this type of waste. When following the “ladder of Lansink” (SenterNovem, 2008a); rejects can not practically be reduced or prevented directly because this depends on the resource. Also, rejects can not be reused or recycled, because of the ever changing composition. The best option would then be in using rejects as fuel to produce energy, otherwise the energy contained in the rejects would be lost.

Using reject as a fuel source to fulfill Eska’s energy needs can change a gas to energy power plant into a waste to energy power plant. As a result, there will be reduced dependency on natural gas as fuel source.

There are several options in using rejects to produce energy; these are on-site and export options. Tauw bv is called upon to investigate the benefits and/or the drawbacks of this major change and to investigate which option is the most suitable in producing energy while using rejects as a fuel source.

The main aim of this research is to analyze several solutions in handling the waste of the cardboard factory and to determine the most sustainable option. The cost or profit (environmental, financial), will be determined by handling the cardboard factory’s ‘reject’ waste in different scenarios over time.

Of the option of on-site on-site energy production using rejects as fuel; an on-site boiler produces the lowest amounts of CO₂ per produced GJ due to its high efficiency. The second best option is the on-site CHP-system. A gasification installation produces the highest amount of CO₂ compared to the other two options, but the difference in emission between all of these options is minimal.
When using the annual amount of rejects for export purposes only, the best option would be sending the rejects to an off-site gasification installation, which has the lowest CO₂ emission per produced energy compared to all other available export options. The cement factory is the second best option, but the CO₂ production per GJ compared to the off-site gasification installation is almost twice as high. The option of sending rejects to a Municipal Solid Waste Incinerator is the least favorable option compared to the others.

When using natural gas to produce energy; the level of CO₂ per GJ when compared to all of the on-site options are much lower than when using rejects as a fuel source. However, the available export option produces more CO₂ per GJ compared to the on-site boiler. The best option will be using rejects on-site. This will prevent higher emissions of CO₂ when using rejects as fuel and reduces the need for natural gas.

Using rejects to produce a maximum output of around 11MW for all of the installations, the amount of emitted CO₂ is about equal for all of the installations. The effect of exporting remaining rejects does not have a significant effect on the overall CO₂ emission. When increasing the maximum output for all of the installations, the option of importing rejects becomes necessary. The CHP-system and the gasification installation are almost equal in the production of CO₂ but the least amount of CO₂ is produced by the boiler, which is around 10% lower than the other options.

When including the prevention of CO₂ by selling the electricity to the local grid, the emission of CO₂ by the CHP-system and the gasification installation will decrease. The gasification installation will in this case be responsible for the amount of CO₂ which is almost equal to the emission of boiler. The CHP-system however will responsible for the least amount of CO₂ compared to the other options. On a local scale, the boiler would be the best choice when looking at the emission of CO₂. But when looking on a larger regional scale, the CHP-system will be responsible for lower CO₂ emissions.

The financial payback time of all given options are between 3 and 3.5 years when using the annual amount of rejects to produce energy (around 11MW) on-site. The best option will be the CHP-system with the shortest payback time period of all other options.

Using a higher maximum output (around 25MW) when importing rejects will have a significant impact on the payback time period of the boiler and the gasification installation; which becomes higher than 5 years. The CHP-system however, has no large increase of payback time.

From these results we can conclude that the CHP-system is the most cost effective and can prevent more CO₂ emission than the other option on larger scale independent of importing rejects. The boiler and the gasification installation will only be acceptable alternatives when no rejects are imported.
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1 Introduction

Eska Graphic Board is a cardboard factory which requires large amounts of energy in the form of heat for the production of graphical cardboard. Currently, Eska has on-site gas powered boilers to produce heat and a combined-heat-and-power system to produce a combination of heat and electricity.

To make these installations more sustainable, a plan was made to use the waste of the factory left over from recycled paper, to be used in producing energy. This waste consists mainly of plastics and non-recyclable organic matter and is known as ‘rejects’. These rejects can be used as a fuel source for several power plants.

Using rejects as a fuel can be the best sustainable option in handling this type of waste. When following the “ladder of Lansink” (SenterNovem, 2008a); rejects can not practically be reduced or prevented directly because this depends on the resource. Also, rejects can not be reused or recycled, because of the ever changing composition. The best option would then be in using rejects as fuel to produce energy, otherwise the energy contained in the rejects would be lost. Eska is using natural gas as a fuel source to fulfill their energy needs. Using reject as a fuel source can change a gas to energy power plant into a waste to energy power plant. As a result, there will be reduced dependency on natural gas as fuel source.

There are several options in using rejects to produce energy; these are on-site and export options. Tauw bv is called upon to investigate the benefits and/or the drawbacks of this major change and to investigate which option is the most suitable in producing energy while using rejects as a fuel source.

Finally, this research can also be used as promotion material to demonstrate that the energy producing methods of Eska can be made more sustainable when using its own waste as fuel. This could start identical changes throughout the paper/cardboard producing industry, and could eventually pave the way to a more sustainable future when producing paper/cardboard.

Research aim
The main aim of this research is to analyze several solutions in handling the waste of the cardboard factory and to determine the most sustainable option.
The waste in question is the cardboard factory’s ‘rejects’ which consists mainly of plastics, but also contains sand, glass and metals.
Furthermore, the possibility of using this method for converting waste to energy by using this type of waste products for other (cardboard/paper) factories will be analyzed.
Main research question
What will the cost (environmental, financial) be, or profit, for handling the cardboard factory’s ‘reject’ waste in different scenarios over time?
And can these options be used for other (paper) factories?

Sub questions
1. Can the available waste of a cardboard factory be used more efficiently by other companies (currently the situation)? And what will be the cost or profit (environmental, financial) when compared to all other choices?

2. Can the available waste of a cardboard factory provide sufficient energy in a boiler in order to replace the existing natural gas fuel? And what will be the cost or profit (environmental, financial) by such a choice when looking at the direct and indirect costs of using these fuel sources?

3. Can the available waste of a cardboard factory also be sufficient to generate electricity in a Combined-Heat-and-Power (CHP) system to be an acceptable alternative to the electricity grid? And what will be the cost or profit (environmental, financial) by such a choice compared with the currently used electricity from a conventional power plant (grid)?

4. Can the available waste of a cardboard factory be used in a gasification installation to produce fuel gas to be used for other purposes (e.g. fuel source CHP-system)? And what will be the cost or profit (environmental, financial) by such a choice?

5. Can the conversion method (waste to energy) be used for other cardboard/paper factories, or even other types of factories?
2 Methodology

A model will be created to compare the energy balance of the available waste to energy options. The energy balance includes direct and indirect energy of all energy sources. The model will also include a comparison of the costs/profits (environmental, financial) of the available waste to energy options, also including direct and indirect environmental stress (greenhouse gasses) of the energy sources.

To indicate the effects using different waste to energy options, the model will be placed in fixed timeframe (1 to 10 years).

2.1 Boundaries

As a boundary condition for this research, we are going to assume that all installations will be new installations, build for the purpose of handling rejects.

The location in question will be Eska Graphic board; however, the research will not focus solely on Eska. Other relevant companies will be included in the research but will not be studied in detail.

The calorific value of rejects differs over time due to differences in the production process and/or the efficiency of the waste extractor. For this research we are going to assume that the calorific value of rejects remains constant. The only factor what will affect the calorific value for the purpose of this research is the moist content.

The research includes only the given export options: cement industry, waste incinerator, and gasification. These are the most likely options for export of rejects.

Using rejects as fuel to produce energy will produce more emissions than merely CO$_2$. For the sake of this research, only the emission of CO$_2$ will be calculated.

Also a boundary condition for this research is the production of indirect CO$_2$. The sources of indirect CO$_2$ emission are for this research are based only upon transport and pretreatment of rejects.

The payback time of the considered installations is based upon the usage and prevention of natural gas when using rejects as fuel. The profits and losses of the entire factory are not included in the calculations.
The use of subsidies and permits could influence the results of the research in a positive or negative manner. Due to uncertainties for the possibility of using certain subsidies and permits, the use of subsidies and permits are not included in the calculations and the results of this research.
3 Companies

3.1 Tauw bv

Tauw is an independent consulting and engineering company in the Netherlands specialized in the design, improvement and management of the natural environment, built-up environment and infrastructure. Tauw is an expert and leading company in the field of environmental consultancy, spatial development, civil engineering and the monitoring of environmental quality.

In the year 1928 the Technical Consultancy of the Union of Water Boards (Technische Adviesbureau van de Unie van Waterschapsbonden) was established in the city of Haarlem in the Netherlands. Today, the name for the consultancy is simply ‘Tauw’. The headquarters of Tauw is now located in Deventer, but today Tauw has branches all over the Europe.

3.2 Eska Graphic Board

Eska Graphic Board (Eska) is a specialized cardboard factory located in the Netherlands in the cities of Hoogezaand and Sappemeer. In the year 2006 Eska became independent of their mother company; Kappa Packaging and became Eska Graphic Board, named after the products they produce. Currently Eska is the world market leader in their type of cardboard.

The products of Eska Graphic Board are sold mainly in Europe, but also to the rest of the world. Some of these locations are as far as the US or Singapore.

3.2.1 Energy transition

In the year 2004 a prediction was made by the ‘Koninklijke Vereniging Nederlandse Papier- en Kartonfabrieken’ (VNP) that the price for energy will exceed the price for labor in the year 2006. This prediction was proven to be accurate. Because of this change, the paper/cardboard sector had to adapt. Not so long ago, the paper/cardboard sector maintained a firm attention to optimizing their energy efficiency. Today the attention of this sector changed to also include improving environmental aspects combined with new technologies. This is also known as the energy transition. (Wagenaar T.M.M., 2007)

The overall aim of the energy transition is to attain a sustainable energy supply within 50 years. As a result, the demand for fossil fuels will decline, while the level of comfort will increase. (SenterNovem, 2008c)

The step made by Eska in this direction by using their waste products to generate energy is corresponding with the aim of the energy transition.
4 System analysis of Eska

The first part of analyzing the found data is creating a system analysis of the project. The system design of the situation at Eska is created as a flow diagram.

Figure 1 System analysis of Eska Graphic Board

Figure 1 is a representation of inputs and outputs of Eska. The central area is the factory (both Hoogezand and Sappemeer) of Eska which only displays the demand and the production part. Dark gray areas are the in- and outputs of the factory. The blue (light gray) areas are the option that are energy production and/or waste treatment options considered for further research. One of these options is the transport of rejects to other companies like cement factories or a municipal solid waste incinerator (MSWI) for instance. Another option is using rejects on-site for energy production; in a boiler or a CHP-system for instance. Also the option of using rejects in a local or on-site gasification installation is considered.
4.1 Production process

Waste paper is the main resource for producing graphical cardboard. This paper is collected and is mixed with water to make pulp (98% moist). All the materials that can not be used in the production process are removed. This waste is called ‘rejects’. The cleaned pulp than undergoes a manufacturing process (figure 2) which will transform the pulp into very specific graphical cardboard. The first step is sieving of pulp with the help of a vacuum which compacts the pulp and reduces the water content to around 65%. The product of this process is called ‘Web’. The web is than pressed to reduce the water content to around 50%. The ‘web’ is then dried with the help of steam at a pressure of around 11 to 14 bar. The dry web is finished by pasting a layer of paper on each side. The paper used for this step is also produced by Eska. After this step, the newly produced cardboard is cut and prepared for export.

Figure 2 Eska’s production process of graphical cardboard

Per year Eska produces around 300,000 tons of graphical cardboard which is sold to be converted to a variety of products, like book binders or board games.

(Eska Graphic Board, 2006)
4.2 Rejects

Rejects is a name for all waste that originate from recyclable paper that can’t be used in the production process of Eska’s factories. These rejects consists of all kinds of different plastics, fibers, wood chips, paper fibers, but also different types of metals, stones, sand and glass. These heavier parts of rejects are separated from the main rejects waste flow and can therefore be excluded from the common rejects composition. (Eska Graphic Board, 2007)

The production of rejects (without stones, metals, sand and glass) for location Hoogezand is around 15000 tons per year and location Sappemeer produces around 10000 tons of rejects per year. The total production of rejects for Eska is around 25000 tons per year. (Eska Graphic Board, 2006)

The calorific value of dry (100%) reject is estimated to be around 20GJ per ton of reject (Eska Graphic Board, 2007). When transported from Eska, rejects have a moist content of around 40%. This has an effect on the calorific value of the rejects. According to a report from Ingenia, (2007) the calorific value of wet (±40%) rejects is around 14 GJ per tons of reject.

A simple method in calculating the calorific value of rejects per percentage of moist, the following formula can be used:

\[
HHV_{wet} = HHV_{dry} \cdot \left[ 1 - \left( \frac{w}{100} \right) \right]
\]

Equation 1 Calculation of the calorific value of rejects (Source; Eska Graphic Board, 2008)

The equation is used to calculate the higher calorific value (lower calorific value + evaporation of moist). The equation is based upon the formulas in appendix 1, which are based upon weight fractions of the elements in the rejects (hydrogen, oxygen, carbon, nitrogen and sulfur). Part of the equations in appendix D is based upon measurements.

With help of the formula for the calculation of calorific value for rejects, estimations can be made for rejects with different moist contents.
4.3 Heat and Electricity

The factory at Hoogezand produces its own electricity on-site with means of Combined-Heat-and-Power systems and sells remaining electricity to the local grid.

There are several types of CHP-systems and the most common one is the steam turbine based CHP-system. A steam turbine based CHP-system produces electricity and steam by starting to boil water in a large boiler. The produced steam then continues to the steam turbine which powers a dynamo, thus producing electricity. The exhaust steam of the turbine continues its way to be used for other processes.

Figure 3 displays a schematic overview of a CHP-system using a steam turbine.

![Figure 3 Schematic overview of a steam turbine based CHP-system (Source: www.energik.be)](image)

Another example of a CHP-system is a gas turbine based CHP-system. A gas turbine based CHP-system produces electricity and steam by fueling, in this case natural gas, to a turbine. The turbine is linked to a dynamo which in turn produces electricity. The exhaust gasses of the turbine continue to a water filled boiler which in turn produces steam. The (pressurized) steam continues to the factory for further use.
Figure 4 displays a schematic overview of a CHP-system using a gas turbine.

![Schematic overview of a gas turbine based CHP-system](http://www.eon-uk.com)

Eska has three of the gas turbine based CHP-systems on-site. These three are operating continually for the factory in Hoogezand to produce electricity and steam.

The factory at Sappemeer on the other hand has no CHP-system operational, but it has a large natural gas heated boiler for production of steam. The factory of Sappemeer buys the needed electricity from the local grid.

(Eska Graphic Board, 2007)
4.4 Permits

Eska is located in a dense urban environment. The factory of Hoogezand for instance, is located in the center of the city. The close proximity of residential homes that surrounds the factory has resulted in implementing permits (by the province of Groningen) to minimize disturbances emanating from the factory.

4.4.1 The Province of Groningen

Eska has several environmental permits which are needed to prevent (environmental) disturbances which are issued to them by the Province of Groningen. These permits are also in place to limit the emissions of smell, noise and air emissions. One of these permits is the permit of surface water contamination (Wet Verontreiniging Oppervlakewater). Other permits Eska has are for soil protection and groundwater protection. But the permit that has the most relevance for this research is the permit of emission to the air. The limit on emission of NOx by Eska is the following;

CHP-system: 65 g[NOx]/GJ.
Boiler: 70 mg[NOx]/ Nm$^3$ (±20 g[NOx]/GJ) (Nm$^3$ stands for normal cubic meters of gas measured at 1 atmosphere and 0°C)

(Provincie Groningen, 2002)

4.4.2 IPPC

The permits given by the Province of Groningen are based upon the Integrated Pollution Prevention and Control (also known as the IPPC-directive). The IPPC-directive was created to prevent or minimize emissions to air, water and soil, as well as waste, from industrial and agricultural installations in a community, in achieving a high level of environmental protection for all members of the EU.

The IPPC-directive defines basic obligations to be met by all the industrial installations (new or existing). These obligations cover a list of measures for tackling discharges into water, air and soil. These obligations also cover a list of measures for tackling (industrial) waste, wastage of water, energy and environmental accidents. These obligations serve as the basis for drawing up operating licenses or permits for the installations concerned.

An operating license or permit for an installation by the IPPC is based upon the best available techniques (BAT). The IPPC also issues BREF documents. BREF stands for a BAT reference document. A BREF is an aide to find the best available technique for a specific process. (The Council of the European Union, 1996, RIVM, 2008, SenterNovem, 2008b)
4.5 Subsidies

4.5.1 EIA
The subsidy; Energy Investment Subtraction (energie-investeringsaftrek: EIA) is a method to reduce the investment costs of a new installation. 44% of the investment costs can be subtracted from the overall profit, thus reducing taxes. The overall tax deduction when using this subsidy is around 13%.

The EIA subsidy for biomass can however not be applied to Eska. The subsidy is for an installation that includes residues of a paper/cardboard industry for the production of energy, but the used residues can not contain plastics. Because the residue in question is mainly plastics (rejects), the EIA subsidy can not be applied. (EcoFys, 2006)

4.5.2 SDE
An alternative to the EIA is the subsidy of ‘Stimuli for sustainable production of energy’ (Stimulerings duurzame energieproductie), or simply SDE. This is the successor of the MEP subsidy (Milieukwaliteit Elektriciteitsproductie). The aim of the MEP subsidy was using financial stimulation to increase the environmental quality of energy production in the Netherlands. The MEP subsidy used to focus on the production of electricity (CHP-system) by using alternative fuels.

The SDE subsidy came active early this year, thus no research has been done by Eska on using this type of subsidy because the subsidy currently lacks certain issues relevant for Eska. (Ministerie van Economische Zaken, 2008, EnerQ, 2008, EcoFys, 2006)
4.6 Export of rejects to other companies
Disposing rejects by means of dumping it in a landfill has became illegal in the year 2000. Transporting this waste to be dumped a foreign country’s landfill is also illegal. Thus, other alternatives must be used. Eska, on the other hand, already disposes its reject wastes with help of an external company. This company in particular has contacts in Germany which can use rejects in its production. These contacts vary in all kinds of waste treatments.

4.6.1 Cement production
One of these contacts is a cement factory. And to understand how a cement factory can utilize reject as a fuel source, one should first understand the production process of cement production.

The process of cement production starts at mining the raw materials which is mainly limestone (CaCO$_3$). The limestone is than grinded and than mixed with other materials like; calcium, silicon (sand), aluminum oxides and iron oxides. The produced meal is than preheated to around 950°C to initiate the decomposition of limestone to calcium oxides (CaO) and CO$_2$. Fuel is added to the preheating system to keep the temperature high. The preheated meal continues to the rotary kiln for heating and reaction between the calcium oxides and other materials to form calcium silicates and aluminates at temperatures between 1450 and 1500°C. To maintain this temperature for the required reaction, fuel is added to the kiln. The material produced after this step is called clinker. The produced clinker is than mixed with gypsum, limestone and/or ashes and is grinded to produce final product; cement. The entire process can be seen in figure 5. Figure 5 is a schematic overview of the cement manufacturing process.
There are all kinds of different types of cement. All these types differ in composition and treatments, but the principle of producing cement remains the same.

The cement industry can use all kinds of alternative fuels to be used in a rotary kiln. The most common fuel for a rotary kiln is gas, oil or coal. Alternative fuels for the kiln can be materials like waste oils, plastics, rubber, and even sewage sludge. There are other types of alternative fuels, but these fuel types are the most common alternative fuels for the cement industry. Rejects of a cardboard/paper factory is also perfect as an alternative fuel, because its composition consists mainly out of plastics. The choice for using an alternative fuel in the cement industry is based upon the contents of energy, ash, moisture or volatiles within the alternative fuel. However, the choice of alternative fuel is mainly depending on price and availability. (Kääntee, U, et al., 2004)
4.6.2 MSWI

Another option to use a waste source as rejects is to convert it directly to energy. One of several waste-to-energy methods is incineration of waste with energy recovery.

The principle of generating energy by means of incineration is the capturing of the heat generated during the combustion of the incinerator’s fuel. The heat from the incineration flue gas is then used to heat water in a boiler. The water is turned to steam and the steam powers the turbines to generate electricity.

Using municipal waste in such an incinerator, the incinerator becomes a municipal solid waste incinerator or MSWI for short. An example of such an MSWI can be seen in figure 6.

Figure 6 A modern municipal solid waste incinerator (Source: Werther, J., 2007)

The fuel types of a MSWI are mainly domestic wastes. The use of rejects could easily be added to the waste to produce energy. However, the principle of a MSWI is to reduce waste to ash. The production of energy is actually considered a by-product.

The overall waste to energy efficiency of a common European MSWI is around 22 percent (Eska Graphic Board, 2007, ECN, 2008).
There are eleven operational MSWI’s in the Netherlands. And these three are located all over the country. (ECN, 2008)

4.6.3 Gasification

Currently becoming more popular is the conversion of waste (organics, like biomass but also plastics) to combustible gas. This process is also called gasification. There are all kinds of gasification processes, but these processes are the most commonly used for gasification of plastics similar to rejects;

**Production of Syngas**

Syngas is a mixture of hydrogen ($H_2$) and carbon mono-oxides (CO). One of the methods in producing Syngas from waste (e.g. plastics, biomass, coal, oil) is the Texaco-process. Texaco is experienced with gasification for over 40 years, but using plastics with the Texaco-process to produce Syngas is a relative recent development.
The Texaco process consists of two parts, a liquefaction step and the gasification step. In the liquefaction step the plastic waste is mildly thermally cracked (depolymerization) into synthetic heavy oil and some condensable and non-condensable gas fractions. The non-condensable gases are reused in the liquefaction as fuel (together with natural gas). The added heavy oil is filtered to remove large inorganic particles. The oil and condensed gas are then injected to the gasification unit. The gasification is carried out with oxygen and steam at temperatures between 1200 and 1500ºC.

After a number of cleaning processes, Syngas is produced. The produced Syngas consists of CO and H₂, with some amounts of CH₄, CO₂, H₂O and some inert gases.

A schematic overview of the Texaco-process is shown in figure 7.

As an example to indicate the amount of Syngas that can be produced from plastics; 150 ton's of mixed plastics per day produces roughly 350,000 Nm³ clean synthesis gas.


![Figure 7 The Texaco-process (Source: Tukker, A, et al, 1999)](image-url)
Production of SNG

SNG stands for Synthetic Natural Gas and consists mainly of methane (CH\textsubscript{4}). The production of SNG is not much different from the production of Syngas. The difference is that the production of SNG uses the earlier produced Syngas to be transformed into SNG. This transformation is done by a process called methanation (figure 8).

![Figure 8 The SNG production process](image)

The Syngas will go after the clean-up process to the methanation process. In the gas clean-up phase of the process, impurities (ammonia for example) are reduced in concentration. The cleaned Syngas than undergoes the methanation process. Here the Syngas reacts with CO\textsubscript{2} and CO to form water (H\textsubscript{2}O) and methane (CH\textsubscript{4}). After the conditioning of this newly formed gas mixture, it is conditioned until it has become SNG.

(Mozaffarian, M., Zwart, R.W.R., 2003)
5 Scenarios

In order to choose the most sustainable solution for handling rejects, several scenarios are needed to indicate the impact of the used methods of reject waste management.

5.1 Options
A previous research on Eska’s reject waste management has as result that there are only a few options available for such a goal. Some of these options for the scenarios when handling rejects are the following:

Table 1 The available option for handling rejects

<table>
<thead>
<tr>
<th>n°</th>
<th>Option</th>
<th>Production</th>
<th>location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Boiler</td>
<td>Steam</td>
<td>on-site</td>
</tr>
<tr>
<td>2</td>
<td>CHP-system</td>
<td>Electricity and steam</td>
<td>on-site</td>
</tr>
<tr>
<td>3</td>
<td>Gasification</td>
<td>Electricity and steam</td>
<td>on-site</td>
</tr>
<tr>
<td>4</td>
<td>Gasification</td>
<td>Electricity and steam</td>
<td>export</td>
</tr>
<tr>
<td>5</td>
<td>Cement industry</td>
<td>Cement</td>
<td>export</td>
</tr>
<tr>
<td>6</td>
<td>MSWI</td>
<td>Electricity</td>
<td>export</td>
</tr>
</tbody>
</table>

For this research, these six options are used for handling rejects.
The first three are methods to use rejects on-site (Eska).
The other three are the options when the reject is transported to other companies.

The scenarios that follow will be divided into two parts concerning the use of rejects; The first part will be a theoretical use of all produced rejects on-site. These scenarios will be used to show a clear comparison between the given options. The second part will be a more realistic scenario on handling rejects. This scenario will be limited at the maximum reject on-site consumption per option and a combination of these options will also be used.
5.2 Scenario outline

When all options within the given boundaries are combined, the following scenarios are created. Table 2 is an outline of the scenarios:

Table 2 100% reject use scenarios and the realistic reject use scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>on-site</th>
<th>export</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>boiler</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>CHP</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>gasifcation</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>gasification</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>Cement</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td>MSWI</td>
</tr>
<tr>
<td>7</td>
<td>boiler</td>
<td>gasifc, cement, MSWI</td>
</tr>
<tr>
<td>8</td>
<td>CHP</td>
<td>gasifc, cement, MSWI</td>
</tr>
<tr>
<td>9</td>
<td>gasifc.</td>
<td>gasifc, cement, MSWI</td>
</tr>
</tbody>
</table>

Scenarios 1 to 3 are the 100% use of reject scenarios, thus using all produced rejects by Eska on-site. Scenarios 4 to 6 are the 100% use of reject scenarios when all of the produces rejects is transported to other companies. These scenarios are based upon extreme situations but the results of which will show a clear difference in energy production and CO₂ emission when using the given options.

Scenarios 7 to 9 are based upon more realistic situations, using the situation of Eska, and these scenarios cover a combination of multiple options when not all rejects are consumed.

5.3 Timeframe

All scenarios will be calculated in a specific timeframe; 1 to 10 years of implementation of the scenarios. The time period is chosen to give an indication of the impacts of the given scenarios over time. The maximum of 5 years is considered the maximum time that Eska is willing to invest in.
6 Results

The following results are based upon using rejects as a fuel source by the chosen options in different scenarios which are shown in chapter 5.
The produced results are calculated using the following data:

**Calorific value of rejects:**
The calorific value of rejects differs per scenario option. The caloric value of rejects is recalculated to match the moist content when used as fuel.
On-site use of rejects use a caloric value of around 14 GJ per ton of rejects (moist content of around 40%). In comparison, dry reject has a caloric value of around 20 GJ per ton of rejects.
(Eska Graphic Board, 2007, Ingenia, 2007)

**CO₂**
The stoichiometric amount of CO₂ per reject is estimated to be around 2200 kilograms per ton of dry rejects (moist content of 0%) (Eska Graphic Board, 2007). Natural gas on the other hand has a higher calorific value of 35 MJ per Nm³ of gas and the stoichiometric amount of CO₂ per cubic meter of natural gas is around 1.776 kilograms (this is equal to 2100 kilograms of CO₂ per ton natural gas).
(IPCC, 1996)

**Indirect CO₂ production:**
There are two types of indirect energy/CO₂ productions used to calculate the results for all scenarios. The first one is transports of rejects. Assumed is that exported rejects have to travel up to 800km, thus producing up to 600 tons of CO₂ per 25000 tons of reject (0.024 tons of CO₂ per ton reject) (Eska Graphic Board, 2007).
The second type of indirect energy is the pretreatment of rejects. The moist content of newly produced rejects is around 40%. This ‘wet’ rejects is used in most installations without pretreatment (drying). The only exception is the cement industry. The moist content of rejects for the cement industry is on average 20% or lower when considering an alternative fuel as rejects (Mokrzycki, M., Uliaś-Bocheńczyk, A., 2003)
According to an estimation, this pretreatment (decreasing the water content) is around 0.2 kg of CO₂ per ton reject in order to reduce the moist content per each percentage. (The calculations made to reduce moist are based upon using natural gas as fuel in order to evaporate the water.) (Eska Graphic Board, 2007)
6.1 100% use of rejects

Annually, Eska produces around 25000 tons of rejects. The following six scenarios are based upon an extreme situation with full use of the produced rejects as fuel for the given options.

6.1.1 Scenario 1

The first scenario in line of 100% use of rejects is by using the boiler located on-site by Eska. The overall efficiency of the boiler of converting fuel to steam is around 90% (Eska Graphic Board, 2007). For this scenario we are going to ignore the maximum output of the boiler and use the full amount of available rejects. This scenario is a comparison between the 100% use of reject by the boiler and by the same energy equivalent of natural gas by the same boiler (currently, the boilers are powered by natural gas). The results are the following:

<table>
<thead>
<tr>
<th>Reject</th>
<th>Natural gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>25000</td>
<td>-</td>
</tr>
<tr>
<td>324000</td>
<td>10285714 m³ [natural gas]</td>
</tr>
<tr>
<td>33000</td>
<td>18267 ton [CO₂]</td>
</tr>
</tbody>
</table>

As it can be seen in table 3, the use of natural gas produces less CO₂ emissions when producing the same amount of energy. To show a clear comparison between the two, the following graph has been made which shows the amount of produced CO₂ per GJ of both fuel sources in a boiler:

![Figure 9 Comparison of emission per fuel source in an on-site boiler](image-url)
There is a clear difference visible of the comparison of the amount of CO$_2$ per GJ per fuel source which can be seen in figure 9. Using rejects as fuel in a boiler produces almost doubles the amount of CO$_2$ per GJ compared to conventional natural gas.

### 6.1.2 Scenario 2

Scenario 2 is using 100% of rejects in a CHP-system located on-site by Eska. There are three CHP-systems situated at Eska and they have a maximum power production of 70 MW in total. The CHP-system used by Eska is a gas turbine based system. Using rejects as fuel will require a steam turbine based CHP-system.

Based upon the data from (Eska Graphic Board, 2008) the overall efficiency of the steam turbine based CHP-system of converting fuel to steam and electricity is around 83%. 80% of the produced energy consists of steam. The remaining 20% is electricity.

The CHP-systems used by Eska are currently powered by natural gas thus a comparison is made between the different fuel types.

#### Table 4 Calculations of CO$_2$ in an on-site CHP-system

<table>
<thead>
<tr>
<th>Reject</th>
<th>Natural gas</th>
<th>CO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>25000</td>
<td>-</td>
<td>10285714 m$^3$ natural gas</td>
</tr>
<tr>
<td>298800</td>
<td>298800</td>
<td>18267 ton CO$_2$</td>
</tr>
<tr>
<td>33000</td>
<td>18267</td>
<td>298800 GJ</td>
</tr>
</tbody>
</table>

The production of CO$_2$, when using natural gas when comparing to rejects, is identical to the amount of CO$_2$ produced by the boiler. The difference is in the produced energy.

The following graph is a comparison of the amount of produced CO$_2$ per GJ per fuel source.
Producing energy from cardboard factory waste

Also here a clear difference is visible of the comparison of the amount of CO₂ per GJ per fuel source. Using rejects as fuel in a CHP-system also produces almost twice the amount of CO₂ per GJ compared to conventional natural gas.

6.1.3 Scenario 3

This scenario is based upon the option of using rejects in an on-site gasification installation. The installation in question is based upon the data provided by HoSt (2008a, 2008b). The type of gasification is used for waste which consists mainly of plastics. The conversion of reject like materials in the gasification installation based on the installation of HoSt is around 90%. The usable gas will be used in an integrated CHP-system, which also has an efficiency of 90%. Thus the overall efficiency of the installation is estimated to be around 81% (HoSt, 2008b). Around 86% of the produced energy is converted to steam and the remaining percentage is electricity.

A comparison is made between the types of energy production, steam, electricity and the overall energy production.

Table 5 Calculations of CO₂ in an on-site gasification installation

<table>
<thead>
<tr>
<th>total energy</th>
<th>ton[reject] (wet)</th>
<th>GJ</th>
<th>ton[CO₂]</th>
<th>ton[CO₂]/GJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>25000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>291600</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The amount of CO$_2$ is also identical to the previous options. The amount of tons of CO$_2$ per GJ of the on-site gasification installation (0.12 ton[CO$_2$/GJ]) is also almost identical to the CHP-system. The almost identical results are caused by the relative comparable waste to energy efficiencies of all previous options.

### 6.1.4 Scenario 4

One of the options in using rejects for energy is by using an off-site gasification installation. This scenario is based upon scenario 3 with the difference that the installation is treated as an export option. The calculations are therefore modified to include the CO$_2$ production of transport and pretreatment.

The results are the following:

**Table 6 Calculations of CO$_2$ in an off-site gasification installation**

<table>
<thead>
<tr>
<th>total energy</th>
<th>ton[reject] (wet)</th>
<th>ton[CO$_2$]</th>
<th>ton[CO2]/GJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>25000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>291600</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33600</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The amount of tons of CO$_2$ per GJ of the off-site gasification installation (0.12 ton[CO$_2$/GJ]) is identical to the on-site gasification installation. From these results we can conclude that including transport does not have a significant impact on the emissions.

### 6.1.5 Scenario 5

Scenario 5 is when all the produced rejects is transported abroad to a cement factory. An assumption is made that a cement factory uses on average around 20% of plastics as fuel for rotary kiln. (Mokrzycki, M., Uliasz-Bocheńczyk, A., 2003) The efficiency of the rotary kiln is estimated to be around 50%.

This scenario also includes the added CO$_2$ emissions of transporting and pretreatment of rejects in the calculations. The remaining fuel for the rotary kiln can be hard coal or brown coal. The following results are combinations between rejects and a coal type and the coal type without rejects:
Table 7 Calculations of CO\textsubscript{2} in a cement factory using different fuel types

<table>
<thead>
<tr>
<th>reject + hard coal</th>
<th>hard coal</th>
<th>reject + brown coal</th>
<th>brown coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>25000</td>
<td>-</td>
<td>25000</td>
<td>-</td>
</tr>
<tr>
<td>41143</td>
<td>51429</td>
<td>84706</td>
<td>105882</td>
</tr>
<tr>
<td>900000</td>
<td>900000</td>
<td>900000</td>
<td>900000</td>
</tr>
<tr>
<td>175152</td>
<td>176940</td>
<td>178584</td>
<td>181980</td>
</tr>
<tr>
<td>272727</td>
<td>272727</td>
<td>272727</td>
<td>272727</td>
</tr>
</tbody>
</table>

To put the differences in a better perspective, the following graph has been made where the CO\textsubscript{2} emissions per ton of cement are shown per fuel types in a cement factory:

Figure 11 Comparison of emission per fuel type in a cement factory

As can be seen in figure 11, the use of rejects will decrease the production of CO\textsubscript{2} per ton of produced cement. However, adding 20% of rejects to hard coal produces almost the same amount of CO\textsubscript{2} per ton of cement compared with using 100% brown coal (0.642 compared with 0.649 tons of CO\textsubscript{2} per ton cement). Thus, based on these results we can say that using rejects in a cement factory will increase the CO\textsubscript{2} production by a few margins. On an overall scale however, the changes in CO\textsubscript{2} per ton cement per fuel source is only marginal (2 to 3% increase in CO\textsubscript{2} per ton cement when using rejects).
6.1.6 Scenario 6

One of the options in reject waste management is transporting the rejects to other companies. These options are often abroad like Germany. Scenario 4 is the option where all rejects is transported to a MSWI abroad. The calculations made for this scenario includes the added CO\textsubscript{2} emissions of transporting rejects (pre-treatment is not required for a MSWI).

The MSWI plants have different waste to energy efficiency per location, thus, a maximum and minimum efficient levels are used of 15% and 25% (Eska Graphic Board, 2007). The results are the following:

Table 8 Calculations of CO\textsubscript{2} in a MSWI

<table>
<thead>
<tr>
<th>Min</th>
<th>Max</th>
<th>% efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>25000</td>
<td>25000</td>
<td>ton[reject]</td>
</tr>
<tr>
<td>54000</td>
<td>90000</td>
<td>GJ</td>
</tr>
<tr>
<td>33360</td>
<td>33360</td>
<td>ton[CO\textsubscript{2}]</td>
</tr>
</tbody>
</table>

The amount of CO\textsubscript{2} remains the same per efficiency level, but the energy level is different. To give a better comparison between the two options, the following graph has been made:

Figure 12 Comparison of emission per efficiency level in a MSWI

A reduction in efficiency from 25% to 15% has as result that the maximum efficiency MSWI produces more than half (60%) of the tons of CO\textsubscript{2} per GJ compared with the minimal efficiency when using rejects.
Based upon these results, a correlation can be calculated between the level of efficiency and the production of tons of CO$_2$ per GJ for a MSWI using only rejects. The following graph is a representation of the correlation:

![Correlation between efficiency and tons of CO2 per GJ in a MSWI](image)

Figure 13 Correlation between efficiency and tons of CO2 per GJ in a MSWI

The correlation, seen in figure 13, indicates that the correlation can be calculated using the formula $y = 9.262x^{-1}$ where ‘$y$’ is the percent of efficiency in a MSWI and ‘$x$’ is the value of tons of CO$_2$ per GJ when using rejects in a MSWI.

### 6.1.7 Summary 100% use of reject scenarios

When all rejects is used, the total production of CO$_2$ is around 33 kton (based on dry rejects) depending on added indirect CO$_2$ production. However, when the data from the scenarios from above are combined we can get a better comparison of the available option when using rejects. The following graph is a comparison of the amount of produced CO$_2$ per GJ per option when using 25000 tons of rejects.

(In the case of the production of cement; the value used in the graph is the based upon the use of 20% rejects only)
Boiler
The on-site boiler option is the best option with the lowest production of CO$_2$ per GJ, when using rejects as fuel, due to its high efficiency. Using natural gas produces the lowest level of CO$_2$ compared to all options.

CHP-system
Using rejects in a CHP-system will increase the CO$_2$ production with a few margins compared with the boiler. The CHP-system is the second best option in using rejects on-site. However, using natural gas as an alternative to rejects will produce far less CO$_2$ per GJ.

Gasification
An on-site gasification installation produces the highest amount of CO$_2$ per GJ of the on-site options due to its lower efficiency (81%) compared to the others. As an export option, using rejects in an off-site gasification installation will produce slightly more CO$_2$ than the on-site option but the changes are minimal. In this case, the off-site gasification installation would be the best available option for export of rejects.

Cement industry
The second best available option for export of rejects is the cement industry. The cement industry produces more CO$_2$ per GJ compared to the gasification installation, but is more efficient than a MSWI.
**MSWI**
Other export options, like the MSWI, produce far more CO$_2$ per GJ compared to the other options. The MSWI is therefore the least favorable option.

From these results we can conclude that using rejects on-site (preferably in a gasification installation) will be a better option compared to the export options (not including a off-site gasification installation). When rejects are exported, the best option would be to be transported to a gasification installation.

### 6.2 Realistic use of rejects
The following scenarios are a representation of the actual situation at Eska where they can’t use all of its produced rejects and start exporting the remaining rejects. These scenarios are based upon the previous scenarios but also include the option of buying more rejects to fulfill their energy needs.

For these scenarios, a few assumptions were made:

**Investments costs**
The total investments cost of a new installation is assumed to be around 1 million euros per MW. This is based upon the investment costs of a new boiler for Eska. Also we are going to assume that other installations like a gasification installation require similar investments.

(Eska Graphic Board, 2007)

**Export/import costs rejects**
The costs for exporting rejects to another company are assumed to be around 115€ per ton reject (these costs include; transport, pretreatment and gate fee). We also assume that the price decreases with 5 euros each year. In the case of importing rejects, the costs only include the transport of rejects. Importing rejects has as effect that Eska also receives the income of gate fee. Also the assumption is made that the imported reject is of the same quality of Eska’s rejects.

(Eska Graphic Board, 2007)

**Gas price**
The price of natural gas in the Netherlands is around EUR 0.20 per Nm$^3$. (Essent, 2008). We assume the increase in price of natural gas is around 5 percent each year (Eska Graphic Board, 2007).
Additional costs/profits
To calculate the total amount of costs or profit, the calculations include the costs of maintenance of the installations, which is assumed to be around 10% of the investment costs. Also, an interest rate is included in the calculations. The used interest rate is around 5% per year. (Eska Graphic Board, 2008)
In case of a CHP-system and a gasification installation, the total costs can be reduced by selling the electricity to the local grid. As an assumption we are going to assume that all produced electricity is sold to the local grid.

6.2.1 Scenario 7
The first of the realism based scenario is a combination of the available boiler with a maximum output of around 11MW (Eska Graphic Board, 2007, 2008) and the available export options. Three export options are available: Gasification, MSWI and the cement industry. First we are going to determine the differences of CO₂ production per combination.

CO₂ emissions
In order to show a correlation between the maximum output of the boiler and the production of CO₂ per combination, the following graph is made:

![Total CO₂ emissions of the boiler per export combination per maximum output](image)

Figure 15 Total CO₂ emissions of the boiler per export combination per maximum output
The boiler gasification and the boiler MSWI combinations produce the lowest amount of CO\textsubscript{2} per different maximum outputs. The boiler cement industry combination has a higher production of CO\textsubscript{2} compared to the other options. This is caused by also including the pretreatment of rejects when using the cement industry option. However, when we look at the scale of the produced CO\textsubscript{2} emission, we can see that the difference between the options are very small (less than 0.1 ktons of CO\textsubscript{2} per year). The combinations show a steady decline in CO\textsubscript{2} emission when the maximum output of the boiler is increased.

According to the calculations made by using the model; 25000 tons of rejects can produce a maximum output of 11.25MW when used in the boiler. A method for increase the energy output of the boiler is to import rejects from other companies. To show the influence of importing rejects, the following graph is made with a maximum of 25MW:

![Graph showing total CO\textsubscript{2} emissions of the boiler per maximum output when importing rejects.](image)

Figure 16 Total CO\textsubscript{2} emissions of the boiler per maximum output when importing rejects

A linear increase of CO\textsubscript{2} can be seen in figure 16 due to the amount of imported rejects. The blue bar is the amount of rejects that is imported.
Costs
The next thing to determine is the changes in costs when exporting or importing rejects. The following graph is based upon using a new boiler. The costs are calculated per variable maximum outputs of the boiler, to a maximum of 11MW, in a timeframe of 10 years.

![Figure 17 Total costs when using rejects in a boiler per year per maximum output](image)

As can be seen in figure 17, the total costs are decreasing over time per each maximum output of the boiler. The payback time of each maximum output is less than 5 years. When the total amount of rejects is used for producing energy with an output of around 11MW, the payback time can be around 3,5 years.

When the boiler has to produce more energy, rejects can be imported. Figure 18 is a graph of the calculated costs per variable maximum outputs of the boiler, to the maximum output of 25MW, in a timeframe of 10 years.
Producing energy from cardboard factory waste

Figure 18 Total costs when including imported rejects in a boiler per year per maximum output

With the maximum output of the boiler of 12MW the payback time becomes around 4 years. Increasing the maximum output by importing rejects has as result that the payback time also increases. A maximum output of the boiler of 25MW has a payback period of around 6.5 years. Based upon this data we can conclude that the costs for imported rejects increase per increase of output, but the payback time remains around the 5 year limit.

6.2.2 Scenario 8

The second of the realism based scenario is a combination of a steam turbine based CHP-system with also a maximum output of around 11MW and the available export options (Gasification, MSWI and the cement industry).

CO$_2$ emissions

According to the calculations, the maximum output for the steam turbine based CHP-system, when using the annual amount of rejects, is around 10.4MW. The following graph is made to show the correlation between the maximum output of the CHP-system and the production of CO$_2$ per combination:
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Total CO\textsubscript{2} emissions of the CHP-system per export combination per maximum output

Also here, the CHP gasification and the CHP MSWI combinations produce the lowest amount of CO\textsubscript{2} per different maximum outputs. The combinations show a steady decline in CO\textsubscript{2} emission when the maximum output of the CHP-system is increased by using all of Eska’s rejects.

When importing is included, the following graph is made which can be seen in figure 20. The graph has a sharp increase of imports and the corresponding CO\textsubscript{2} emissions. When the maximum output of the CHP-system becomes 25MW, the required import of rejects becomes around 1,4 times the annual production of Eska’s rejects.
Producing energy from cardboard factory waste

Costs

When calculating the costs for using a CHP-system while exporting and importing rejects, we get the following graph:

Figure 20 Total CO₂ emissions of the CHP-system per maximum output when importing rejects

Figure 21 Total costs when including imported rejects in a CHP-system per year per maximum output
Figure 21 is a representation of the costs per the different values of maximum outputs in a timeframe of 10 years. As can be seen in the graph, the payback time becomes less than 10 years when using the maximum output of more than 5MW. When using a maximum output of 10MW, the payback time becomes around 3 years. Also, a clear switching point is visible when all installation types have the same costs. This is in this case around 1,7 years. The switching point of the CHP-system is much earlier in time compared to the boiler. This is caused by the production of electricity, which is sold to the local grid, thus reducing costs.

When the maximum output of the CHP-system is increased to 25MW, importing of rejects becomes necessary. The following graph is a representation of increasing the maximum output from 10 to 25MW when importing rejects in a timeframe of 10 years.

![Figure 22 Total costs when including imported rejects in a CHP-system per year per maximum output](image)

Importing rejects to a CHP-system has as result that the payback period remains in the area of 3,5 years, which can be seen in figure 22. The cause for the reducing total costs in time by increasing the import of reject is due to the fact that the produced electricity by the CHP-system is sold to the local grid. With higher maximum output of the installation, more electricity is produced, thus lower total costs which reduces the payback time.
6.2.3 Scenario 9
The last scenario is based upon using a gasification installation on-site. The data used for the installation originates from HoSt (2008). The installation is used with the available export options (Gasification (off-site), MSWI and the cement industry).

CO₂ emissions
According to the calculations, the maximum output for the gasification installation, when using the annual amount of rejects, is around 10MW (10,1). The following graph is made to show the correlation between the maximum output of the gasification installation and the production of CO₂ per combination:

![Graph showing Total CO₂ emissions of the gasification installation per export combination per maximum output](image)

Figure 23 Total CO₂ emissions of the gasification installation per export combination per maximum output

The results are not unlike the previous two scenarios, the on-site and off-site gasification combination and the gasification MSWI combinations produce the lowest amount of CO₂ per different maximum outputs. A steady decline in CO₂ emission can be seen when the maximum output of the gasification installation is increased by using all of Eska’s rejects.

When importing of rejects is included, the results can be seen in the following graph:
A linear increase of CO₂ emission can be seen in combination with a linear increase of imported rejects. When the installation produced around 25MW, the amount of imported rejects becomes around 1.5 times the annual production of Eska’s rejects.
Costs
When costs are included, we get the following:

Figure 25 Total costs when including imported rejects in a gasification installation per year per maximum output

Figure 25 is a representation of the costs when using a gasification installation with a maximum output of 1MW to 10MW.

Like the CHP-system, the payback time becomes less than 10 years when using the maximum output of more than 5MW. When using a maximum output of 10MW, the payback time becomes around 3 years. The switching point is also almost identical to the CHP-system.

When the maximum output of the gasification installation is increased to 25MW, importing of rejects becomes necessary. The following graph is a representation of increasing the maximum output from 10 to 25MW when importing rejects in a timeframe of 10 years.
The payback time for each maximum output of the boiler, starting with 11MW, becomes around 3,4 years. Increasing the maximum output by importing rejects has as result that the payback time increases. A maximum output of the boiler of 25MW has a payback period of around 5,5 years. The payback time period of the gasification installation by 25MW is lower than the boiler with the same maximum output, but higher than the CHP-system. The gasification installation produces electricity which is sold to the local grid, but the production of electricity by the gasification installation is lower than the CHP-system. As a result, the gasification has a longer payback time period than a CHP-system, but remains around the 5 year limit.

Figure 26 Total costs when including imported rejects in a gasification installation per year per maximum output
6.2.4 Summary of the realistic use of rejects scenarios

When all the scenarios of the realistic use of rejects are combined, we get the following results:

\( \text{CO}_2 \) emissions

The graph in figure 27 is a representation of the amount of \( \text{CO}_2 \) emission in combination with the total amount of needed rejects per maximum output of one of the three options.

![Total CO\(_2\) emission when importing rejects](image)

Figure 27 Total \( \text{CO}_2 \) emission when including imported rejects in a Boiler, CHP-system and a gasification installation per maximum output

The trend of the amount of needed rejects is equal to the trend in emission of \( \text{CO}_2 \) (solid lines). The trend with the least incline of \( \text{CO}_2 \)/rejects is the boiler; this is due to its high efficiency. The CHP-system is second best, but due to its lower efficiency, it requires much more rejects to produce the same amount of energy compared to the boiler. Thus based upon these results, using the boiler without importing rejects produces more energy than the other options and when import is possible, lesser amounts of import rejects are needed when producing more energy compared to the other options.

The dotted lines are an indication when the produced electricity is sold to the local grid and used by a consumer which in turn prevents to use electricity produced by a conventional power plant. The reduction in \( \text{CO}_2 \) is minimal when comparing to the non-reduced \( \text{CO}_2 \) lines (solid lines). However, the prevention of \( \text{CO}_2 \) becomes larger when using a higher maximum output (>10MW prevents >25 ktons of \( \text{CO}_2 \) per year). This can be seen for the example of the CHP-system. The gasification option does not have a clear difference between the lines.
Based on these results we can conclude that using a reject powered CHP-system in combination with selling electricity to the local grid can prevent a limited amount of CO₂ emissions produced by a conventional power plant.

Also the effect of exporting rejects to other companies has little effect on the overall CO₂ production. The level of CO₂ remained around 55 ktons of CO₂ per year. Only importing rejects will increase the amount of CO₂ drastically.

**Costs**
To give an indication of the total costs of the three available options when importing rejects, a comparison of results are made when these option have a maximum output of 11 and 25MW. The following graph is the comparison between the options over a fixed time period.

![Total costs when importing rejects to produce 11 and 25MW](image)

**Figure 28 Total costs when including imported rejects in a Boiler, CHP-system and a gasification installation per year with a maximum output of 7 and 13MW**

The graph contains two types of lines, the thick line (11MW) and the dotted line (25MW). The starting points of the options are the initial investment costs.
As an assumption, the total investments for the installations are identical. Thus the starting points for the installations are also identical. Over a period between 3 and 3.5 years the total costs become zero. Therefore we can conclude that the payback time for all options with a maximum output of 11MW are lower than 3.5 years. Increasing the output to 25MW will also increase the payback time beyond the 5 year line in case of the boiler and the gasification installation. The exception is the CHP-system which does not increase much in payback time (3.2 to 3.6 years). The main reason for this difference is caused by selling electricity to the local grid. The CHP-system produces more electricity than the gasification installation; therefore the payback time for the gasification installation is higher than the CHP-system. The boiler on the other hand does not produce electricity which can be sold, thus no added reduction in costs.

Other option in handling Eska’s rejects like using a combination of energy producing option onsite is not possible. The amount of available rejects produced by Eska is barely enough to provide energy to Eska. To split the reject stream into two separate fuel lines for two energy producing installations will result in very low energy production and very high costs.

The calculations made to indicate the total costs for all of the available options do not include subsidies. Using subsidies can influence the outcome significantly and the results must show a clear difference between the available options.
7 Discussions

Subsidies
All cost calculations are made without the use of subsidies or other kinds of financial aid. Using these kinds of financial aids will influence the outcome by reducing the payback period. However, these financial aids have a limited lifespan and could eventually make previous acceptable options far less acceptable than other options in the near future. To prevent such an event, all calculations are without financial aid.

Using and importing rejects
By importing rejects, which will be used as fuel to produce energy for the factory, one could prevent other companies to handle rejects in a less sustainable manner. Other companies could choose to transport the rejects to a MSWI, which is very inefficient waste to energy power plant. An efficient boiler could produce more energy when producing the same amount of CO$_2$. Also the need for fossil fuel (e.g. natural gas, coal) will be reduced when the produced energy is used accordingly.

However, by importing rejects and using own rejects which will not be exported, one could also ensure the use of more polluting resources. For example; the produced rejects could go to a cement factory in Germany, but now continues its route to the on-site energy plant of Eska. The cement factory is now forced to search for alternative fuel sources. The cement factory could resort to using brown coal (common in Germany) as a substitute fuel, which can be responsible for increasing emissions of other pollutants like sulfur oxides.

The costs of importing of rejects are, for the sake of this research, assumed to decrease with time. There is the possibility that the costs of importing rejects will actually decline to zero and eventually start to become a profitable resource. The costs (or profits) of rejects are linked in some manner to the costs of oil. When the oil price increases, the costs for rejects will decline. In time rejects could become an interesting fuel source which can be sold. Such a change could result in positive financial situation when not having to use rejects as on-site waste-to-energy option at all.

Selling heat
Produced heat which is not needed by the factory could be sold to nearby urban areas for heating (or cooling). This could also change the outcome of the results of this research. The changes would be mainly focused on the on-site boiler, which does not produce electricity compared to the other options. The payback time of the boiler would in this case decrease.
Different perspective on payback time
Another method in indicating the payback period of one of the given options would be including the costs and profits of the entire factory. This type of method can include a comparison of the existing energy producing installation with the reject powered installation. The payback time will be influenced, most likely making the alternative reject powered option more attractive.

Sensitivity of used variables
The model for this research bases upon several sensitive variables. An example is the calorific value of rejects. A fixed number is used for the sake of the research, but in practice the value varies constantly. Changing a major value like the calorific value of rejects will influence the results significantly. From this we can conclude that the calorific value of rejects is a highly sensitive variable.

Using this research for other paper/cardboard companies
The possibility for using this research, in specific the model, for other projects within Tauw has been assessed. The produced model is based upon the specific requirements of Eska, but the model is sufficiently variable in order to be changed for other paper/cardboard companies. Thus in short; it is possible to use this research for other companies.
8 Conclusions

100% use of rejects (scenarios 1-6)

Of the available option for on-site energy production using rejects as fuel; the boiler produces the lowest amounts of CO$_2$ per GJ due to its high efficiency. The second best option is the on-site CHP-system. The gasification installation produces the highest amount of CO$_2$ compared to the other two options, but the difference in emission between all of these options is minimal.

When using around 25000 tons of rejects for export purposes only, the best option would be sending the rejects to an off-site gasification installation. The CO$_2$ emission per produced energy when using rejects in an off-site gasification installation is the lowest of all other available export options. The cement factory is the second best option, but the CO$_2$ production per GJ compared to the off-site gasification installation is almost twice as high. The option of sending rejects to a MSWI is the least favorable option compared to the others. A MSWI has a very low efficiency in waste to energy conversion, thus using a MSWI should be avoided.

However, when using natural gas to produce energy; the level of CO$_2$ per GJ when compared to all of the on-site options are much lower than when using rejects as a fuel source. On the other hand, when rejects are not used on-site it has to be exported to another company. Because the available export option produces more CO$_2$ per GJ compared to the on-site boiler, the best option will be using rejects on-site. This will prevent higher emissions of CO$_2$ when using rejects as fuel and reduces the need for natural gas.

Realistic use of rejects (scenarios 7-9)

Around a maximum output of around 10MW for all of the installations, the amount of emitted CO$_2$ is about equal for all of the installations. The effect of exporting remaining rejects does not have a significant effect on the overall CO$_2$ emission. When increasing the maximum output for all of the installations, the option of importing rejects becomes necessary. The CHP-system and the gasification installation are almost equal in the production of CO$_2$ but the least amount of CO$_2$ is produced by the boiler, which is around 10% lower than the other options. Also, the boiler would require fewer amounts of rejects to produce larger amounts of energy compared to the other options.
When including the prevention of CO₂ by selling the electricity to the local grid, the emission of CO₂ by the CHP-system and the gasification installation will decrease. The gasification installation will in this case be responsible for the amount of CO₂ which is almost equal to the emission of boiler. The CHP-system however will responsible for the least amount of CO₂ compared to the other options. On a local scale, the boiler would be the best choice when looking at the emission of CO₂. But when looking on a larger regional scale, the CHP-system will be responsible for lower CO₂ emissions.

**Payback time (scenarios 7-9)**

The payback time of all given options are between 3 and 3,5 years when using the annual amount of rejects to produce energy on-site. To illustrate the best available option when including the emission of CO₂, the following graphs are made. These graphs show the pro's and cons of the chosen scenarios with maximum outputs of 11 and 25MW. A maximum output of 11MW is the maximum output of the boiler when using all of Eska's annual rejects and a maximum output of 25MW is used to indicate the effect of importing rejects.

![Graph](image.png)

**Figure 29 Results of the used scenarios per 11MW installations**

The graph contains a raster where the most favorable option lies between the lowest investments, the lowest payback time and the lowest CO₂ emissions. Each option is a bar showing the maximum investment (left y-axis) in combination with the payback time (x-axis). The investments are in this case identical for all options (7,7mil. €). Each bar has a ruler which is the amount of produced of CO₂ per year (right y-axis).
The best option, which can be seen in the 11MW installation graph, will be the CHP-system with the shortest payback time period (<3.5 years). However, the boiler has the lowest CO$_2$ emission. The differences between these options are however not very significant. Therefore, all options can be favorable when choosing an installation for handling rejects.

When increasing the maximum output of the installations to 25MW, rejects are imported and the production of CO$_2$ will increase. The results are illustrated in the following graph:

![Figure 30 Results of the used scenarios per 25MW installations](image)

The investments are in this case also identical for all options, and are around 20mil. EUR. A higher maximum output of 25MW when importing rejects will have a significant impact on the payback time period of the boiler and the gasification installation which becomes higher than 5 years. The CHP-system however, has no large increase of payback time. Therefore we can conclude that the CHP-system is the most cost effective option in handling rejects when import is included.

When looking at the emission of CO$_2$, the lowest amount of CO$_2$ is produced by the boiler. On a local scale, the boiler would be a good option when looking at the CO$_2$ emissions. But looking at a regional scale, the sold electricity of the CHP-system prevents CO$_2$ emission produced by a conventional power plant. The total emission of the CHP-system would be in this case lower than a boiler.
From these results we can conclude that the CHP-system is the most cost effective and can prevent more CO$_2$ emission than the other option on larger scale independent of importing rejects. The boiler and the gasification installation will only be acceptable alternatives when no rejects are imported.

To shortly summarize the conclusions in order to answer the sub questions:

1 - It is possible to use rejects more efficiently by other export companies. In this case the off-site gasification installation will be the best choice.

2 - Using an on-site reject powered boiler will be a good option in using rejects to prevent the use of natural gas. Using a CHP-system or a gasification installation will be a better choice in the long-run.

3 - Using an on-site reject powered CHP-system will be the best available option in using rejects to produce steam and electricity. Using this option can also prevent CO$_2$ when electricity is sold to the local grid.

4 - Rejects can be used in an on-site gasification installation in order to produce steam and electricity, but the CHP-system is more efficient.

5 - <See discussions; page 60>
9 Recommendations

Other emissions
This research is based upon the emissions of CO\(_2\) when using rejects as fuel to produce energy. Other emissions are therefore not included, but do play a role in overall emissions. This can be the case of comparing reject powered installations to energy producing installations fueled by brown coal for instance. Brown coal contains (relative) large amounts of sulfur. When rejects is used as fuel for Eska, can have the effect that the previous destination of rejects will switch to brown coal. Further investigation should be needed to indicate if such a change in fuel source by previous export companies is probable.

Life Cycle Assessment
A Life Cycle Assessment of the factory should be preformed to determine the exact amount of direct and indirect CO\(_2\) emissions produced by the factory. The data can be used to make more accurate calculations on the produced and prevented CO\(_2\) emissions by using one of the given scenarios.

Selling heat
A method in decreasing the payback period is finding financial beneficial option which can be included in the research. One of these options is selling excess heat, which could be not only beneficial financially, but could also prevent the production of CO\(_2\) compared to the previous source of heat.

Subsidies and permits
A subsidy scan should be preformed to reduce the payback period even further. Currently, the relevant subsidy is in the process of refining, thus not usable at this time. A subsidy scan could indicate if there are other options available which can be used.

Using an alternative energy source will also require a new permit issued by the IPPC. The use of a reject powered power plant can depend on this permit. Thus further research should be preformed in order to comply with the criteria issued by the IPPC.

Increasing use of local on-site reject powered power plants
The usage of reject powered power plants has as effect that the need for conventional power plants can be reduced. This is the case when excess electricity is sold to the local grid. When more paper/cardboard factories will follow in the footsteps of Eska, what would be the result in the reduction of the need for more power plants on a regional/national scale? In order to answer this question, more research must be preformed to determine the effect of large scale use of local on-site reject powered power plants.
**Oil price**

The price of oil is increasing steadily over time. As an effect, the price of rejects could decline. The cause for decline in reject price is the fact that rejects will be considered as fuel source instead of waste. This could influence the choice of using rejects as an on-site fuel source or as a profitable commodity.

The oil price has also an effect on the price of natural gas, which is the current fuel source of a Dutch paper/cardboard factory. The increasing gas prices could make the option of using an on-site reject powered power plant by a paper/cardboard factory more attractive.

Because the oil price can influence a number of factors, a study should be preformed in determining the effects on the use of rejects by increasing oil prices over time.
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<th>Full Form</th>
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<tbody>
<tr>
<td>BAT</td>
<td>Best Available Techniques</td>
</tr>
<tr>
<td>BREF</td>
<td>BAT reference document</td>
</tr>
<tr>
<td>CHP</td>
<td>Combined-heat-and-power</td>
</tr>
<tr>
<td>EIA</td>
<td>Energy Investment Subtraction (energie-investeringsaftrek)</td>
</tr>
<tr>
<td>Eska</td>
<td>Eska Graphic Board</td>
</tr>
<tr>
<td>GHG’s</td>
<td>Greenhouse Gasses</td>
</tr>
<tr>
<td>IPPC</td>
<td>Integrated Pollution Prevention and Control</td>
</tr>
<tr>
<td>MEP</td>
<td>Environmental quality of electricity production (Milieukwaliteit Elektriciteitsproductie)</td>
</tr>
<tr>
<td>MSWI</td>
<td>Municipal Solid Waste Incinerator</td>
</tr>
<tr>
<td>MW</td>
<td>Megawatt</td>
</tr>
<tr>
<td>Nm³</td>
<td>Normal cubic meters of gas measured at 1 atmosphere and 0°C</td>
</tr>
<tr>
<td>SDE</td>
<td>Stimuli for sustainable production of energy (Stimulerings Duurzame Energieproductie)</td>
</tr>
</tbody>
</table>
Appendix 4

Formula’s for the calorific value of rejects
Definitions
The definitions used in the report on biomass are generally accepted as described by Energyund Energie
energ und Energie (ECE) as used in the Physically hieare database last revised on July

Proximate analysis:
Ash:
Ash content expressed as weight % on dry basis (db) and on as received (ar) material. Through the
water content, the two contents are related:
Ash content (wt% dry) = ash content (wt% ar) * 100 / (100 - water content (wt%))

Water content:
Water content in weight % on wet basis (wb received). It is important to note that there can be a large
difference between the water content of the material as it is available and the water content at the
moment of analysis. Also by natural drying during storage the water content can be lowered.

Ultimate analysis:
Carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S), chlorine (Cl), bromine (Br) and iodine
(I) content in weight % dry material (wt% dry), dry and ash free material (wt% db) and on as
received material (wt% ar):

<table>
<thead>
<tr>
<th>Component</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>C + H + O + N + S + Cl + Br + ash + 100</td>
</tr>
<tr>
<td>H</td>
<td>C + H + O + N + S + Cl + F + Br = 100</td>
</tr>
<tr>
<td>O</td>
<td>C + H + O + N + S + Cl + F + Br + ash + water content = 100</td>
</tr>
</tbody>
</table>

In many cases the oxygen content is not measured but calculated on the difference between 100 and
the measured components. When the oxygen content is measured the total sum usually does not
equal 100 due to experimental error in the analysis. For each component it is indicated whether it is
measured or calculated.
Calorific value (kJ/kg).

The calorific value is expressed as Higher Heating Value (HHV) and Lower Heating Value (LHV). The difference is caused by the heat of evaporation of the water formed from the hydrogen in the material and the moisture:

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>English</th>
<th>Dutch</th>
<th>German</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHV</td>
<td>Higher Heating Value</td>
<td>Bovenaard</td>
<td>(Groter Houtwert)</td>
</tr>
<tr>
<td></td>
<td>Calorific value</td>
<td>Verbrandingswaarde</td>
<td>Brennwert</td>
</tr>
<tr>
<td></td>
<td>Heat of combustion</td>
<td>Verbrandingswarmte</td>
<td>Brennwert</td>
</tr>
<tr>
<td>LHV</td>
<td>Lower Heating Value</td>
<td>Sloopwaarde</td>
<td>(Lijker Houtwert)</td>
</tr>
<tr>
<td></td>
<td>Moisture content</td>
<td>Sloopwaarde</td>
<td>Holzvacht</td>
</tr>
</tbody>
</table>

The determination of the calorific value normally results in a value for the HHV. For comparison, HHV can also be calculated from the elemental composition using the Milne formula:

\[ \text{HHV}_{\text{Milne}} = 0.241 \times H + 0.624 \times O - 0.12 \times N + 0.0896 \times S - 0.013 \times \text{ash}, \]

where H, O, N, and ash are the mass and the ash fractions in wt% of dry material and HHV the heating value in MJ/kg.

By using the hydrogen and ash fractions (wt% dry) and moisture fraction \( w \) (wt% as the different

\[ \text{HHV}_{\text{dry}} = \text{HHV}_{\text{wt}} \times (1 - w/100) \]
\[ \text{HHV}_{\text{wt}} = \text{HHV}_{\text{dry}} \times (1 - \text{ash/100}) \]
\[ \text{LHV}_{\text{dry}} = \text{HHV}_{\text{dry}} - 2.442 \times 0.935 \times H/0.5 \]
\[ \text{LHV}_{\text{wt}} = \text{LHV}_{\text{dry}} \times (1 - \text{ash/100}) - 2.442 \times w/100 \]
\[ \text{LHV}_{\text{wt}} = \text{LHV}_{\text{dry}} \times 2.442 \times (0.935 \times H/100 + 1.5 \times w/100) \]

Ash composition (wt% dry):

A large number of data on ash composition after conversion is available. In general, these data are expressed as weight % of oxides. The selected oxides are not representative for the actual chemical form of the components.
Lead (Pb), vanadium (V), copper (Cu), mercury (Hg), manganese (Mn) and chromium (Cr) are expressed in mg/kg ash.

**Biomass analysis (mg/kg dry):**

The metal content is expressed in mg/kg dry (original) material. For each element, it is shown whether it is measured or the value is below the detection limit.

**Biochemical composition (wt%):**

The biochemical composition of materials is expressed in weight % of the dry material (cellulose, hemicelluloses, lignin, fats, protein).