

# Life cycle assessment

Comparative study of virgin fibre based packaging products with competing plastic materials

Commissioned by BillerudKorsnäs

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*Lena Dahlgren, Håkan Stripple, Felipe Oliveira*

**Author:** Lena Dahlgren, Håkan Stripple, Felipe Oliveira

**Commissioned by:** BillerudKorsnäs

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IVL Swedish Environmental Research Institute Ltd.,

P.O Box 210 60, SE-100 31 Stockholm, Sweden

Tel:+46-8-598 563 00 Fax:+46-8-598 563 90

[www.ivl.se](http://www.ivl.se)

This report has been reviewed and approved in accordance with IVL's audited and approved management system.

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# Summary

On commission of BillerudKorsnäs AB, IVL Swedish Environmental Research Institute (IVL) has performed an attributional LCA on four products which are based on paper produced by BillerudKorsnäs at Gruvön and Skärblacka. These products were also compared to similar products in plastic material. Two system expansion were made separately by also including end-of-life and environmental credit from the excess energy produced at the mills which are utilized in the district heating systems. The LCA was performed on regard to the four environmental key performance indicators (KPIs): Global warming potential (GWP), Acidification potential (AP), Eutrophication potential (EP) and Photochemical ozone creation potential (POCP).

The study has taken place during 2014 using primarily data for 2013 for the BillerudKorsnäs pulp and paper sites in Gruvön and Skärblacka. The study has been performed in accordance with ISO 14044:2006 and reviewed by a third party reviewer.

The main conclusion of the study for the packaging products is that material production is in general the most important factor, having a significant impact to all KPIs, both for the plastic and paper products. Plastic material production is, generally, more dominating than the Kraft paper production, on the total life cycle of the product.

Other conclusions from the study are:

- For the Gruvön and Skärblacka mill, emissions released during manufacturing are important contributors to all KPIs. Also, emissions associated with manufacturing of chemicals are important for GWP and AP for Gruvön likewise for GWP and EP for Skärblacka. Figure 1 and Figure 2 show the GWP for Skärblacka and Gruvön.

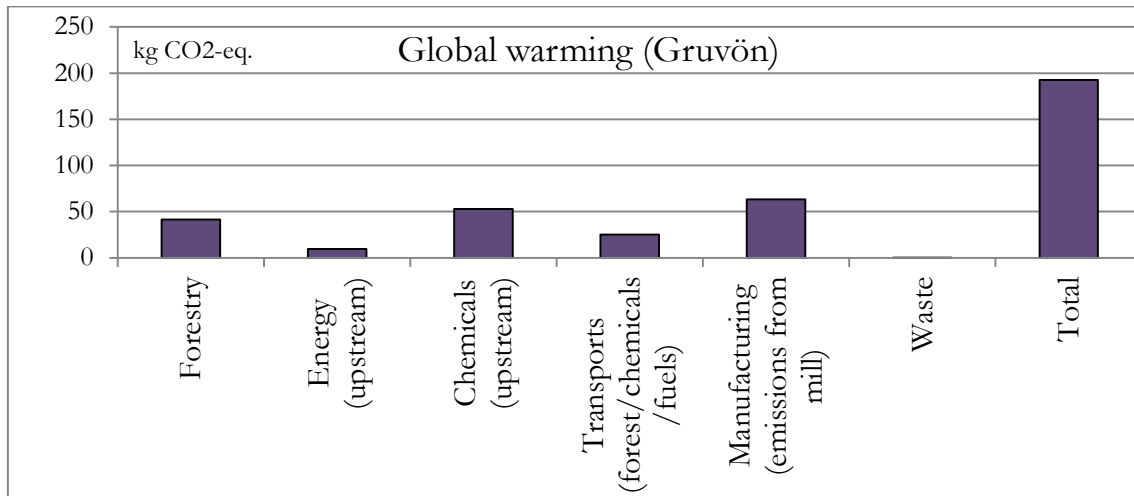


Figure 1. GWP for the production of one tonne bleached Kraft paper at Gruvön mill.

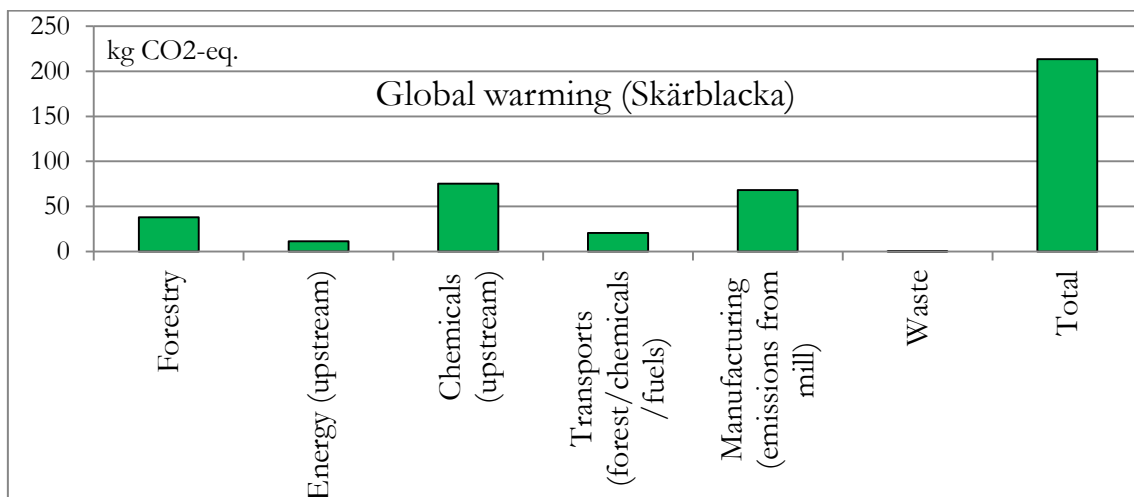


Figure 2. GWP for the production of one tonne bleached Kraft paper at Skärblacka mill.

- The results showed that GWP was consistently higher for the plastic products than for the paper products, this was true both when end-of-life were included or not.
- The paper cement sack (with Kraft paper from Skärblacka) has an advantage over the plastic sack on regard to GWP, EP and AP. But not for POCP, mainly due to the large transport distance of the paper from Sweden to Indonesia. GWP of the products is shown in Figure 3.
- The paper pasta bag (with Kraft paper from Gruvön) has an advantage over the plastic pasta bag on all KPIs except EP, due to the high COD and nitrogen oxides (NO<sub>x</sub>) released during manufacturing of the Kraft paper. GWP of the products is shown in Figure 4.

- The paper grocery bag (with Kraft paper from Skärblacka) has an advantage over the plastic bag on regard to GWP and AP. For POCP the paper and plastic bag are almost equal and for EP the plastic bag has an advantage mainly due to emissions of COD, nitrogen oxides and nitrogen to water, from Skärblacka mill during manufacturing of the Kraft paper. GWP of the products is shown in Figure 5.
- The FibreForm Packaging bottle has an advantage over the PET bottle on all KPIs, mainly due to the high emissions associated with the material production for PET, but also to some extent the higher energy demand during conversion. GWP of the products is shown in Figure 6.

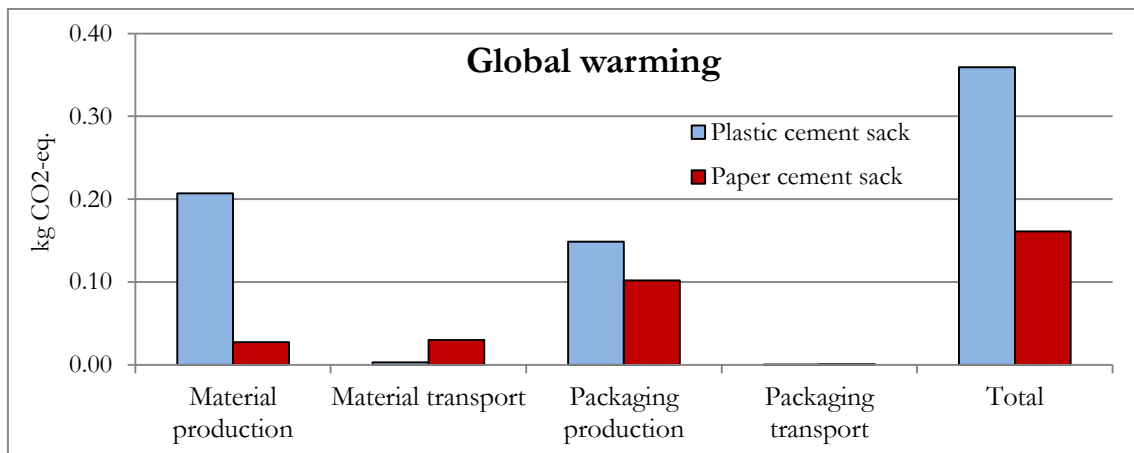


Figure 3. Comparison of GWP between a cement sack in paper from BillerudKorsnäs and a competitive sack in plastic (PP) produced in Indonesia

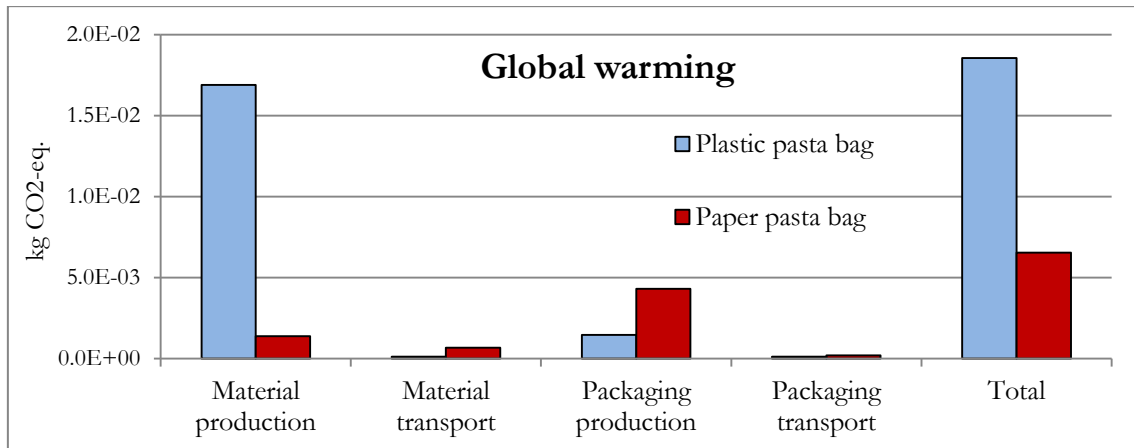


Figure 4. Comparison of GWP between a pasta bag in paper from BillerudKorsnäs and a competitive bag in plastic (PP).

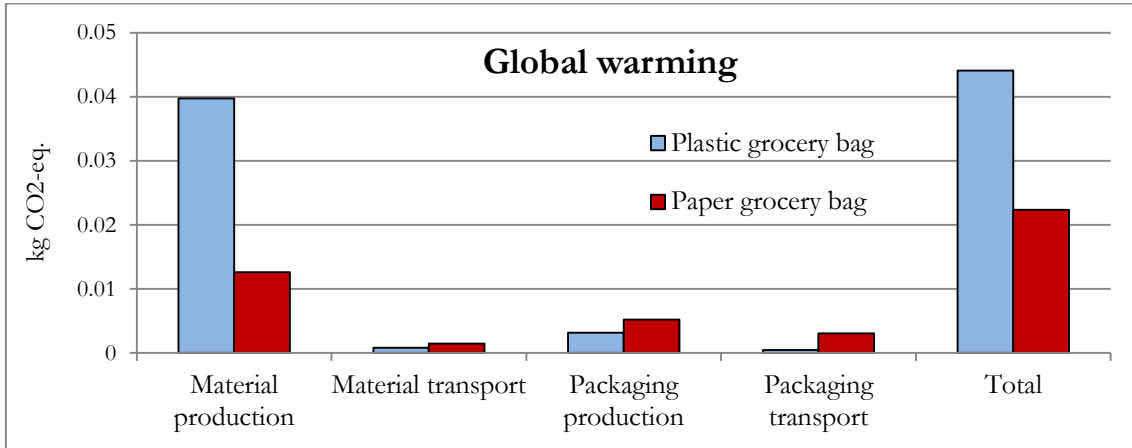


Figure 5. Comparison of GWP between a grocery bag in paper from BillerudKorsnäs and a competitive bag in plastic (HDPE).

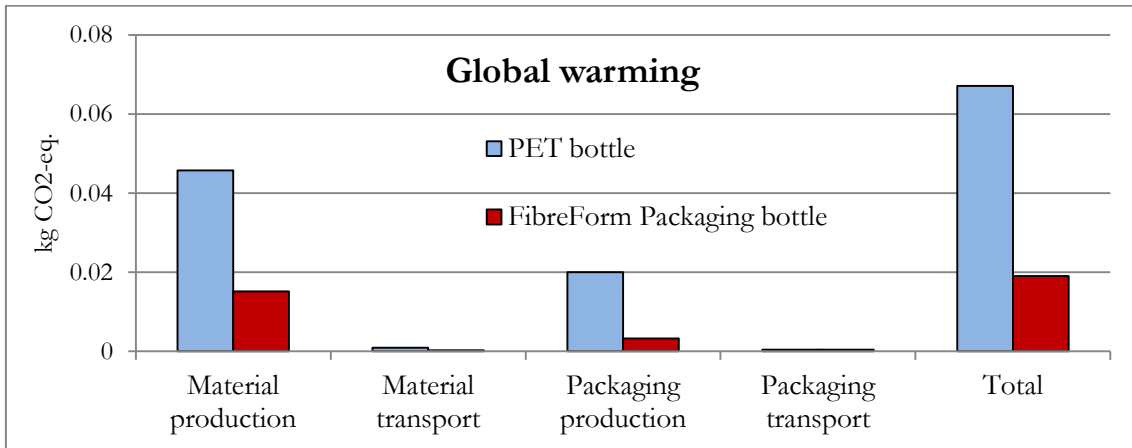


Figure 6. Comparison of GWP between a FibreForm Packaging bottle in paper from BillerudKorsnäs and a competitive bottle in plastic (PET).

System expansion was also performed by including end-of-life for the different products, This was performed to show the effect the processes in a system can have on the surrounding society, however, it should be observed that the system expansion of this assessment is not part of the directly related impact of the product.

Some conclusions from the system expansion were:

- Including end-of-life showed that a total reduction was received for all the paper products, (with the exception of POCP for the cement sack) on regard to AP, EP and POCP. This was due to the avoided emissions mainly from avoided use of virgin material. GWP was increased for all paper products when end-of-life was included. POCP for the cement sack was increased due to emissions from the paper landfill in Indonesia. Likewise a reduction was received for all the plastic products on regard to AP, EP and POCP. Meanwhile GWP was increased.



- Including credit from district heating had small effect on the KPIs for Gruvön and Skärblacka, due to the small amount of energy which can actually be utilized for district heating.

## 1 Introduction

As the environmental awareness is growing among customers and business today, there is a need for companies to communicate their products environmental performance in a structured and understandable way. Life cycle assessment (LCA) can work as a tool for measuring the environmental performance of products and processes, and hence, contributing to increased knowledge both for companies and their customers.

Environmental LCA is the calculation and evaluation of the environmentally relevant inputs and outputs and the potential environmental impacts of the life cycle of a product, material or service (ISO 14044:2006).

Environmental inputs and outputs refer to demand for natural resources and to emissions and solid waste. The life cycle consists of the technical system of processes and transports used at/needed for raw materials extraction, production, use and after use (waste management or recycling). LCA is sometimes called a "cradle-to-grave" assessment (Figure 7). The LCA calculations are based on a functional unit, meaning the function which is provided by the product system, for instance 1 kg material or 1 type of product.

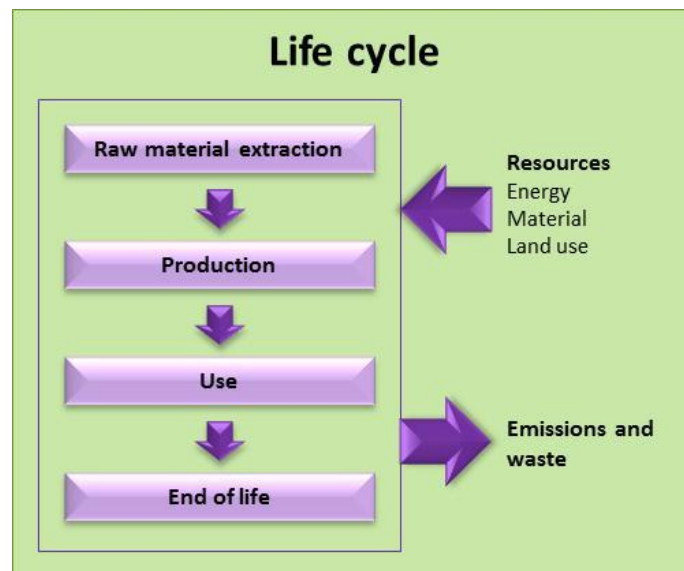


Figure 7. Illustration of the LCA-framework.

This report presents the LCA performed for BillerudKorsnäs in 2014. The study can partly be seen as an update of the carbon footprint study of the Billerud (now named BillerudKorsnäs) products made in 2009. However, this has now been expanded to four specific products and to an assessment fully in line with the recent LCA standards in order to cover all environmental impact of

importance. Also, due to the increasing request for other environmental characterizations besides carbon footprint among buyers, customers and other stakeholders, this study was extended to a full LCA. Hence, considering not only global warming potential (GWP) but also eutrophication potential (ED), acidification potential (AD) and photochemical ozone creation potential (POCP).

The LCA has been carried out by IVL Swedish Environmental Research Institute, to which BillerudKorsnäs have delivered information regarding their products and processes, which have, when necessary, been supplemented by data from IVL. This life cycle assessment has been carried out in accordance with the ISO Standard (ISO 14044:2006).

The project group have consisted of the following members:

Bengt Brunberg, BillerudKorsnäs, Stockholm  
Patrik Bosander, BillerudKorsnäs, Stockholm  
Anders von Dolwitz, BillerudKorsnäs, Gruvön  
Eddy Sandström, BillerudKorsnäs, Gruvön  
Bertil Lundberg, BillerudKorsnäs, Skärblacka  
Lena Dahlgren, IVL, Stockholm  
Håkan Stripple, IVL, Stockholm  
Felipe Oliveira, IVL, Stockholm

## **2 Goal and scope definition**

The results from this study can be used by BillerudKorsnäs for communication and presentations to customers or other stakeholders. Also, it will give BillerudKorsnäs increased knowledge about the environmental impact from the different parts of their product chain.

### **2.1 Objective and system boundaries**

The objective of the study was to perform a LCA of four specific products based on BillerudKorsnäs paper on regard to the four environmental impact categories; GWP, AP, EP and POCP. The objective was also to perform a LCA on the same type of products produced from a competing plastic material.

The system boundaries cover the entire production of raw materials to the customer gate, excluding the use-phase. As a base case, a cut-off was made by excluding end-of-life for the products, but this was however regarded in the system expansion scenario, further described in section 4.3. In the end-of-life scenarios avoided emissions have been considered. Avoided emissions are those emissions which are avoided when for instance excess heat or generation of electricity in a process can be used in the society instead of alternative fuel sources, hence, the emissions from the alternative source are considered to be avoided.

The analysed products are distributed in many different ways to the customers. It can therefore be difficult to specify the secondary distribution packaging for the analysed products. Thus, in this study only the primary products have been considered and not the secondary packaging materials.

Secondary product use has not been considered in this study. It is difficult to know how the products are used in a secondary case. Hence, it was assumed that secondary product usage is equal

for the paper and plastic products and in the absence of reliable data it has been assumed that the secondary product use can be excluded. This is valid for the grocery bag, hence the other products doesn't have any secondary usage.

## 2.2 Functional unit

A functional unit is the function provided by the product system in such a way that it becomes comparable between different systems. In this study the functional unit is the specific product fulfilling a defined function, e.g. a bag that should be able to carry 50 kg cement. Due to material properties, the weight of a product in paper or plastic is not necessarily the same. The products and their functional units are further described in the inventory analysis in section 3.

## 2.3 Characterization factors

Characterization factors are used in order to quantify and analyse the potential environmental impact of a product or process. They are based on chemical and biological reactions in air, water and soil to which all emissions have been normalized to a reference unit, using different factors (*characterization factors*). For example, methane emissions have been normalized to carbon dioxide (CO<sub>2</sub>) *equivalents* by multiplying the amount methane released to air, by the factor 25, since methane is considered to have 25 times higher impact on global warming compared to CO<sub>2</sub>, per kg emitted. Below follows a short description of the different impacts categories used in this study.

### 2.3.1 Global warming potential (GWP)

When speaking of global warming today, one usually refers to those emissions released from mankind which enhances the natural occurring global warming, which in the long run raises the average temperature on the earth. GWP is a measure of how much a unit mass of gas contributes to global warming, measured in kg CO<sub>2</sub> equivalents. Other important gases besides CO<sub>2</sub> are methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O).

### 2.3.2 Eutrophication potential (EP)

Eutrophication occurs due to excess nutrients in water and soils. Nitrogen and phosphorous are the most important compounds associated with eutrophication. If seas and lakes becomes rich in nutrients, this can lead to increased algae growth, which during degradation, consumes oxygen at the bottoms, forms hydrogen sulphide and as a consequence, leads to dead bottoms of lakes and seas (SMHI, 2014).

EP is a measure of the potential effect something has on eutrophication of waters and soils. The higher the EP value, the higher the risk of associated environmental damage. The reference unit is kg phosphate (PO<sub>4</sub>) equivalents.

### 2.3.3 Acidification potential (AP)

Acidification means that substances with low pH are emitted to water and soils to such degree that they don't have any chance to become naturally neutralized. Sulphur dioxide (SO<sub>2</sub>) and nitrogen

oxides (NO<sub>x</sub>) are important contributors which form sulphuric and nitric acid in contact with water in the atmosphere, called acid rain. This causes corrosion damages on buildings etc. which results in high costs for the society. Also, acidification of lakes can lead to death of certain species living there and acidification of soil can lead to nutrient leaching and decreased vegetation growth.

AP is a measure for the potential effect something has on acidification of soils and waters. The higher the AP value, the higher the risk of acid rain and associated environmental damage. The reference unit is kg sulphur dioxide (SO<sub>2</sub>) equivalents.

### 2.3.4 Photochemical ozone creation potential (POCP)

POCP is a measure for estimating airborne substances potential to form atmospheric oxidants, these oxidants can in turn, in the presence of sunlight, react with oxygen in the air and form ground level ozone. Typical oxidants are nitrogen oxides, carbon monoxide (CO) and volatile organic compounds (VOC). Motor vehicle exhaust is a common source of these emissions.

Ground level ozone irritate eyes and lungs for humans, they also inhibits the photosynthesis and damages the water balance for plants and vegetation.

### 2.3.5 CML2001

In this study, characterization factors from CML2001 (Centre of Environmental Science of Leiden University) were used, seen in Table 1. These are frequently used within LCA and are sometimes referred to as KPIs (Key Performance Indicators).

**Table 1. Used characterization factors, implemented from Gabi 6.3.**

Characterization factors (KPIs)		
Short name	Name	Unit
GWP	CML2001 – Apr. 2013, Global Warming Potential, excl. biogenic carbon (GWP 100 years)	kg CO <sub>2</sub> -eq.
EP	CML2001 – Apr. 2013, Eutrophication Potential	kg PO <sub>4</sub> -eq.
AP	CML2001 – Apr. 2013, Acidification Potential	kg SO <sub>2</sub> -eq.
POCP	ReCiPe 1.08 Midpoint (H) – Photochemical oxidant formation	kg NMVOC-eq.

## 3 Inventory analysis

The inventory analysis presents the products which have been modelled, how this was performed and possible assumptions made.

### 3.1 Description of the products

The study has been performed on four types of products, both in paper and plastic material; these are listed in Table 2. The products in paper and plastic are considered to have the same function. All raw materials were assumed to be virgin material. The specific places for conversion,

(manufacturing of the packaging product) and country for the end-of-life scenario, were received from BillerudKorsnäs.

**Table 2. Products, materials, weights and place of conversion (packaging manufacturing), as well as place of end-of life for the system expansion.**

Function	Paper solution (material and product weight)	Plastic solution (material and product weight)	Place of conversion	Place for End-of-life (System expansion)
50 kg cement sack	Unbleached Kraft paper (130 g)	Polypropylene (65 g)	Jakarta, Indonesia	Indonesia
0.5 kg pasta bag	Bleached Kraft paper (7.2 g)	Polypropylene (5.3 g)	München, Germany	Germany
20-30 l (11 kg) Grocery bag	Unbleached Kraft paper (59 g)	High density polyethylene (16.2 g)	Hamburg, Germany	UK
330 ml bottle	Bleached Kraft paper (14.6 g) <sup>1)</sup>	Polyethylene terephthalate (21.3 g) <sup>2)</sup>	FibreForm Packaging: Lund, Sweden and Düsseldorf, Germany PET: Düsseldorf	Germany

1) Cap, plastic laminate and LDPE ring are included in the weight.

2) Cap is included in the weight.

## 3.2 Data collection and modelling

The life cycle of the products were modelled in LCA-software Gabi 6.3 (PE International). Data were collected from both BillerudKorsnäs and IVL. For modelling of the pulp and paper production at BillerudKorsnäs sites, data for 2013 have been used. Data for the upstream commodities (electricity, chemicals etc.) have as far as possible been chosen to fit the actual substance, but in some cases analogues or approximations have been made. Primarily, data for 2013 have been used for the upstream commodities but when difficult to find data for 2013, older data have been used supplementary or as approximations.

### 3.2.1 Manufacturing at BillerudKorsnäs

Raw material for the paper products are manufactured by BillerudKorsnäs at two different sites in Sweden; Skärblacka and Gruvön, see Table 3.

**Table 3. Production site and final product of BillerudKorsnäs materials.**

Production site	Material	Product
BillerudKorsnäs		
Skärblacka	Unbleached Kraft paper	Cement sack, Grocery bag
Gruvön	Bleached Kraft paper	Pasta bag, FibreForm Packaging bottle

Site specific data were received by BillerudKorsnäs; this covered data of raw materials, purchased chemicals and fuels, net electricity consumption, emissions to air and water and generated waste.

The emissions associated with the manufacturing process at each mill were calculated by BillerudKorsnäs based on energy balances over the mills. Several products are produced at each paper mill. The emissions and resource uses were all allocated to each specific product used for the applications analysed in this study. The main emissions to air and water measured at each paper mill were obtained from Gruvön and Skärblacka for year 2013. CO<sub>2</sub> (fossil) was calculated by IVL based on data received from the energy balances. Biogenic based CO<sub>2</sub> has been considered as CO<sub>2</sub> neutral i.e. the emissions and uptake have been considered equal. The biogenic CO<sub>2</sub> is therefore not presented in this study. Other emissions associated with the manufacturing of paper, but which are rarely measured at the sites, are nitrous oxide (N<sub>2</sub>O), methane (CH<sub>4</sub>), ammonia (NH<sub>3</sub>), non-methane volatile organic compounds (NMVOC), and polycyclic aromatic hydrocarbons (PAH). These emissions were calculated by IVL based on standard emissions factors developed by the Swedish Forest Industries Federation for general paper production (Kindbom et.al. 2006). The covered emissions for the LCA are summarized in Table 4.

**Table 4. Emissions from the manufacturing process at BillerudKorsnäs, included in the LCA.**

Emissions to water	Emissions to air	By IVL calculated emissions
COD	Nitrogen oxides (NO <sub>x</sub> )	CO <sub>2</sub> fossil
Nitrogen	Sulphur (as SO <sub>2</sub> )	N <sub>2</sub> O
Phosphorous		CH <sub>4</sub>
Suspended solids		NH <sub>3</sub>
		NMVOC
		PAH

As a byproduct, tall oil is produced during the manufacturing process; this is reprocessed externally by distillation. The distillation residue is then returned to the mills and used as biofuel in the manufacturing process. The remaining extracted residues are used externally in different products; these residues have not been considered in this LCA.

BillerudKorsnäs purchase electricity from Vattenfall. This was modelled based on information from the supplier, allocated on nuclear and renewable for the year 2013. The renewable part was allocated to wind and hydropower based on 2011 years mix (Vattenfall 2013; Vattenfall 2011), since no later data was found. Upstream data for nuclear and hydro power was based on Vattenfalls

EPDs (EPD 2013; EPD 2011). The mix for 2013 as well as CO<sub>2</sub>-eq. per kWh can be seen in Table 5.

Both Gruvön and Skärblacka sites have excess energy which is used in the long-distance heating system for the close-by society. This was regarded in the system expansion in section 4.3.6.

### **3.2.1.1 Chemicals and fuels**

For the production of chemicals and fuels, database data from PE International and Ecoinvent 2.2 were used. BillerudKorsnäs buys chemicals for the manufacturing process from retailers in different countries, see Appendix I. Hence, modifications of the database data for the chemicals were made when necessary, by substituting European average electricity mix, for country specific electricity, also from database (Ecoinvent 2.2; PE International). For hydrogen peroxide and sodium chlorate, EPD data from the manufacturer Eka chemicals (Eka 2009a and Eka 2009b) were used.

Information about total purchased fuels (diesel and gasoline) for internal transports at the mill were received from BillerudKorsnäs, this was allocated by mass based on yearly total production of Kraft paper, fluting and market pulp. Emissions from the internal transports were calculated with database data.

For transportation of heavy and light fuel oil used in the manufacturing process, as well as for the internal transports, a distance of 200 km by truck was assumed. The impact of using ship has also been investigated and the results of that have shown very little impact on the overall results for the mills (less than 0.05 %).

## **3.2.2 Modelling of the packaging products**

The Kraft paper produced at the BillerudKorsnäs sites are transported to a converter, which manufactures the actual packaging product, likewise for the plastic products. This chapter presents the data used for the different packaging products. There is also a description of the upstream electricity used in the conversion processes as well as the transports.

### **3.2.2.1 Electricity and energy**

The conversion (manufacturing of the packaging product) takes place in either Indonesia or Germany, hence the electricity mix used in this process is country specific. For the German electricity mix, database data from PE International was used. Due to lack of data for Indonesia, it was modelled as described in Itten et.al, 2013, but adjusted to 2012 years mix according to statistics (International Energy Agency, 2014). The energy types and total CO<sub>2</sub>-eq. emitted per kWh for each country mix is presented in Table 5, which also presents the electricity from the Swedish supplier Vattenfall, used in the manufacturing process at Gruvön and Skärblacka.

For thermal energy used in the conversion of the product, natural gas has been assumed. No data for Indonesian natural gas was found, hence, it was approximated with database data for natural gas from New Zealand (PE international).

**Table 5. Energy type and CO<sub>2</sub> emitted per kWh.**

Energy type	Vattenfall (Sweden)	Germany	Indonesia
Renewable	47 %	16.9 %	11.4 %
Nuclear	53 %	22.5 %	0%
Fossil and waste	0 %	60.6 %	88.6 %
g CO <sub>2</sub> -eq. per kWh	6.7 g	600 g	1016 g

### **3.2.2.2 *Transports***

For trucks, trains and ships, database data from PE International were used. Transports by truck within Europe were modelled with a diesel driven truck (euro 4) 28-34 ton gross weight, and 10 ppm sulphur content in the diesel. The same was used for transports within Indonesia, but with 2000 ppm sulphur content in the diesel (Palguna et.al, 2010). All ship transports were modelled with an ocean going ship running on heavy fuel oil with a sulphur content of 1.0 wt %. Train transports were assumed to be driven by electricity.

Sometimes the plastic products can be packed more compact during transport than the paper products, in this case, the utilization factor for the paper products was calculated by volume and for the plastic products, it was calculated by weight. Thus, the paper products are volume limited and the plastic product is limited by weight. As a consequence, the impact from the truck per product is larger for the paper product than for the plastic product. These effects have been considered in the study.

The transport distances and type of vehicles for the plastic and paper solution are summarized in Table 6.



**Table 6. The transport distances for the raw material and the packaging product.**

Product	Material solution	Material transport	Packaging transport (to final customer)
Cement sack	Paper	Train Skärblacka - Hamburg (815 km) Ship Hamburg – Jakarta (16 300 km)	Truck 100 km
	Plastic	Truck 1000 km to Jakarta	Truck 100 km
Pasta bag	Paper	Truck Gruvön - Hamburg (for printing) (855 km) Truck Hamburg - München (for conversion) (775 km)	Truck München - Frankfurt (420 km)
	Plastic	Truck Ludwigshafen- München (400 km)	Truck München - Frankfurt (420 km)
Grocery bag	Paper	Train Skärblacka - Trelleborg (500 km). Truck Trelleborg - Hamburg (400 km)	Truck Hamburg - London (950 km)
	Plastic	Truck 1000 km to Hamburg.	Truck Düsseldorf –London (560 km)
Bottle	Paper	Truck Gruvön – Lund (500 km)	Truck Lund – Malmö (20 km) Ship Malmö – Lübeck (260 km) Train Lübeck – Düsseldorf (460 km). Truck Düsseldorf – Hamburg (400 km)
	Plastic	Truck 1000 km	Truck Düsseldorf – Hamburg (400 km)

### 3.2.2.3 Cement sack

The plastic solution was made from woven polypropylene (WPP). As raw material upstream data, database data of European average polypropylene film were used (PlasticsEurope). The process of making a woven PP sack is to form tape yarn from a polypropylene film. The yarn is then woven to

a fabric using looms; this process resembles the process of weaving textiles (Rogertechnologies, 2014). Hence, energy required for the weaving process was approximated with weaving of fabric, found in Zamani, 2011. Energy for the paper solution was based on Stripple et.al. 2009.

#### ***3.2.2.4 Pasta bag***

The plastic solution was made from polypropylene (PP). For the raw material, database data for European average polypropylene film (PlasticsEurope) were used. Energy required for thermo-sealing the film to a bag, was based on literature data from Siracusa et.al. 2014. Energy for the paper solution was received from BillerudKorsnäs.

#### ***3.2.2.5 Grocery bag***

The plastic solution was modelled as a t-shirt bag (referring to the shape of the bag) in high density polyethylene (HDPE). For raw material upstream data, European average for HDPE, granulate (Ecoinvent 2.2) were used. The extrusion process was based on European average database data from Ecoinvent 2.2 and thermo-sealing the film to a bag was based on literature data from Siracusa et.al. 2014. Energy for the paper solution was based on Stripple et.al 2009.

#### ***3.2.2.6 FibreForm Packaging/PET bottle***

The plastic solution is made from PET, for raw material upstream data, European average data for polyethylene terephthalate (granulate, bottle grade) (PlasticsEurope) were used. Polypropylene, granulate data from Ecoinvent 2.2 were used for the manufacturing of caps. The material is moulded into a bottle by injection blow moulding; this was based on data from PlasticsEurope.

The paper solution is laminated with polyethylene by extrusion coating; energy required for this was calculated based on the specific heat capacity for polyethylene, including heat losses (Gaur et. al. 1981). Other data for the conversion to a FibreForm Packaging bottle were received from BillerudKorsnäs.

## 4 Results

The results from the LCA are presented below, first, as the impact of producing one tonne bleached and unbleached Kraft paper at Gruvön and Skärblacka site, second, as the finished packaging products in both paper and plastic.

### 4.1 Production at BillerudKorsnäs sites

#### 4.1.1 Gruvön

##### 4.1.1.1 Global warming potential

Figure 8 shows the GWP for the production of one tonne bleached Kraft paper at the Gruvön site.

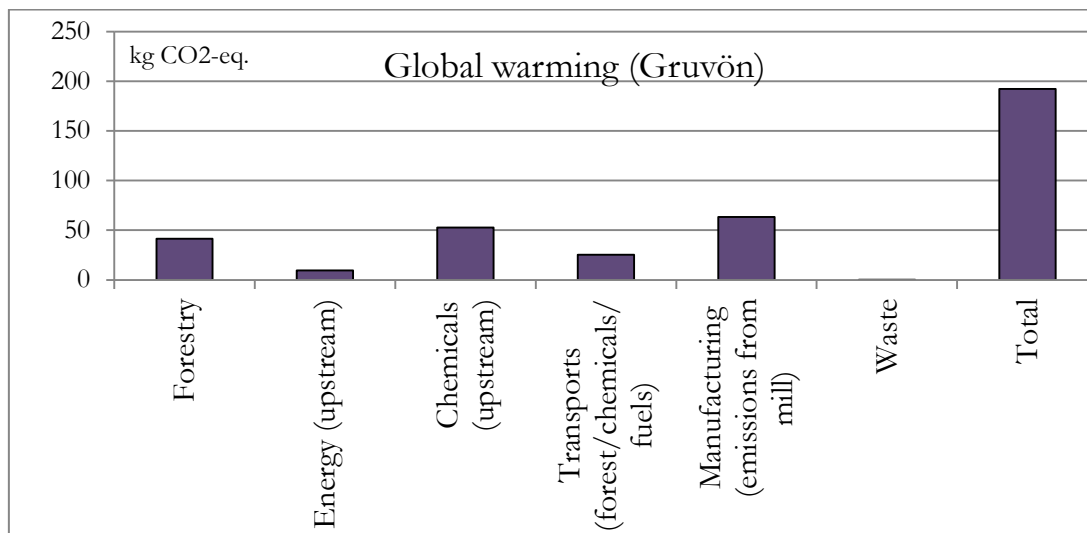


Figure 8. GWP for the production of one tonne bleached Kraft paper at Gruvön mill.

*Forestry* refers to those emissions which are generated during activities in the forest which are required for generating wood such as production of seedlings, silviculture, logging and forwarding.

*Energy (upstream)* refers to those emissions generated during production (upstream) of external energy wares (production of electricity and fuel oil) used in the manufacturing process. Note that the emissions released during combustion of the fuel oil are included in *manufacturing (emissions from mill)*.

*Chemicals (upstream)* refer to those emissions generated during production of the chemicals used in the production of Kraft paper. Hence, these emissions are not emitted at the mill, but where the production of the chemical takes place.

*Transports (forest/chemicals/fuel)* refer to transports of all commodities (forest, chemicals and fuels) to the mill; it also includes upstream production of diesel and gasoline used for internal transportations on the site.

*Manufacturing (emissions from mill)* refers to those emissions which are emitted from the mill as a consequence of paper manufacturing; these emissions are also listed in Table 4. Also, emissions from internal transportations are included in the manufacturing module; these however have a very small impact.

*Waste* refers to the waste which is generated during production of the paper and also transportation of the waste to waste management facility.

The major contributor is the emissions from the mill but chemicals, forestry and transports also make a significant contribution. CO<sub>2</sub> mainly originates from fossil fuels used in the manufacturing process which can be seen in Figure 9. The CO<sub>2</sub> emissions have been calculated based on the energy balance over the mill, whereas nitrous oxide (N<sub>2</sub>O) and methane (CH<sub>4</sub>) have been calculated based on standard emission factors for paper production in Sweden. The impact on GWP for the different chemicals is presented in Figure 10. Lime (CaO) and starch are major contributors. Manufacturing of these chemicals are energy intensive processes. Also, starch originates from agricultural activities, which generally have a high impact on GWP. Both sodium hydroxide and sodium chlorate are produced in electrolytic processes where the production of the electricity (coal power, hydro power, nuclear power etc.) plays an important role for the emission levels. Sulphuric acid can be produced directly for different sulphur sources but can also be a by-product in metal production from different sulphide minerals.

The impact of waste on GWP is almost negligible; this is because the generated waste is mainly inorganic materials, which have no effect on the GWP, hence the major part of the impact from the waste is from transportation to the landfill.

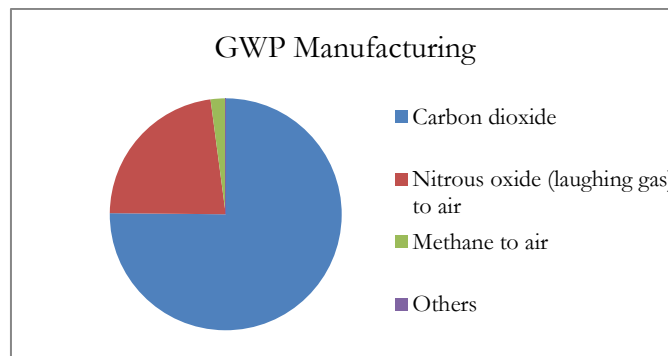


Figure 9. The emissions contribution to GWP from the manufacturing (emissions from mill).

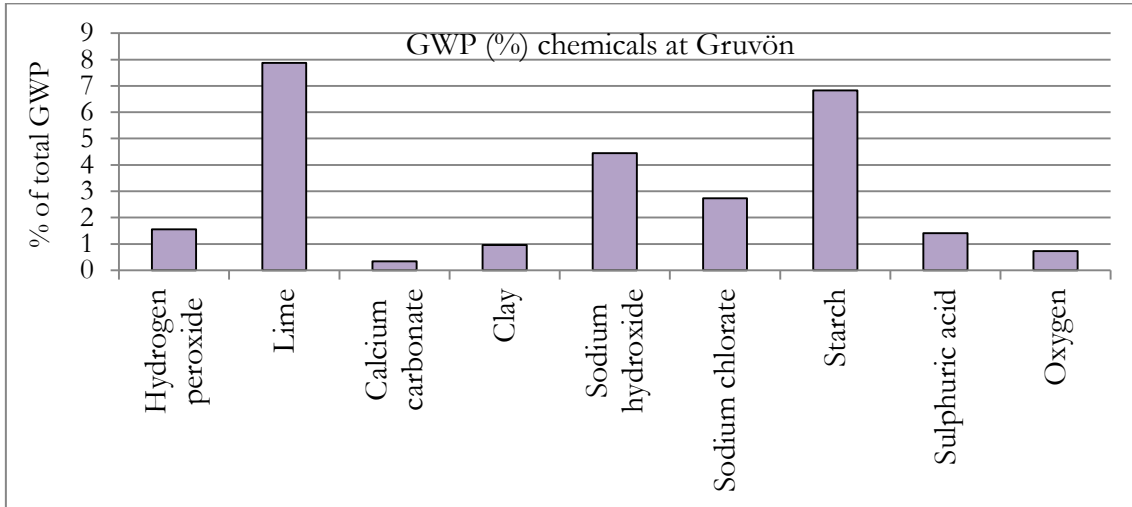


Figure 10. Chemicals contribution (upstream) to the total GWP for Gruvön site (per tonne Kraft paper).

#### 4.1.1.2 Acidification potential

The acidification potential (AP) for Gruvön is shown in Figure 11. The emissions from the manufacturing process is significant, mainly due to the emissions of nitrogen oxides, and also to some extent due to sulphur dioxide and ammonia released to air, see Figure 12. The relatively large contribution from ammonia emissions is also worth to notice. Important sources for ammonia emissions are black liquor melt dissolver, causticizing, white liquor preparation and bark boilers. Upstream production of chemicals as well as transports is also important contributors to the AP, whereas forestry, waste and upstream generation of energy plays a minor role.

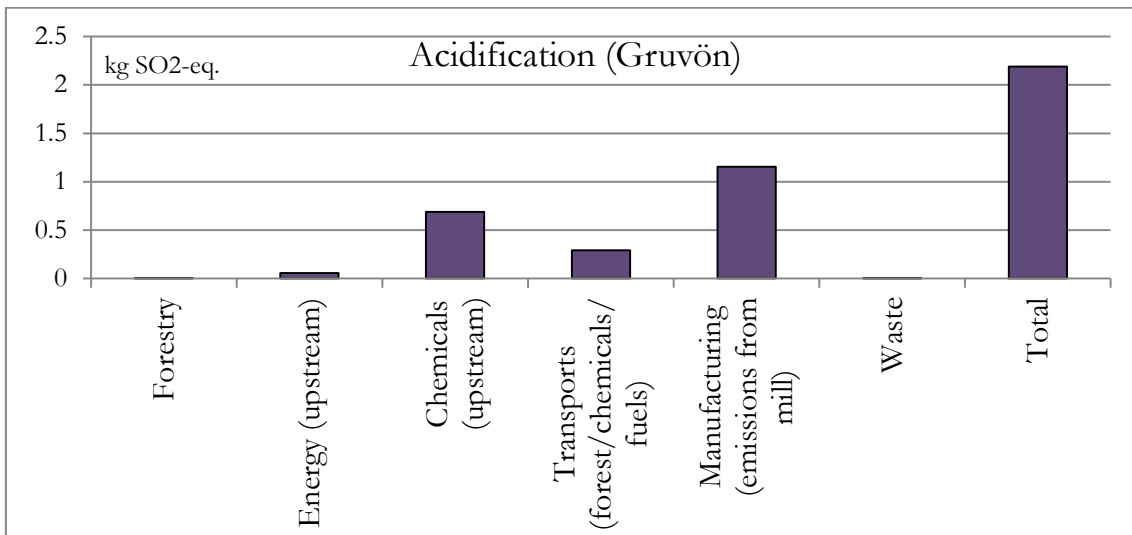


Figure 11. AP for the production of one tonne bleached Kraft paper at Gruvön mill.

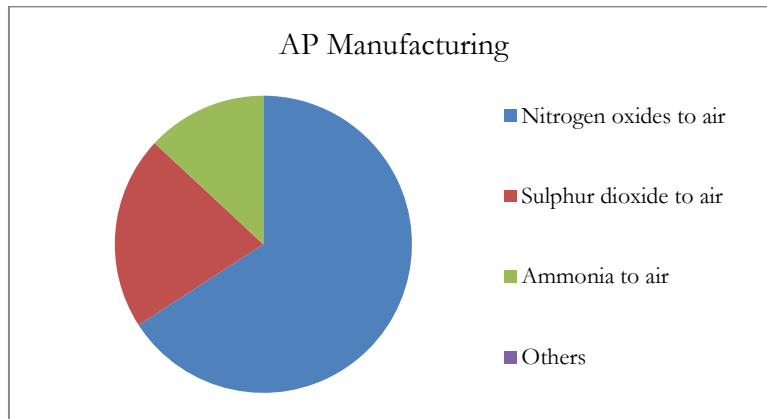


Figure 12. The emissions contribution to AP from the manufacturing (emissions from mill).

#### 4.1.1.3 Eutrophication potential

The results for eutrophication potential (EP) are shown in Figure 13. The emissions from the manufacturing process are dominating the eutrophication potential. This is mainly due to COD, see Figure 14. Upstream production of chemicals and energy as well as transports, forestry and waste, has compared to manufacturing, minor significance to the eutrophication potential.

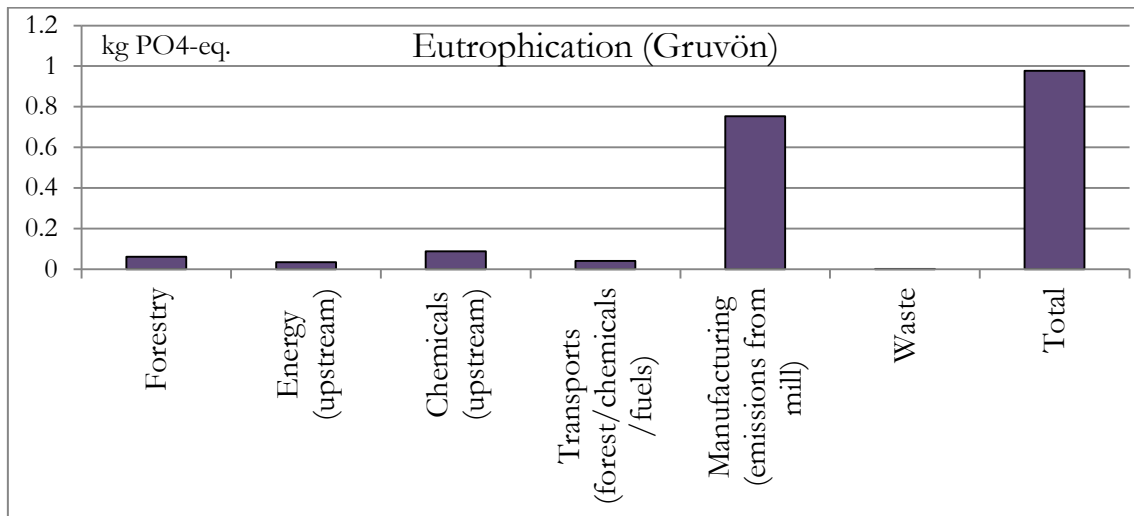


Figure 13. EP for the production of one tonne bleached Kraft paper at Gruvön mill.

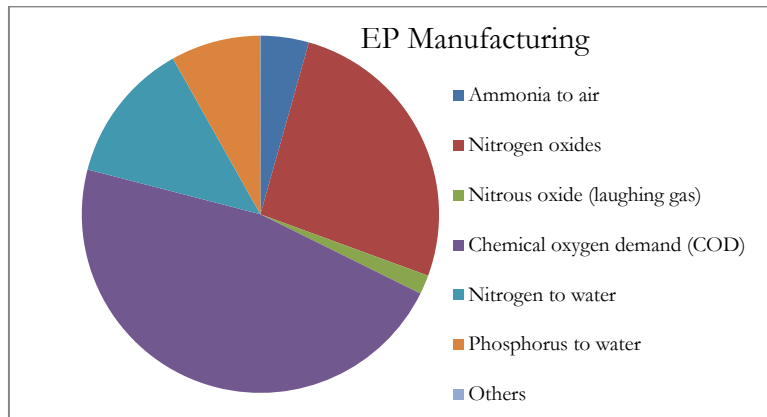


Figure 14. The emissions contribution to EP from the manufacturing (emissions from mill).

#### 4.1.1.4 Photochemical ozone creation potential (POCP)

POCP for Gruvön mill is shown in Figure 15. Emissions from the manufacturing process have the highest impact. Figure 16 shows that nitrogen oxides and NMVOCs released to air are the main contributors for POCP. The impact of transports, forestry, wastes and upstream generation of energy, has compared to manufacturing, minor significance to the POCP.

POCP requires that there is  $\text{NO}_x$  and sunlight present where the oxidants are formed from different hydrocarbons. The value of POCP is hence dependent on the existing quantity (background quantity) of  $\text{NO}_x$  which is set for the characterization factor in question.  $\text{NO}_x$  is however also released from the mill. Hence, it should be mentioned that the POCP can give different results depending on how the background quantity of  $\text{NO}_x$  has been considered for the characterization factor in question.

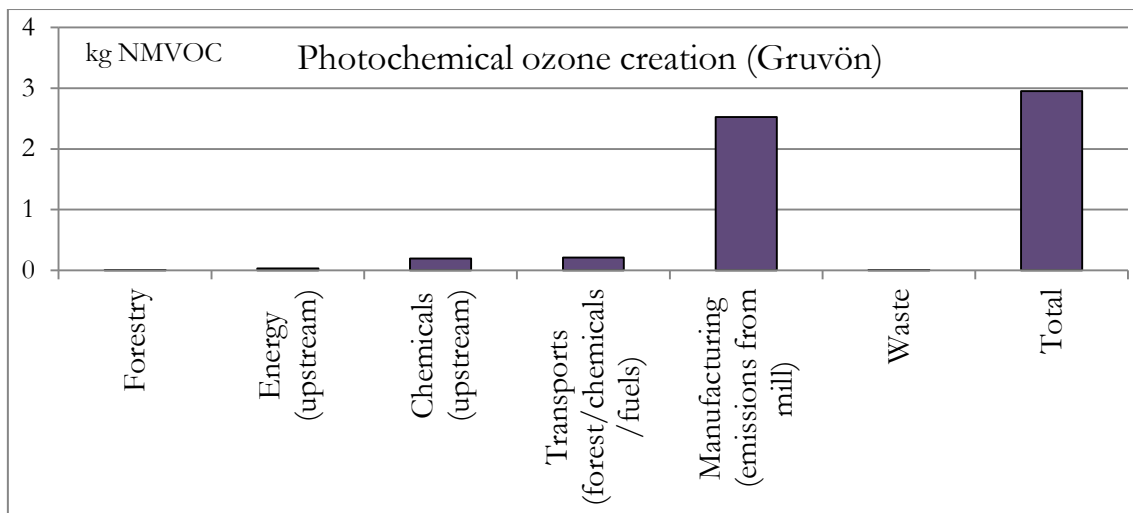


Figure 15. POCP for the production of one tonne bleached Kraft paper at Gruvön mill.

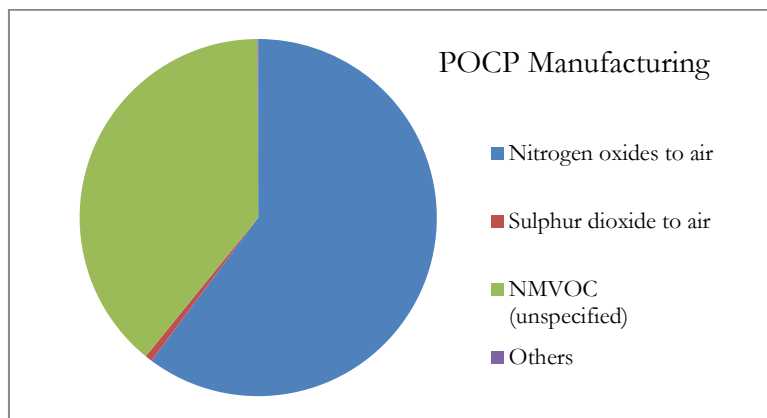


Figure 16. The emissions contribution to POCP from the manufacturing (emissions from mill).

#### 4.1.1.5 Overview impact assessment for Guvön paper mill

AP, EP, GWP and POCP at Guvön mill, are also shown in Figure 17. Here, upstream manufacturing of not only chemicals but also energy and transports have been summarized. Clearly, emissions released during the manufacturing of the paper still have the greatest impact on all KPIs, except GWP, for which the upstream commodities are most important. The main contributor to AP and POCP and also to some extent EP is due to nitrogen oxides emitted to air during the manufacturing process. Emissions associated with forestry are most relevant for GWP and EP, and less for AP or POCP.

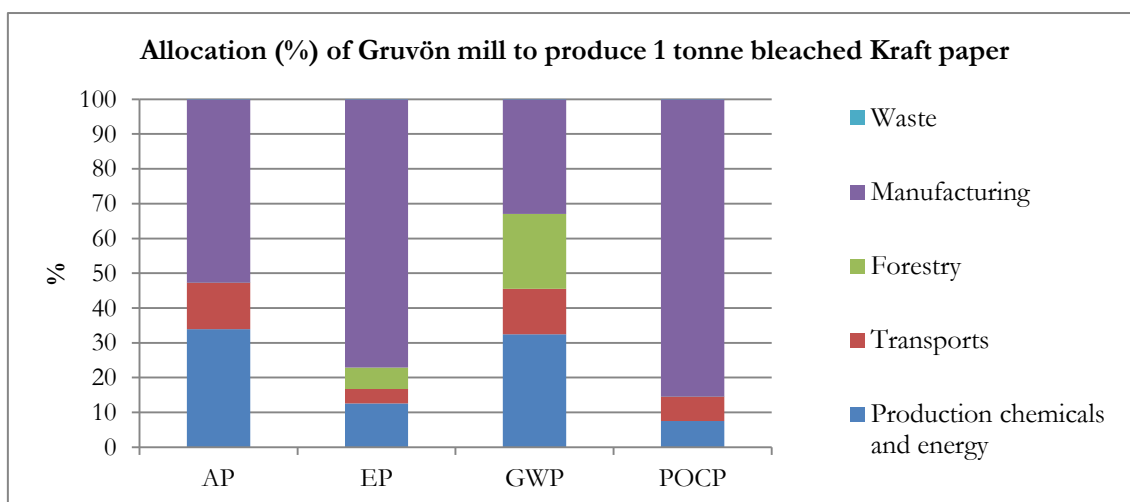


Figure 17. This diagram shows the allocation of the different activities at Guvön mill for production of the bleached Kraft paper used for the pasta bag and FibreForm Packaging bottle.



## 4.1.2 Skärblacka

### 4.1.2.1 Global warming potential

Figure 18 shows the GWP for the production of one tonne unbleached Kraft paper at the Skärblacka site.

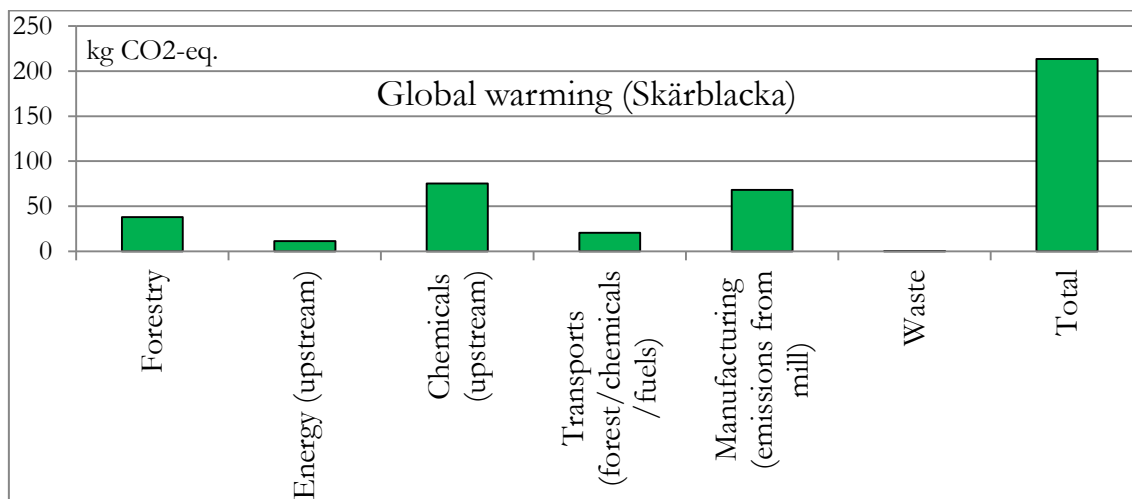


Figure 18. GWP for the production of one tonne unbleached Kraft paper at Skärblacka mill.

*Forestry* refers to those emissions which are generated during activities in the forest which are required for generating wood such as production of seedlings, silviculture, logging and forwarding.

*Energy (upstream)* refers to those emissions generated during production (upstream) of external energy wares (production of electricity and fuel oil) used in the manufacturing process. Note that the emissions released during combustion of the fuel oil are included in *manufacturing (emissions from mill)*.

*Chemicals (upstream)* refer to those emissions generated during production of the chemicals used in the production of Kraft paper. Hence, these emissions are not emitted at the mill, but where the production of the chemical takes place.

*Transports (forest/chemicals/fuel)* refer to transports of all commodities (forest, chemicals and fuels) to the mill; it also includes upstream production of diesel used for internal transportations on the site.

*Manufacturing (emissions from mill)* refers to those emissions which are emitted from the mill as a consequence of paper manufacturing. These emissions are also listed in Table 4. Also, emissions from internal transportations are included in the manufacturing module; these however have a very small impact.

*Waste* refers to the waste which is generated during production of the paper, and also transportation of the waste to the waste management facility.

The major contributors are emissions associated with the production of chemicals used in the manufacturing process. Secondly important are the emissions from the mill, mainly CO<sub>2</sub> originating

from fossil fuels used during manufacturing, which can be seen in Figure 19. The CO<sub>2</sub> emissions have been calculated based on the energy balance over the mill, whereas nitrous oxide and methane have been calculated based on standard emission factors for paper production in Sweden.

The impact on GWP for the different chemicals is presented in Figure 20. The production of sodium hydroxide is an electric energy demanding process. Gruvön uses a higher amount of sodium hydroxide than Skärblacka per tonne paper; however, Gruvön purchases sodium hydroxide from a producer in Sweden, whereas Skärblacka purchases from the Netherlands. Hence, the impact of sodium hydroxide becomes larger for Skärblacka than Gruvön, due to higher greenhouse gas emissions from the Dutch electricity mix than from the Swedish average electricity mix. The emission factors used for European, Swedish, and Dutch electricity are given in Table 10 in appendix 1.

The impact of waste on GWP is almost negligible; this is because the generated waste is mainly inorganic materials, which have no effect on the GWP, hence the major part of the impact from the waste is from transportation to the landfill.

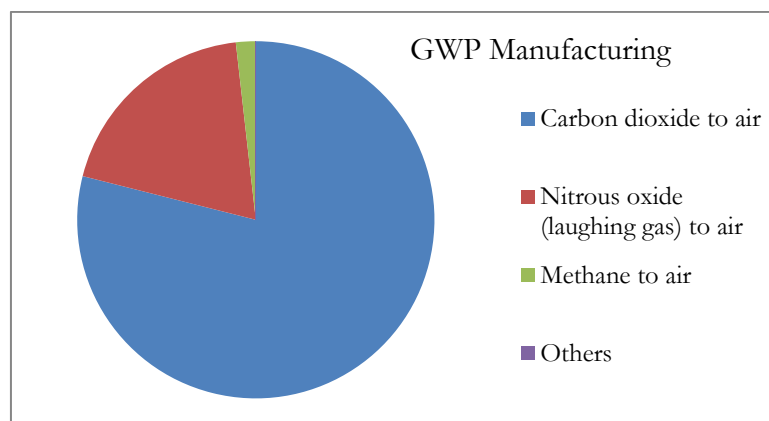


Figure 19. The emissions contribution to GWP from the manufacturing (emissions from mill).

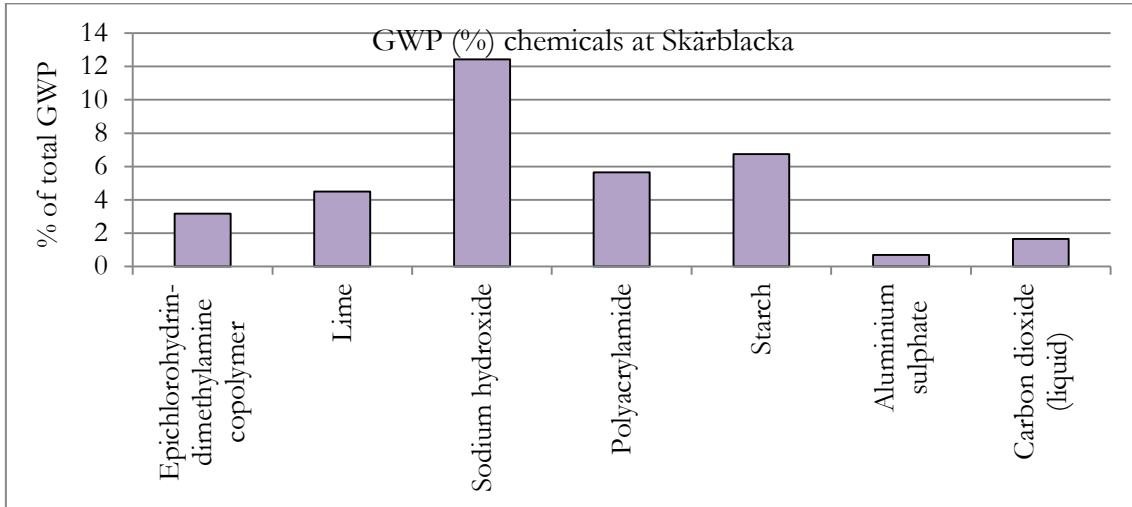


Figure 20. Chemicals contribution (upstream) to the total GWP for Skärblacka site (per tonne Kraft paper).

#### 4.1.2.2 Acidification potential

The acidification potential (AP) for Skärblacka is shown in Figure 21; here are the emissions from the manufacturing process most contributing to the AP, mainly due to emissions of nitrogen oxides and sulphur dioxide released to air, shown in Figure 22. Upstream production of chemicals is the second largest contributor to the acidification potential, whereas transports, forestry, waste and upstream generation of energy has minor significance.

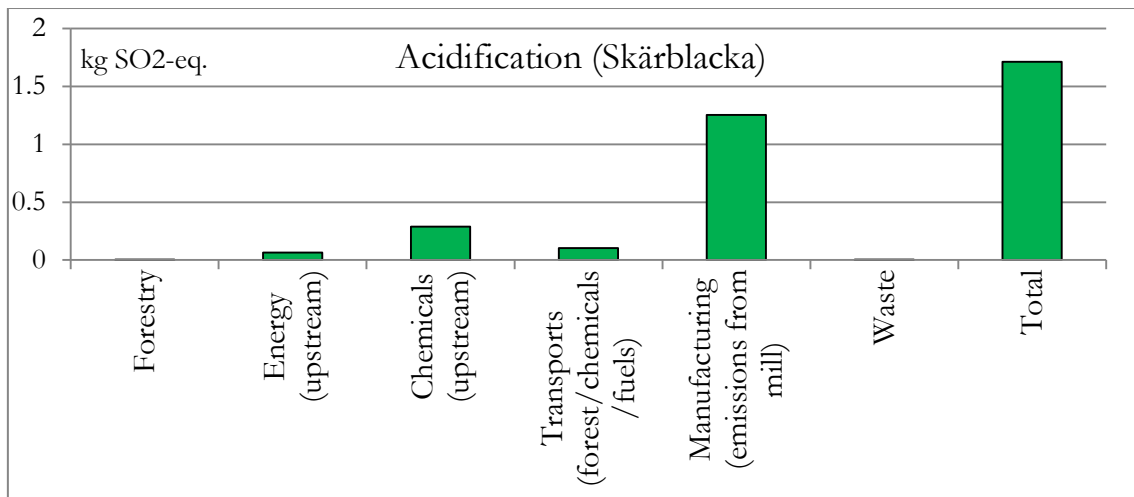


Figure 21. AP for the production of one tonne unbleached Kraft paper at Skärblacka mill.

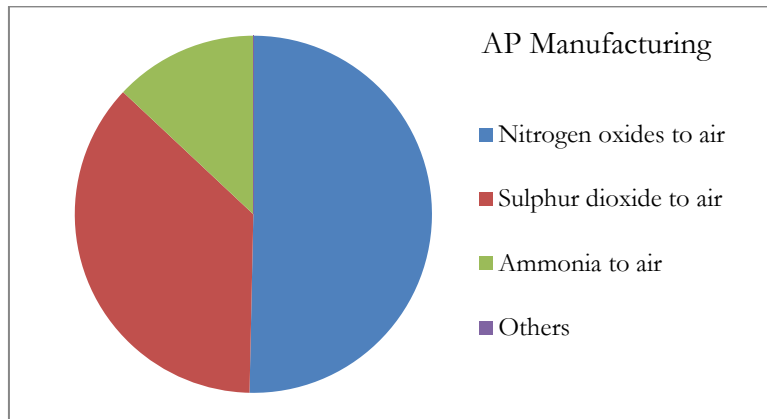


Figure 22. The emissions contribution to AP from the manufacturing (emissions from mill).

#### 4.1.2.3 Eutrophication potential

The eutrophication potential (EP) for Skärblacka mill is presented in Figure 23. Emissions from the paper mill have the largest impact. This is due to the high amount of COD and nitrogen released to water and nitrogen oxides to air (see Figure 24). Chemicals are the second most important contributor, whereas transports, forestry, waste and upstream generation of energy has minor significance to the eutrophication potential for Skärblacka.

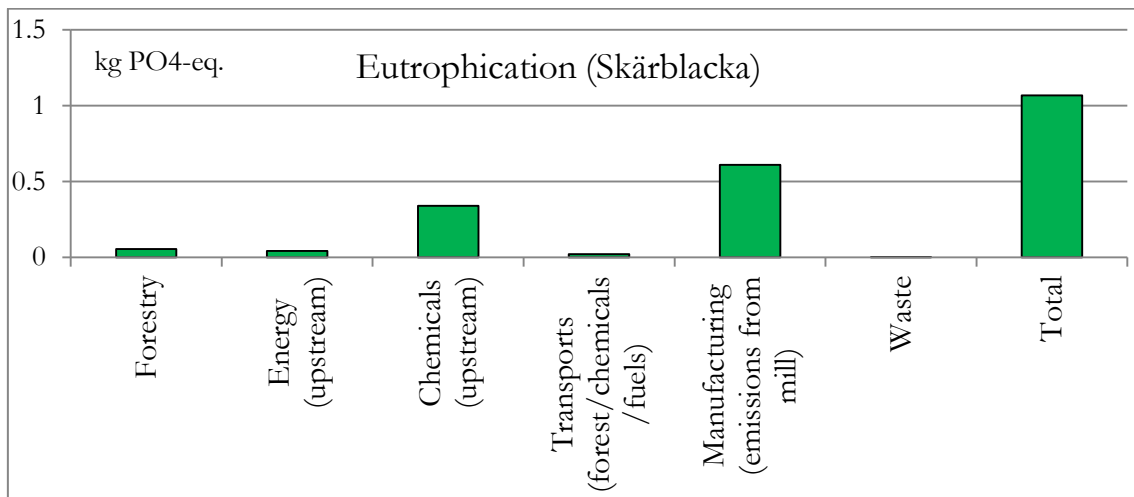


Figure 23. EP for the production of one tonne unbleached Kraft paper at Skärblacka mill.

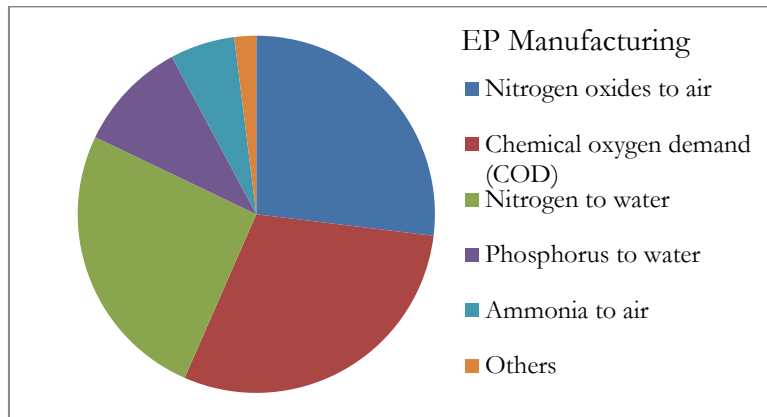


Figure 24. The emissions contribution to EP from the manufacturing (emissions from mill).

#### 4.1.2.4 Photochemical ozone creation potential (POCP)

POCP is shown in Figure 25. Emissions from the manufacturing process have the highest impact; Figure 26 shows that nitrogen oxides and NMVOCs released to air are the major contributors to this<sup>1</sup>. Chemicals have the second largest impact, even though their impact on POCP is relatively small. This is also the case for transports, forestry, waste and upstream generation of energy.

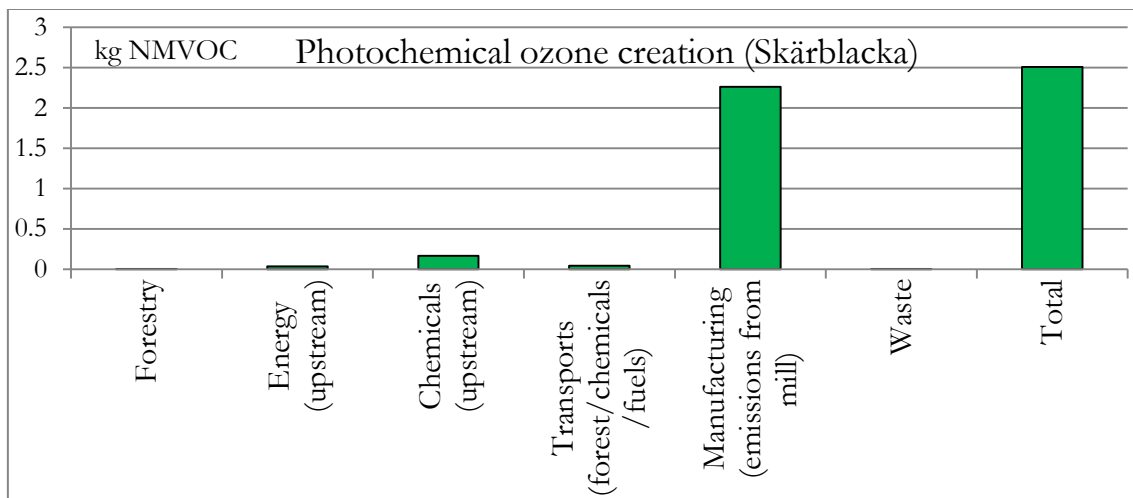


Figure 25. POCP for the production of one tonne unbleached Kraft paper at Skärblacka mill.

<sup>1</sup> See also comments in chapter 4.1.1.4

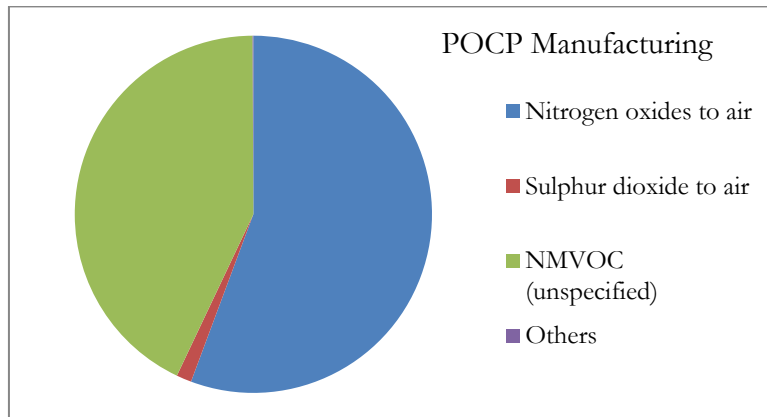


Figure 26. The emissions contribution to POCP from the manufacturing (emissions from mill).

#### 4.1.2.5 Overview impact assessment for Skärblacksa paper mill

AP, EP, GWP and POCP at Skärblacksa mill, are also shown in Figure 27 Here, upstream manufacturing of not only chemicals but also energy and transports have been summarized. Clearly, emissions released during the manufacturing of the paper still have the greatest impact on all KPIs, except GWP, for which the upstream commodities are most important. The main contributor to manufacturing for AP and POCP and also to some extent EP is due to nitrogen oxides emitted to air during the manufacturing process. Emissions associated with forestry are most relevant for GWP and EP and less for AP or POCP.

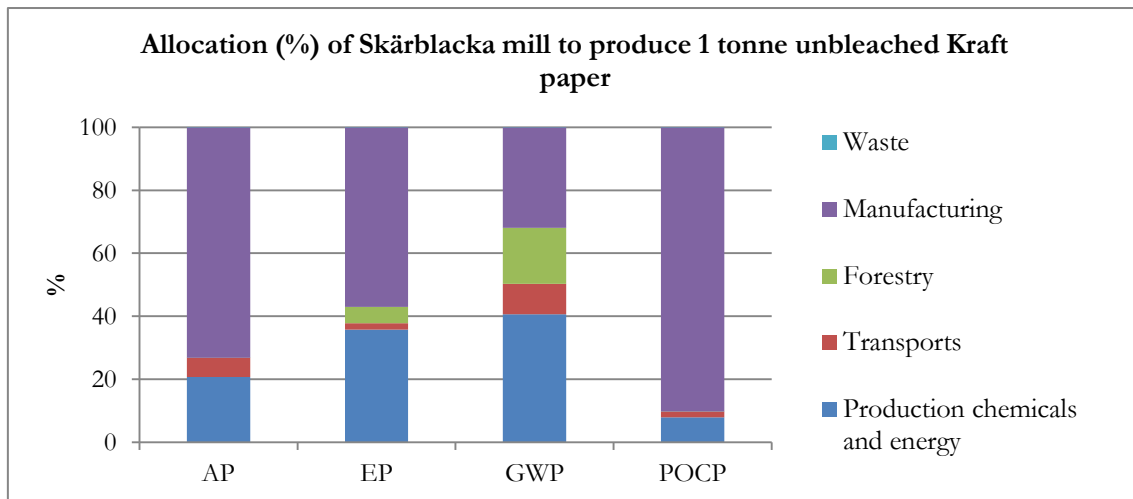


Figure 27. This diagram shows the allocation of the different activities at Skärblacksa mill for production of the unbleached Kraft paper used for the grocery bag and the cement sack.

## 4.2 Packaging products in paper and plastic

Below are the results from the LCA of the packaging products in paper and plastic presented. It should be kept in mind when looking at the results that the weight per functional unit is different both between the compared plastic and paper product, and also between the four product groups. Hence, the relationship between paper and plastic between the product groups is varying. Also, all plastic materials have been assumed to be virgin material, meaning no account to, for instance recycled PET, has been taken and no recycled material has neither been used in the paper products.

### 4.2.1 Cement sack

The material production is dominating the GWP for the plastic sack, whereas for the paper sack, it is the packaging production. The packaging production of both the paper and plastic sack is energy intense, this in combination with large share of fossil energy, especially lignite, in the Indonesian electricity mix, which affects not only the GWP but also EP and AP due to high emissions of phosphate and sulphur dioxide, leads to the high impact of the packaging production on GWP, EP and AP for both the plastic and paper product.

POCP and AP are highly affected by the transport of the Kraft paper from Skärblacka to Indonesia. On regard to AP, the paper sack has an advantage over the locally produced plastic sack, even though the Kraft paper has to be transported from Sweden, whereas the POCP show an advantage for the plastic sack. If the plastic sacks also had been imported to Indonesia, the differences in the transport impacts also had been reduced.

It should be mentioned that for the paper cement sack, the oxidant (ozone) formation from the transports which affects POCP occurs at sea, since the paper is shipped to Indonesia. Even though the ship emits  $\text{NO}_x$ , the background quantities of  $\text{NO}_x$  at sea, are probably quite low. This can lead to an overestimation of the POCP for the material transport of the paper. Also, there is the possibility that if the ozone creation takes place far out on the sea; it does not cause as much damage as if the emissions would have taken place on land. This depends of course on the ship route and the weather/wind conditions.

The impact of the packaging transport is almost insignificant; this is because the distance to customer is relatively short.

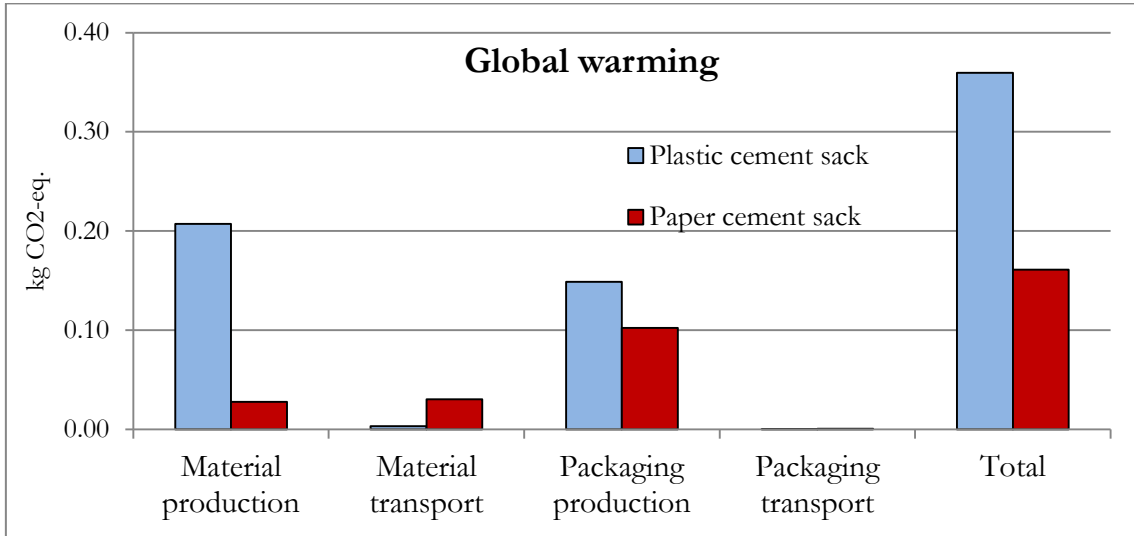


Figure 28. Comparison of GWP between a cement sack in paper from BillerudKorsnäs and a competitive sack in plastic (PP) produced in Indonesia

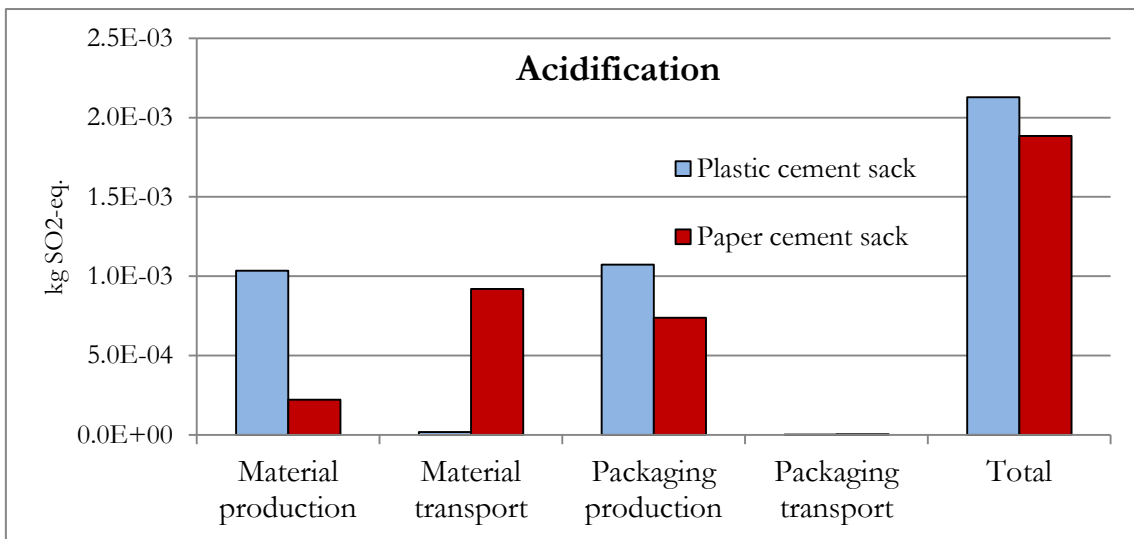


Figure 29. Comparison of AP between a cement sack in paper from BillerudKorsnäs and a competitive sack in plastic (PP) produced in Indonesia.



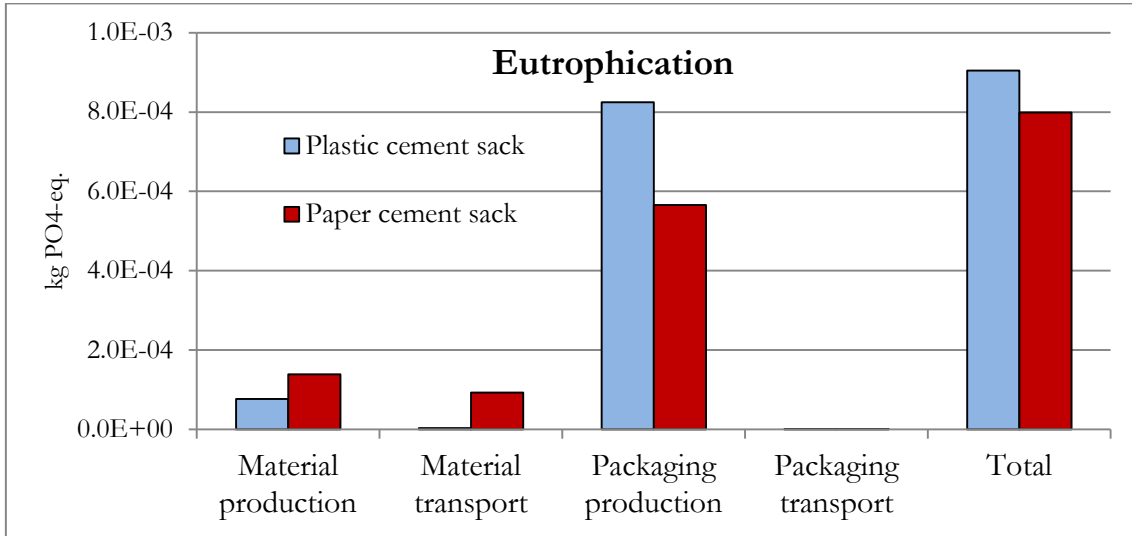


Figure 30. Comparison of EP between a cement sack in paper from BillerudKorsnäs and a competitive sack in plastic (PP) produced in Indonesia.

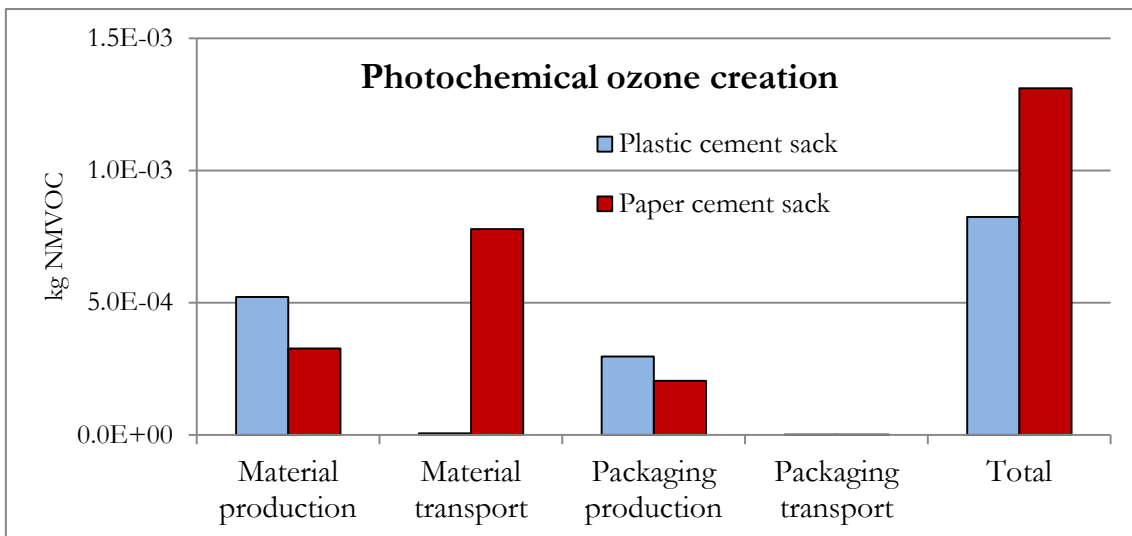


Figure 31. Comparison of POCP between a cement sack in paper from BillerudKorsnäs and a competitive sack in plastic (PP) produced in Indonesia.

#### 4.2.2 Pasta bag

The material production is dominating for all KPIs except GWP for the paper product. The packaging production of the paper pasta bag is somewhat more energy demanding than for the plastic pasta bag. This is however outweighed by the impact of raw material production, which for polypropylene is associated with much higher emissions than for the Kraft paper, this is true for all

KPIs except EP. The reason for this is due to the COD and nitrogen oxides emissions released during the manufacturing at Gruvön mill; this can also be seen in Figure 14

The plastic bags can be packed more compact during transport than the paper bags, hence, the paper bags are volume limited and the plastic bag is limited by weight. Therefore, in this case, the plastic bag has an advantage during packaging transport, since more bags can be packed in one truck. As a consequence, the impact from the truck per bag is larger for the paper bag than for the plastic. However, the total impact of the packaging transport is almost insignificant; this is because the distance to customer is relatively short.

The overall results show an advantage for the paper pasta bag for all KPIs except EP.

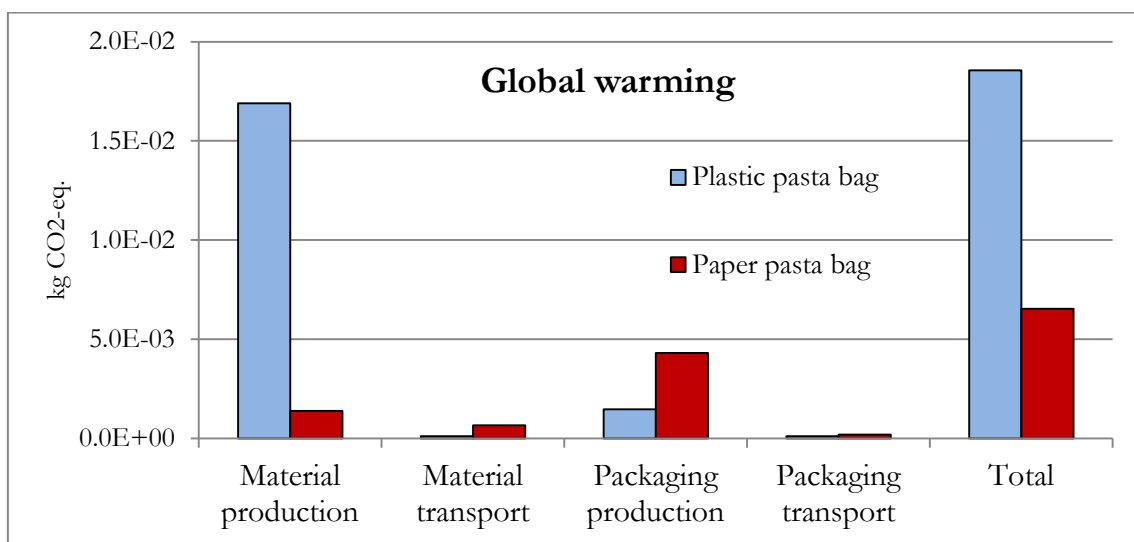


Figure 32. Comparison of GWP between a pasta bag in paper from BillerudKorsnäs and a competitive bag in plastic (PP).

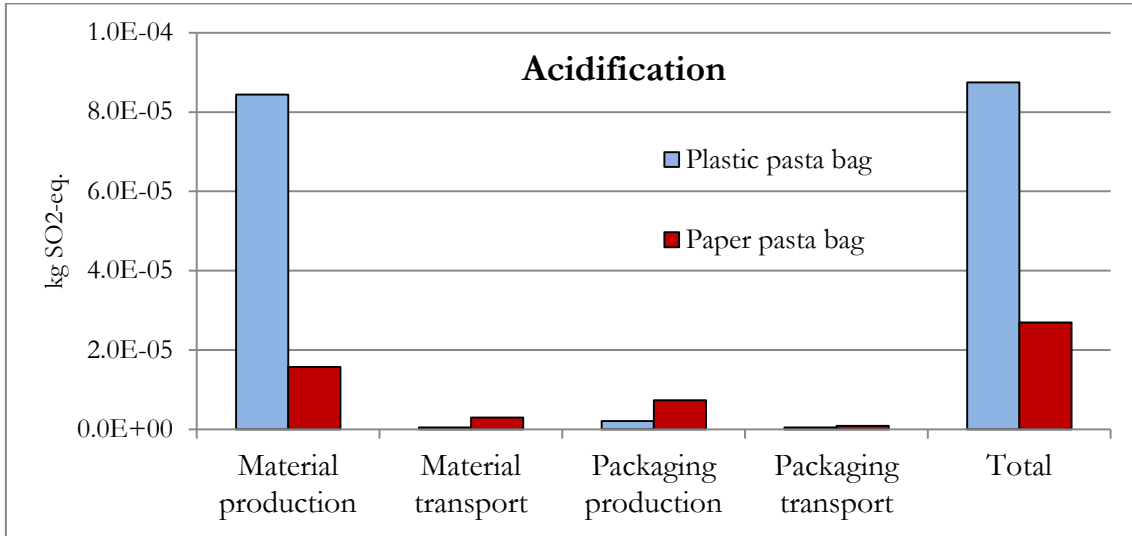


Figure 33. Comparison of AP between a pasta bag in paper from BillerudKorsnäs and a competitive bag in plastic (PP).

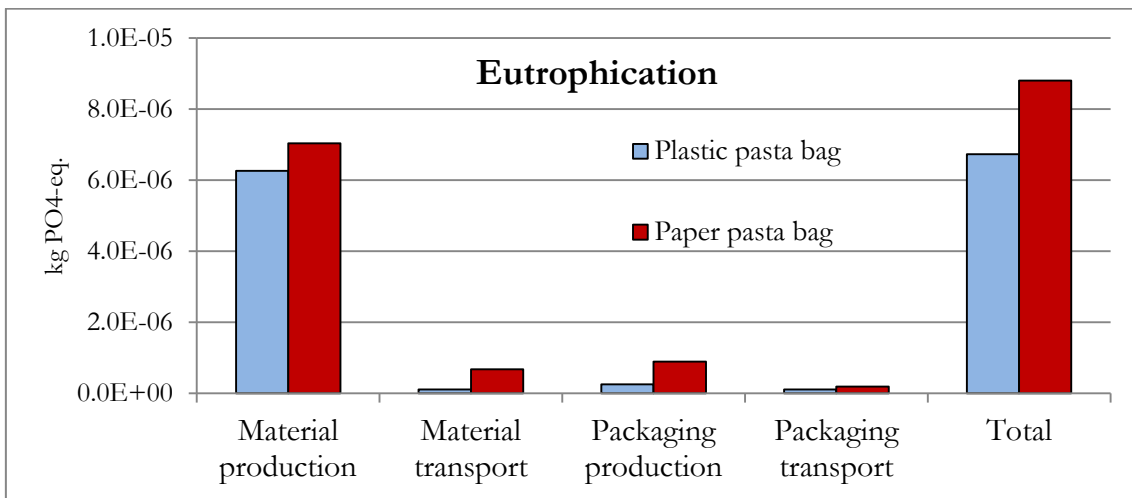


Figure 34. Comparison of EP between a pasta bag in paper from BillerudKorsnäs and a competitive bag in plastic (PP).

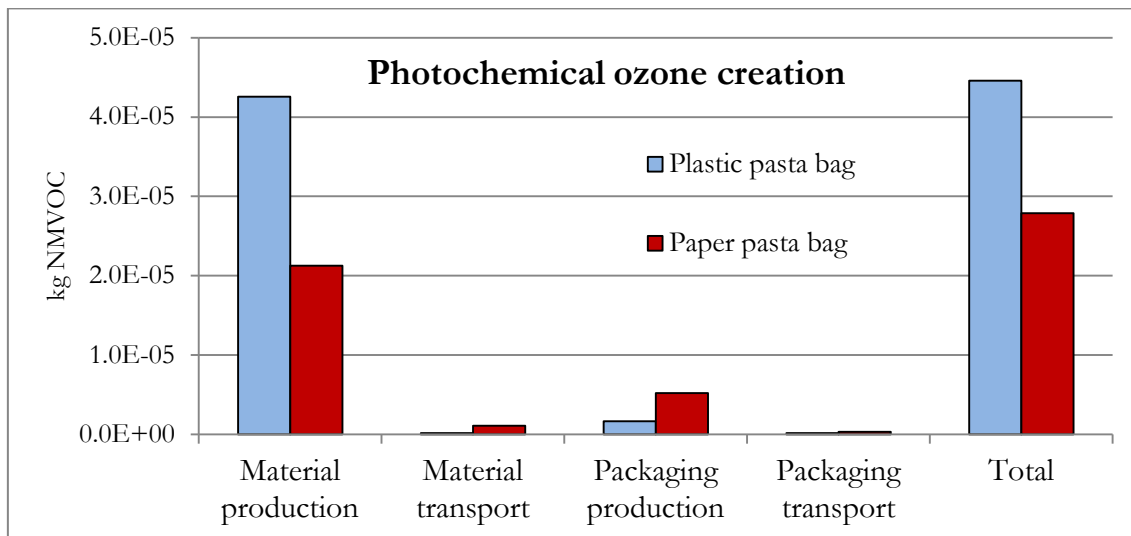


Figure 35. Comparison of POCP between a pasta bag in paper from BillerudKorsnäs and a competitive bag in plastic (PP).

### 4.2.3 Grocery bag

The material production is dominating for all KPIs, both for the paper and plastic bag. The packaging production process for the paper bag is somewhat more energy demanding than for the plastic bag, this is however outweighed by the impact of producing the plastic material (HDPE), which is associated with higher emissions than for the production of the Kraft paper regarding GWP and AP.

The impact of material production on POCP for the plastic and paper materials are more comparable, and since material production is dominating the POCP, the total results for the plastic and paper grocery bag becomes very similar, with a total difference of only 0.6 %.

The paper bag has a higher impact on EP than the plastic bag. This is because of the high amount of COD and nitrogen to water, and nitrogen oxides to air, which are emitted from the Kraft paper manufacturing at Skärblacka.

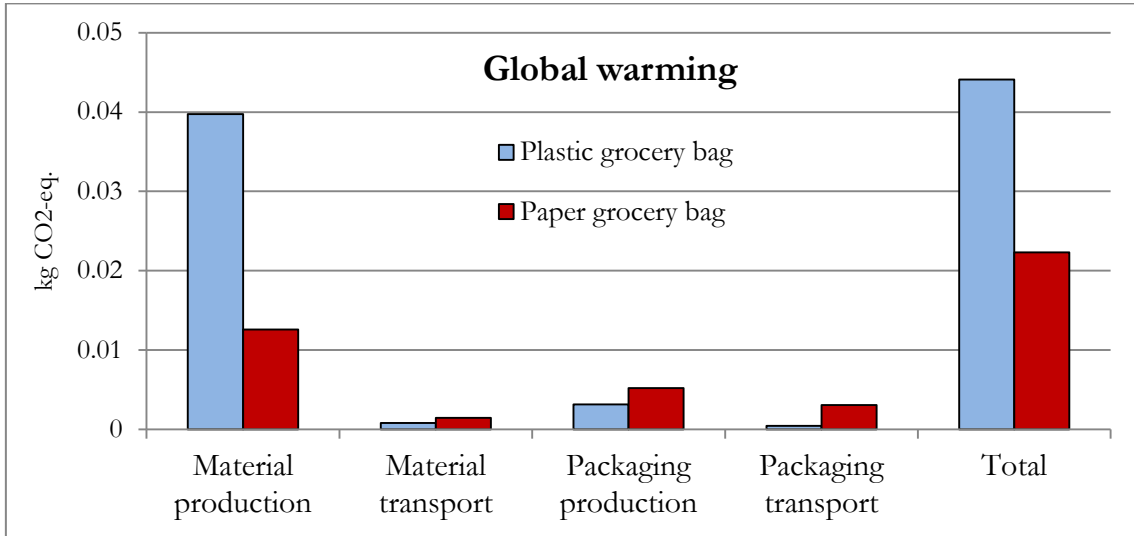


Figure 36. Comparison of GWP between a grocery bag in paper from BillerudKorsnäs and a competitive bag in plastic (HDPE).

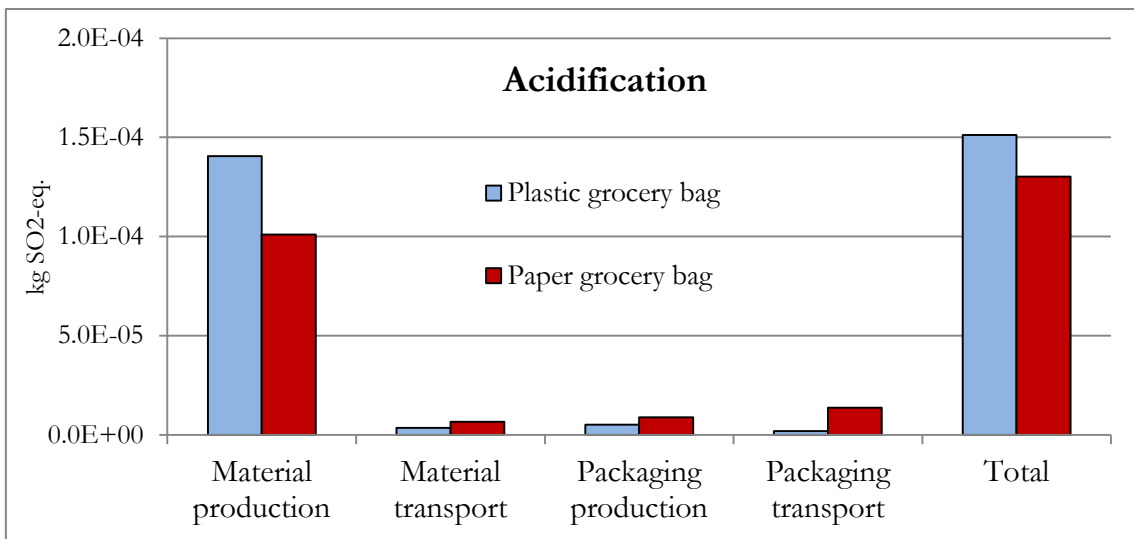


Figure 37. Comparison of AP between a grocery bag in paper from BillerudKorsnäs and a competitive bag in plastic (HDPE).

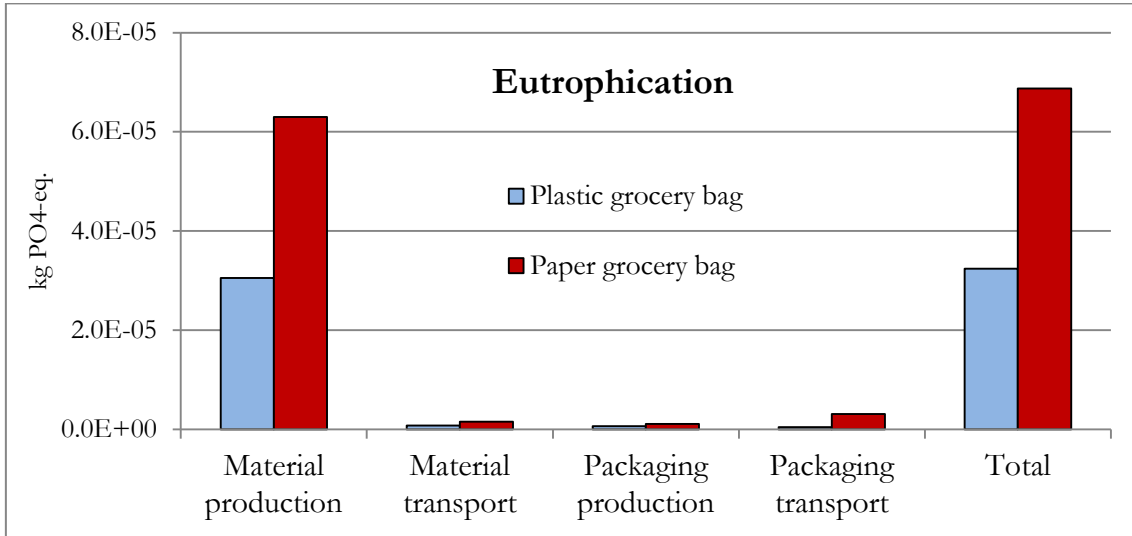


Figure 38. Comparison of EP between a grocery bag in paper from BillerudKorsnäs and a competitive bag in plastic (HDPE).

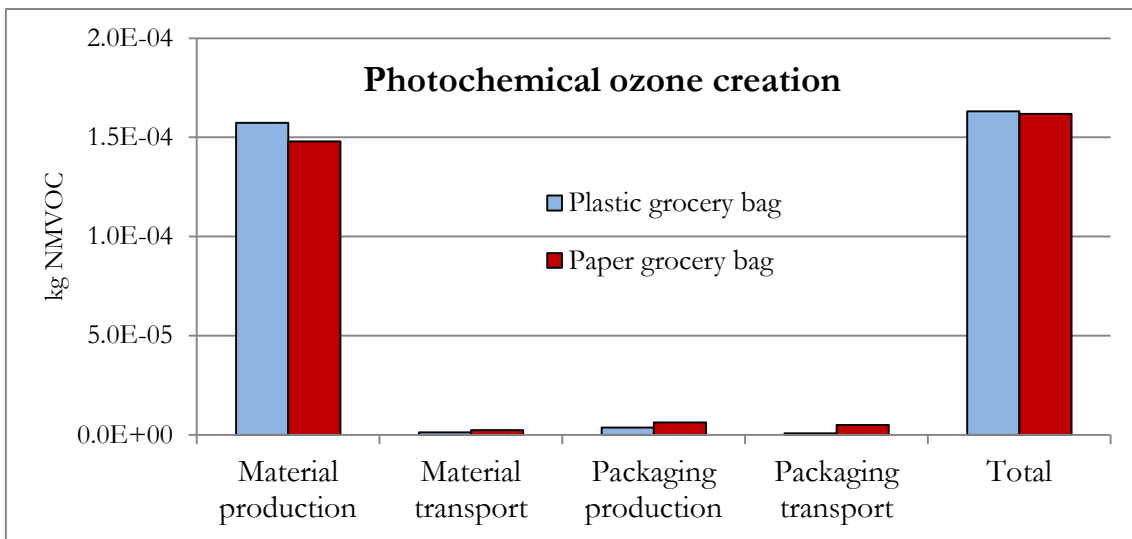


Figure 39. Comparison of POCP between a grocery bag in paper from BillerudKorsnäs and a competitive bag in plastic (HDPE).

#### 4.2.4 Bottle

The material production is dominating for all KPIs, both for the FibreForm Packaging bottle and the PET bottle. Even though manufacturing of Kraft paper are associated with high EP, emissions of nitrogen oxides and phosphates from the manufacturing of PET, gives a higher impact on EP than for FibreForm Packaging bottle. Also, the energy for manufacturing the PET bottle is higher than for FibreForm Packaging bottle.

Material production also includes emissions associated with manufacturing of the caps, laminate and the LDPE ring. The impact of these on GWP is presented separately in Figure 41 (PET bottle) and Figure 42 (FibreForm Packaging bottle). The results in Figure 41 is explained by the greater amount of PET required to produce a bottle, than PP (used for the caps), also, the PET material has a higher GWP than the PP per kg. Figure 42 shows that the impact on GWP from the production of the plastic details is of major significance on GWP for the FibreForm Packaging bottle, due to higher greenhouse gas emissions from manufacturing the plastic details than from the manufacturing at Gruvön, per piece FibreForm Packaging bottle.

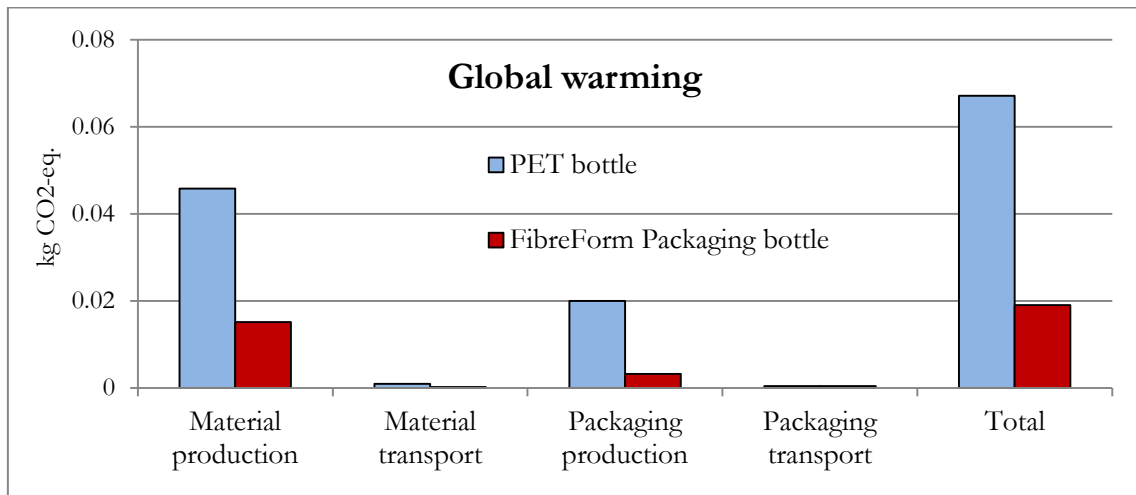


Figure 40. Comparison of GWP between a FibreForm Packaging bottle in paper from BillerudKorsnäs and a competitive bottle in plastic (PET).

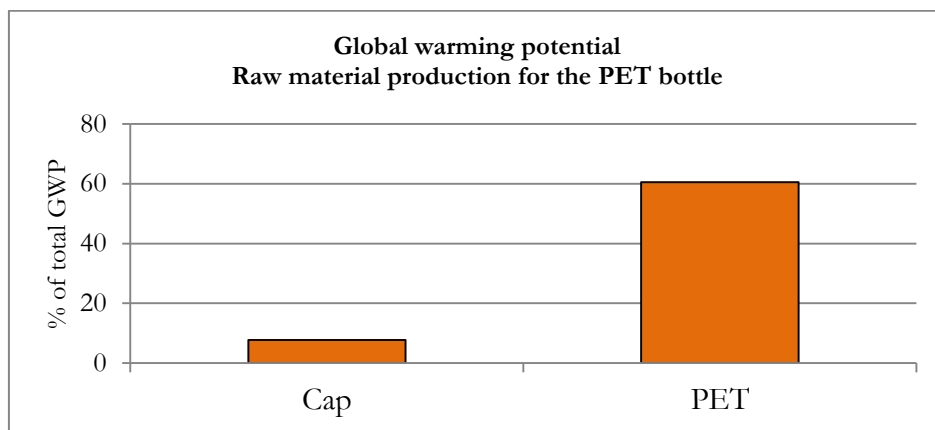


Figure 41. GWP allocated to the different raw materials used for the PET bottle.

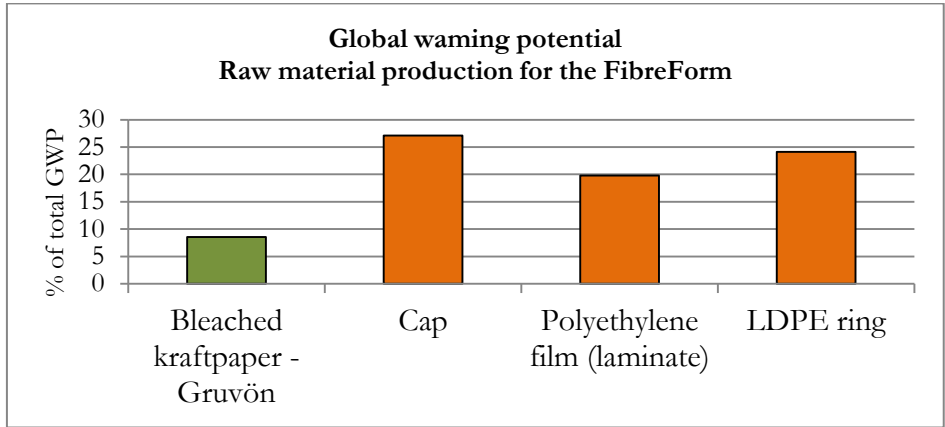


Figure 42. GWP allocated to the different raw materials used for FibreForm Packaging bottle.

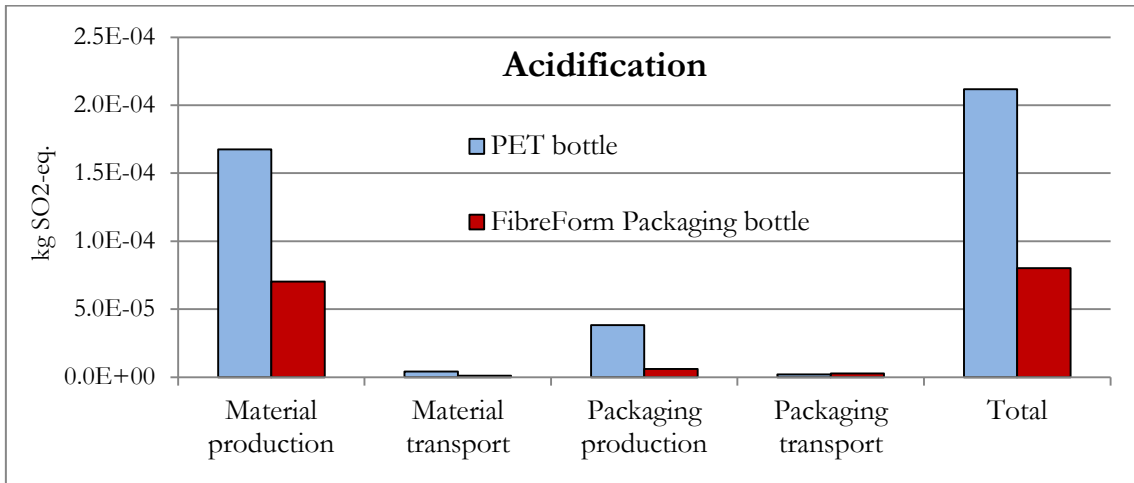


Figure 43. Comparison of AP between a FibreForm Packaging bottle in paper from BillerudKorsnäs and a competitive bottle in plastic (PET).

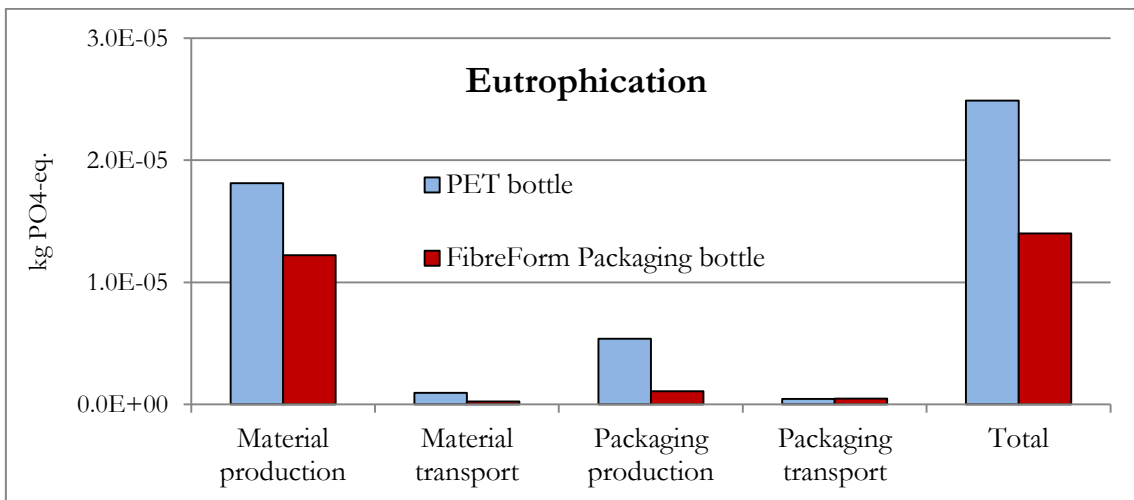




Figure 44. Comparison of EP between a FibreForm Packaging bottle in paper from BillerudKorsnäs and a competitive bottle in plastic (PET).

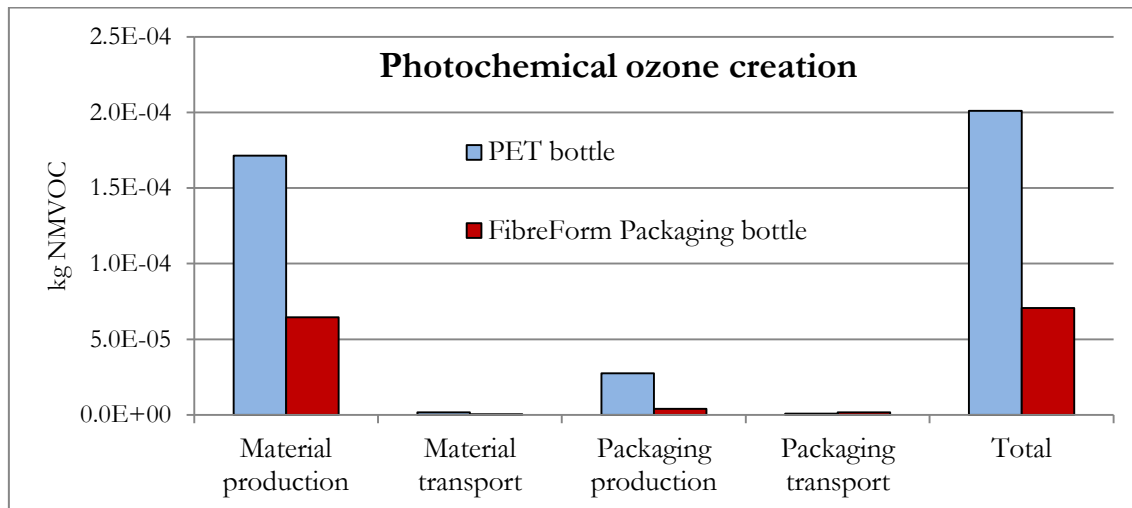


Figure 45. Comparison of POCP between FibreForm Packaging bottle in paper from BillerudKorsnäs and a competitive bottle in plastic (PET)

### 4.3 System expansion and its effects by utilization of formed energy

System expansion means that the stated system boundaries are modified. This is performed to show the effect the processes in a system can have on the surrounding society and to include these effects in the study and in the results. It should be observed that the system expansion of this assessment is not part of the directly related impact of the product. However, the effects are real but are shown separately by convention in the LCA methodology. A typical example of system expansion is to include the positive effects of the use of the heat from waste incineration or process waste heat in the surrounding society. The use of waste heat is an important method for saving energy resources and reducing emissions. It is thus important to show and promote these aspects. In this study, two separate system expansions were made:

- Including end-of-life for the packaging products.
- Including the excess energy generated at the paper mills, which is utilized for district heating in the close-by societies.

#### 4.3.1 End-of-life for packaging products

End-of-life was assumed to take place in the same country as where the products are used, also shown in Table 2. End-of-life was modelled as average waste management scenario for the material and specific country in question, seen in Table 7. This was based on information from statistical databases for the European countries (Eurostat 2014). For plastic in Indonesia, data from Chaerul et al., 2012 was used. Data for paper in Indonesia was based on Meidiana et al. 2010.

**Table 7. Waste scenario for each country, based on statistics (Eurostat 2014; Chaerul et. al 2012; Meidiana et. al. 2010).**

Waste management	Germany	UK	Indonesia <sup>2)</sup>
Recycling paper	88 %	85 %	2 %
Incineration paper <sup>1)</sup>	12 %	10 %	0 %
Landfill paper	0 %	5 %	70 %
Recycling plastic	48.5 %	24 %	37 %
Incineration plastic <sup>1)</sup>	51 %	11 %	0 %
Landfill plastic	0.5 %	65 %	35 %

1) *Incineration which includes energy recovery, both electric and thermal.*

2) *Besides recycling and landfill, waste is also burned openly, disposed on streets/in rivers/in parks, buried, etc. meaning without any energy recovery. For paper this part is 28%. The same amount was assumed for plastic waste. Since no information about this is known, this part is considered as a data gap in the model. As a consequence, these emissions have been neglected and hence the effect from waste management in Indonesia might be somewhat underestimated.*

The possible scenarios are recycling, incineration with energy recovery and landfill. When the material, plastic or paper is recycled, virgin material is most probably replaced, this was assumed in the model. In this study, the emissions from the recycling process have been allocated to the product in question, and the avoided emissions from virgin material production have been subtracted.

The reason for 0 % incineration of paper and plastic in Indonesia is that there aren't any incineration plants which have energy recovery for paper and plastic reported in the literature.

In the recycling process of plastic, there are always material losses, which mean that it can never be 100% replacement of virgin material. This is called the recycling rate, and for plastic it was assumed to be 60 %, meaning 1 kg recycled material replaces 0.6 kg virgin material, and the remaining part is incinerated with energy recovery. This has been considered in the modelling. Energy and material utilization as well as substitution rate of virgin material for recycling of PP, HDPE and PET was based on Nishijima et al. 2011.

For the recycling scenario it has been assumed that virgin material for both the paper and plastic products produces the wastes, which in turn goes to recycling. During recycling this material is assumed to replace other virgin material production, hence emissions from other virgin material production are considered to be avoided, this is called avoided emissions. No effects from possible future recycling processes have been taken into account in this study.

Database data (PE International) were used for modelling the recycling scenario for plastics. The paper recycling process was approximated with the production of Testliner and Wellenstoff (which is paper used for corrugated board made from recycled Fibres), with data from Fefco 2012, including credits from avoiding Kraftliner production.

Incineration was assumed to be performed with energy recovery, both electrical and thermal. It was assumed that the generated electricity from incineration replaces average electricity from grid in the country in question, and that the generated thermal energy replaces thermal energy from natural gas (country specific). For the PET and FibreForm it was assumed that all plastic details (caps, laminate and LDPE ring) are incinerated including energy recovery during the end-of-life phase. Database data (PE International) were used for emissions associated with incineration of paper and plastic, which also included energy recovery.

The landfill scenario for paper was modeled under the assumption that the generated landfill gas (methane) was used for electricity production, because that is a simple achievable use for the landfill gas, also applicable in countries that lack a need from heating. Thus, the produced electricity from the landfill gas has been assumed to replace average electricity from grid. Database data (PE International) were used for landfill of paper and plastic, which for paper also included generation of landfill gas. It should be mentioned that the extent of which collection of methane from landfill, differs from case to case in reality. Since heating is only necessary in countries with colder climate, the case of electricity generation has been chosen in this study.

Transports of the materials to the waste management facilities were assumed to be 100 km truck to recycling, and 10 km truck to landfill and incineration.

The results by including end-of-life for the products are presented for each product. The allocation of the impact on the different waste treatments is shown in a separate figure for each KPI; the allocation was done according to Table 7. The avoided emissions from avoided virgin material production and from energy substitution during energy recovery were calculated as negative values. As a consequence, if the avoided emissions are greater than the emissions released from the waste management process, the value of the KPI becomes negative, meaning that the KPI in question overall has decreased. However, if the emissions from the waste management process are greater than the avoided emissions, the KPI values become positive and the environmental impact will increase. The total impact of end-of-life is the sum of the different waste treatments and the possible effects of the avoided processes.

### **4.3.2 Cement sack**

In Indonesia, the major part of the paper waste is put on landfill, only 2 % is recycled, this means that the effect of landfill will dominate the results for paper. Landfill of paper has a large impact on GWP and POCP, mainly due to methane released during the anaerobic degradation of paper. However, the production of average Indonesian electricity mix is associated with emissions effecting AP and EP and since those emissions which are avoided by replacing average electricity by electricity generated from landfill gas, are larger than the emissions from the actual landfill, gives landfill of paper a credit on regard to AP and EP for the paper sack, see Figure 50 and Figure 51.

When plastic is put on landfill, the degradation process is much slower than for paper, hence, there can be no immediate utilization of landfill gas, and therefore no credit can be accounted for landfill of plastic. Landfill of plastic have a smaller impact on GWP and POCP than paper, since the degradation of plastic (and emissions released) will take place after a long time (longer than what is within the 100 year-system boundary of the study), the effect on regard to GWP and POCP is small. However, a consequence of this is that most of the plastic still remains in the landfill after 100 years and there is a future potential emission source that is not included in the study. A drawback for the degradation emissions from plastic after 100 years is that the collection of landfill

gas most likely has ended. The methane emissions from that part of the degradation are thus not reduced by combustion and avoided affects cannot be used. Also, in Indonesia, the amount plastic put on landfill is less than the amount paper put on landfill.

Figure 46 show a schematic picture of the emissions originating from landfill of paper. During degradation, around 15 % of the bounded carbon is released to atmosphere directly as biotic CO<sub>2</sub>. The remaining part is developed as methane gas of which around 50 % can be utilized for electricity generation. The remaining part is released to atmosphere, having an impact on global warming.

The electricity which is generated is assumed to substitute some alternative electricity generated from oil or coal, hence the avoided CO<sub>2</sub> emission form avoided combustion of fossil fuels are subtracted. However, since the methane emission from the landfill is a much stronger greenhouse gas than the avoided CO<sub>2</sub> emissions, the net impact on global warming still becomes positive.

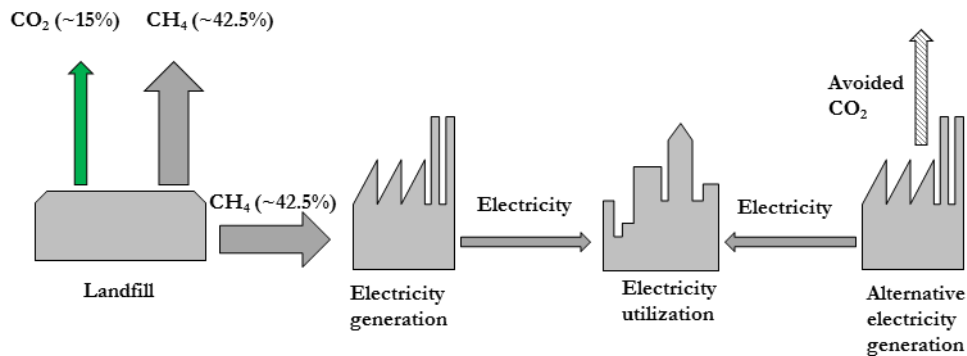


Figure 46. Schematic picture of the emissions originating from landfill of paper

For AP, EP and POCP, the avoided emissions from recycling plastic are larger than the emissions from the recycling process, hence giving a credit for the plastic cement sack.

The impact of including end-of-life however, has minor effect on the entire life-cycle of the cement sack in plastic and the same is true for the paper. The largest effect is seen for GWP of the paper sack, which is increased by about 60 %, however, compared to the plastic sack, the results are unchanged.

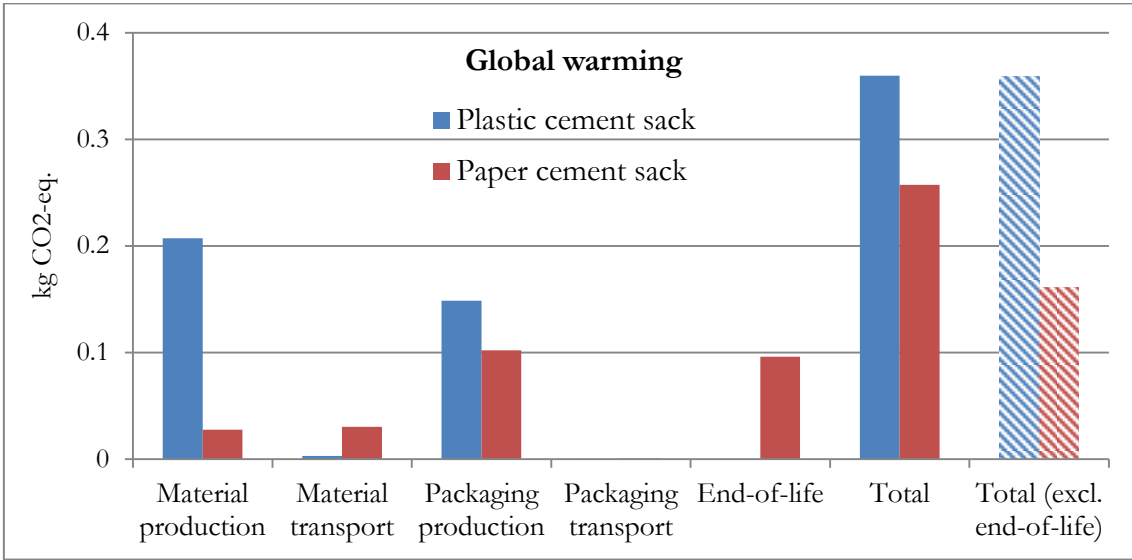


Figure 47. GWP results due to system expansion (incl. end-of-life) for the cement sack.

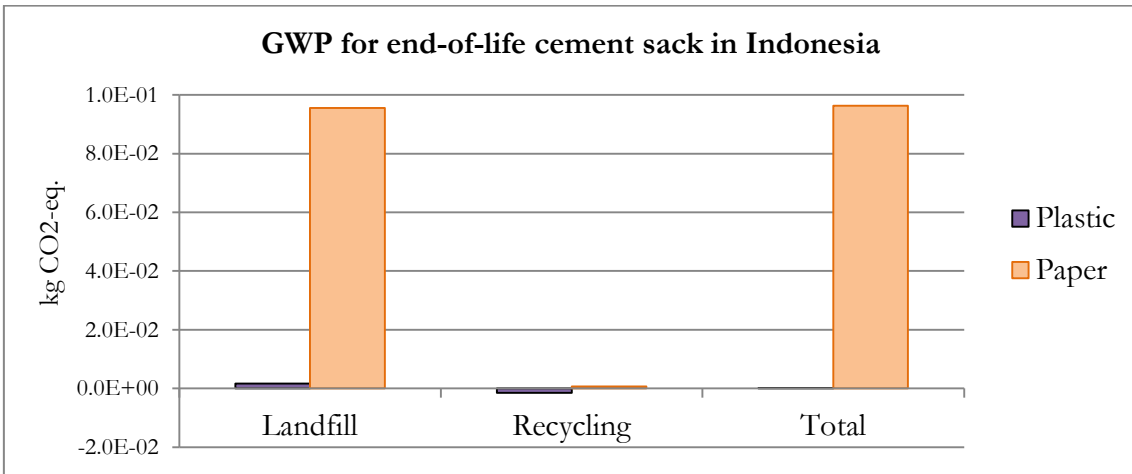


Figure 48. Impact on GWP due to the different waste treatment methods during end-of-life.

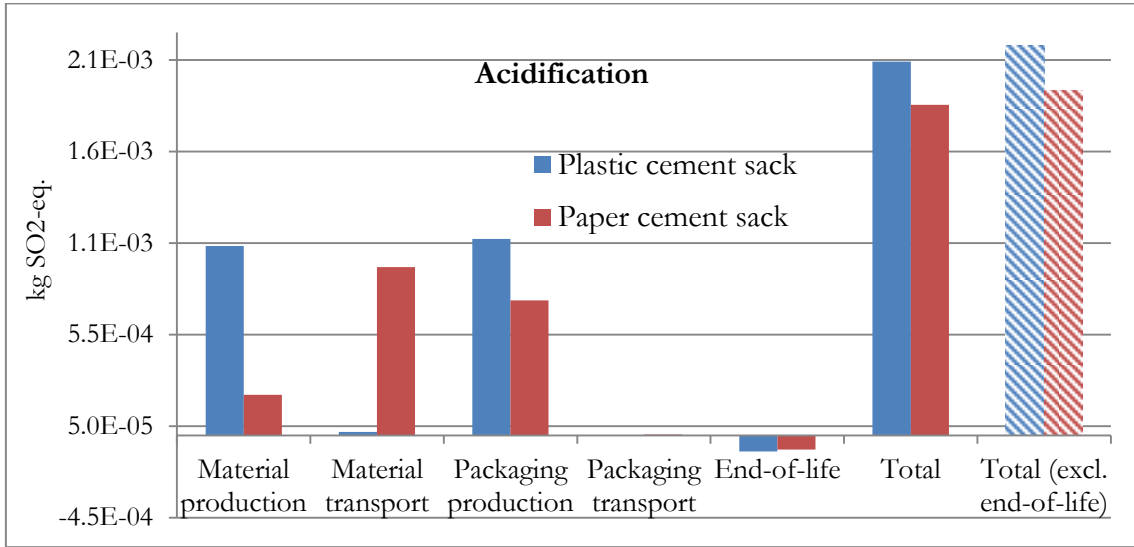


Figure 49. AP results due to system expansion (incl. end-of-life) for the cement sack.

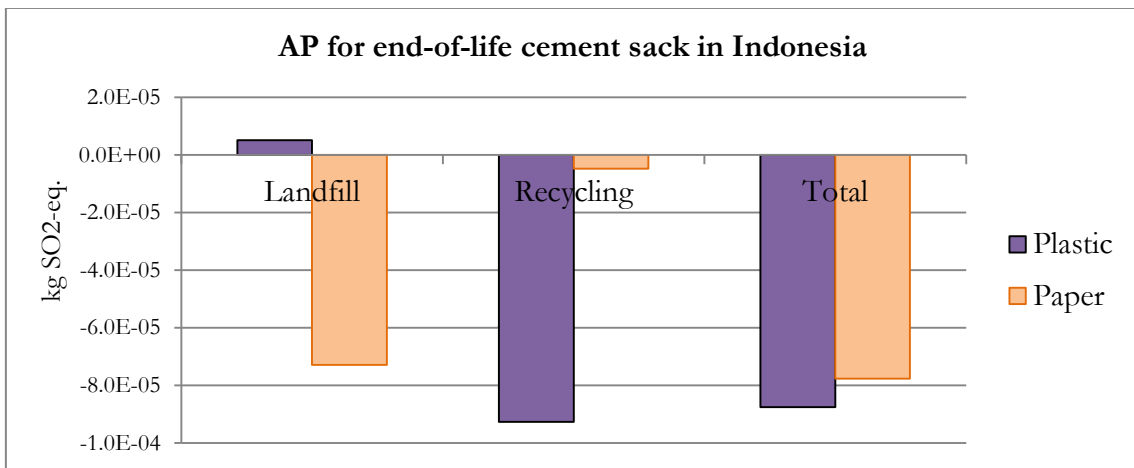


Figure 50. Impact on AP due to the different waste treatment methods during end-of-life.

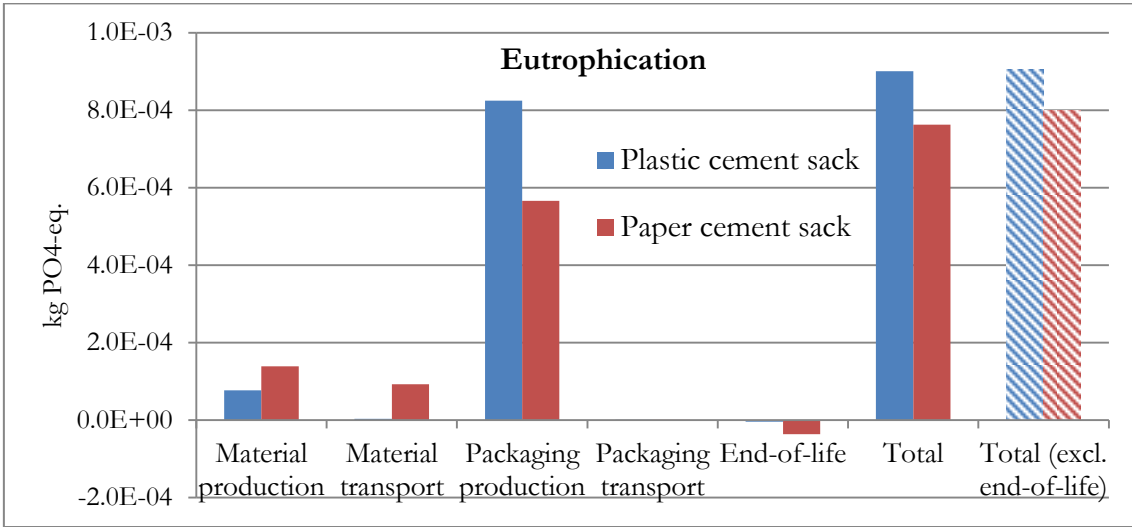


Figure 51. EP results due to system expansion (incl. end-of-life) for the cement sack.

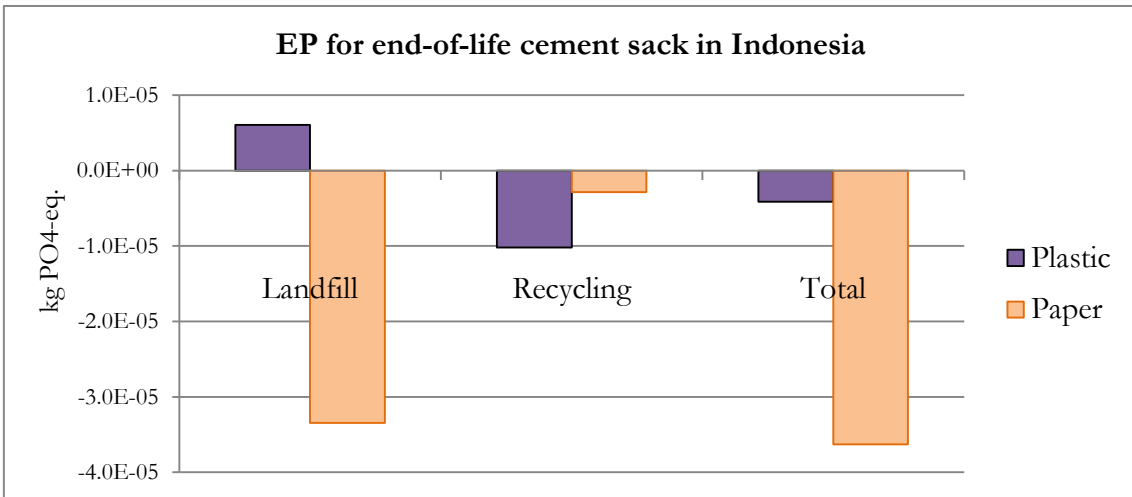


Figure 52. Impact on EP due to the different waste treatment methods during end-of-life.

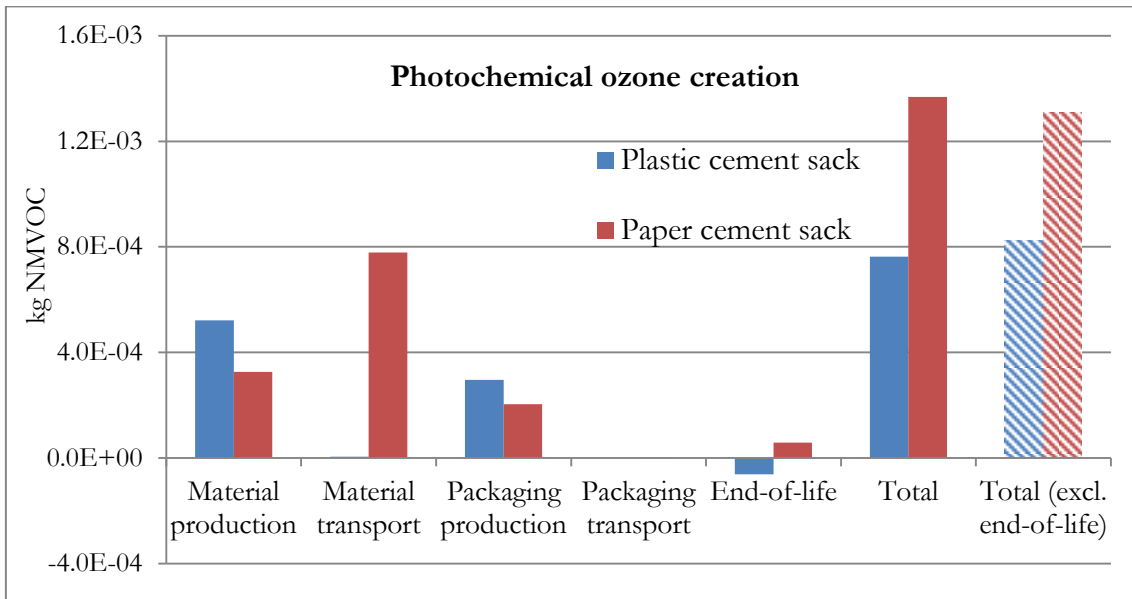


Figure 53. POCP results due to system expansion (incl. end-of-life) for the cement sack.

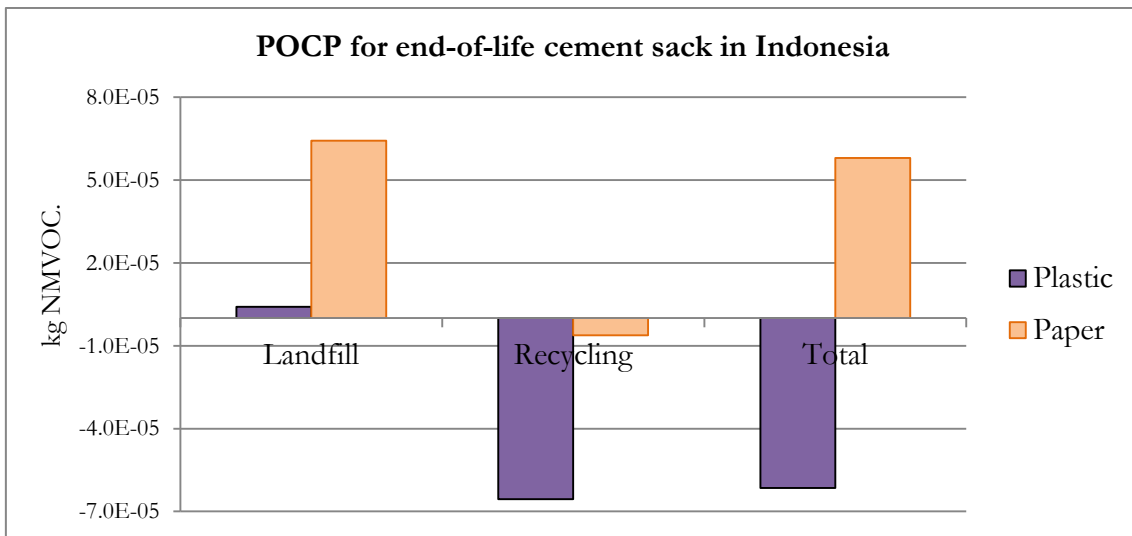


Figure 54. Impact on POCP due to the different waste treatment methods during end-of-life.

### 4.3.3 Pasta bag

For the pasta bag, the effect of landfill is negligible, since only 0.5 % of plastic and 0 % paper are landfilled in Germany.

Most of the paper and plastic waste is instead recycled or incinerated with energy recovery. For the plastic bag: those emissions (affecting AP, EP and POCP), which are avoided are larger than the



emissions from the actual incineration plant/recycling facility, hence there is a credit on AP, EP, and POCP for plastic. However, the greenhouse gases emitted from the incineration plant and the recycling facility is larger than the avoided emissions, which for the plastic alternative increases the GWP in total. The part of paper which is incinerated will give a credit for all KPIs, however, since the major part of the paper waste in Germany is recycled (88 %), the impact of this will dominate the end-of-life results for paper. Recycling reduces all KPIs except GWP.

The impact over the entire life cycle for the plastic pasta bag, when including end-of-life decreases all KPIs, except GWP, which instead is increased. The same is true for the paper bag; however, compared to the plastic sack, the results by including end-of-life are still unchanged on regard to GWP, AP and POCP. The most significant effect is seen for EP of the paper bag, which is decreased by about 80 %, and as a consequence, the total EP of the product is decreased, resulting in an advantage for the paper bag instead of the plastic on regard to EP.

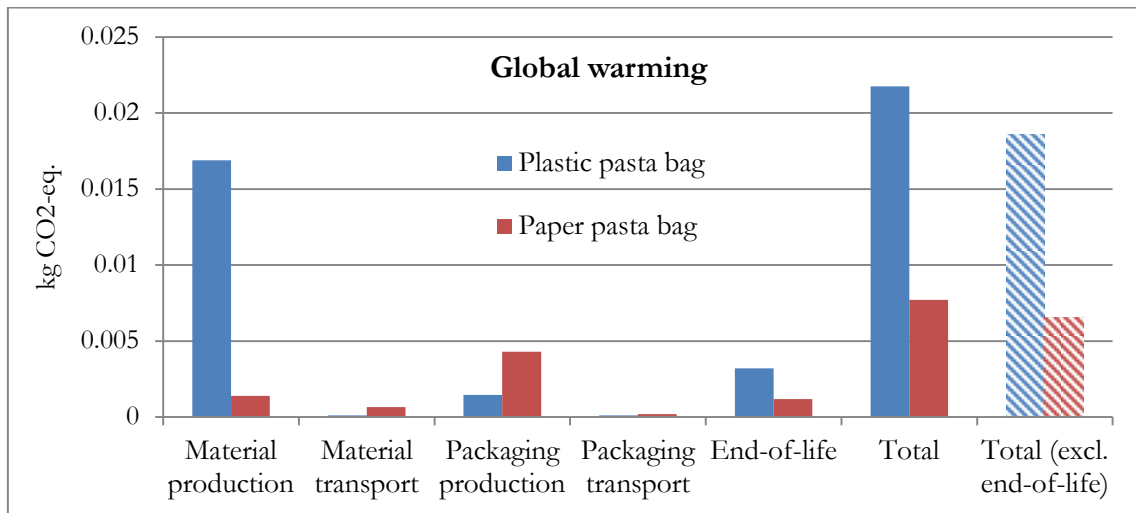


Figure 55. GWP results due to system expansion (incl. end-of-life) for the pasta bag.

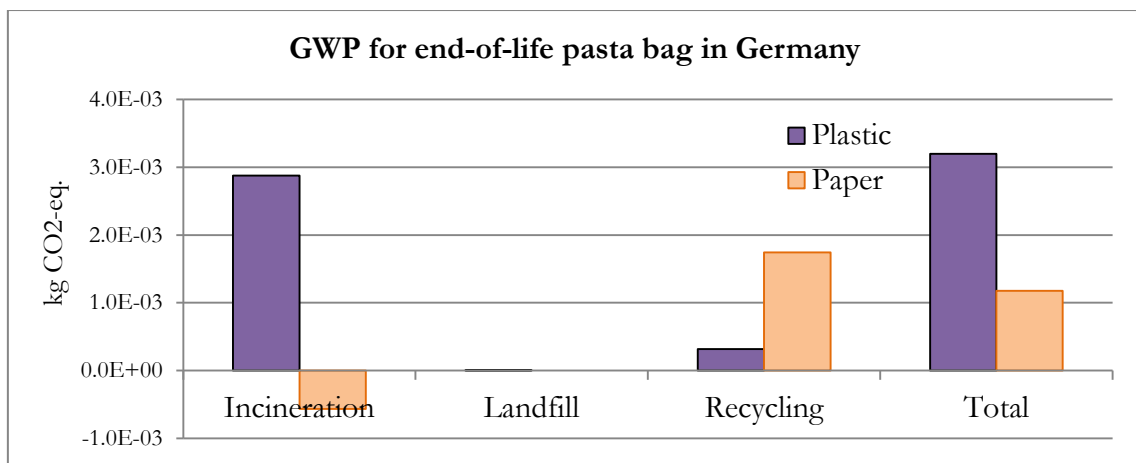


Figure 56. Impact on GWP due to the different waste treatment methods during end-of-life.

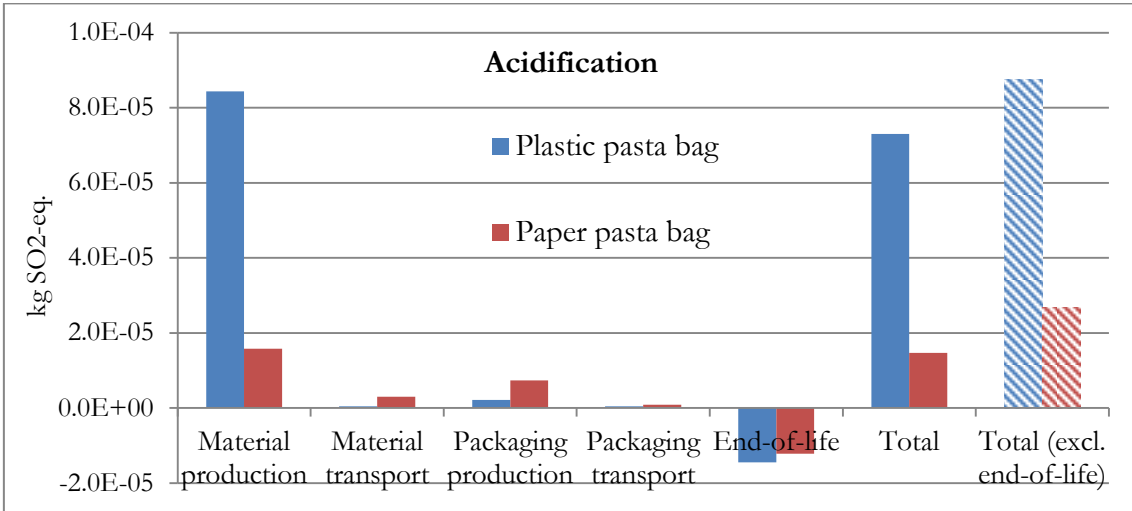


Figure 57. AP results due to system expansion (incl. end-of-life) for the pasta bag.

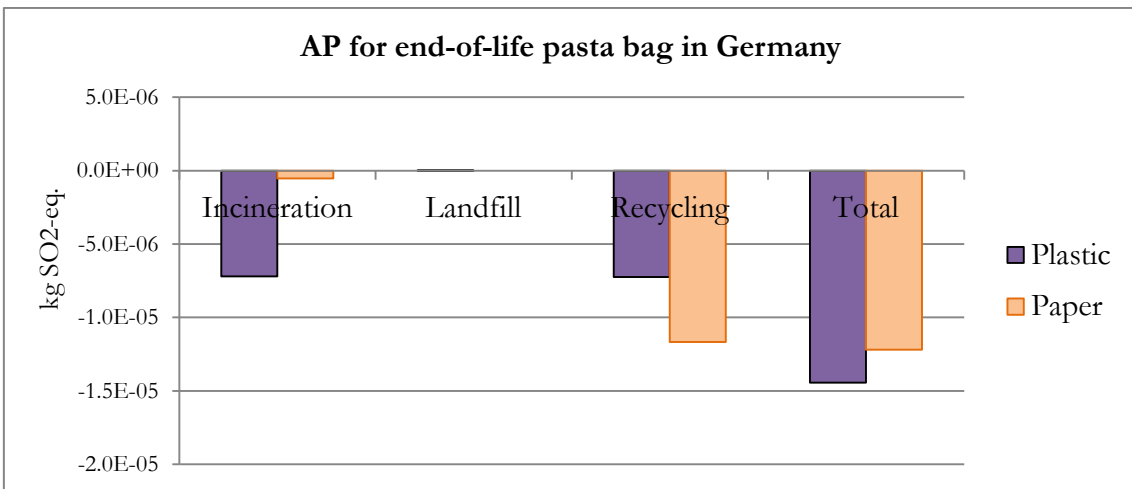


Figure 58. Impact on AP due to the different waste treatment methods during end-of-life.

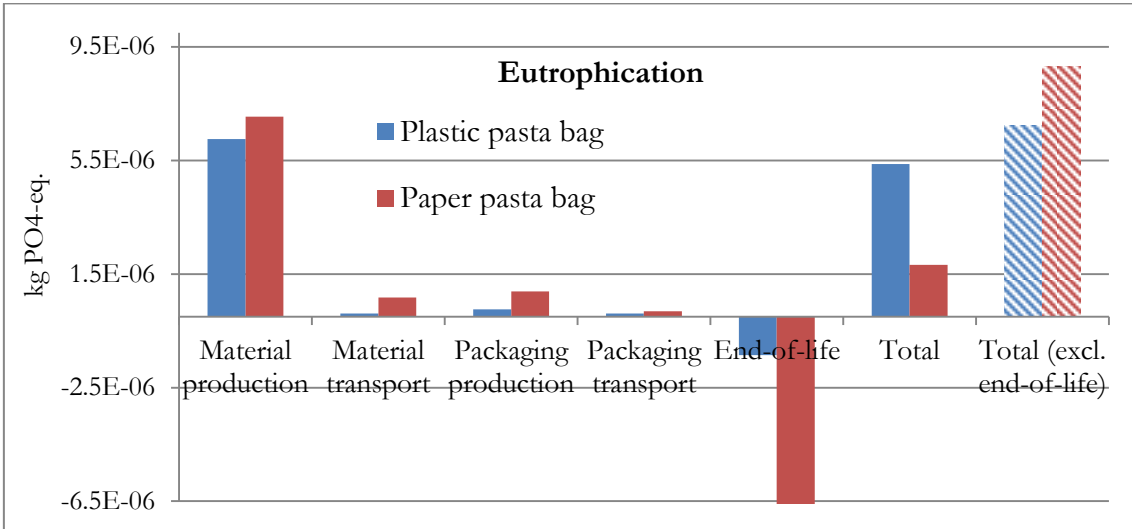


Figure 59. EP results due to system expansion (incl. end-of-life) for the pasta bag.

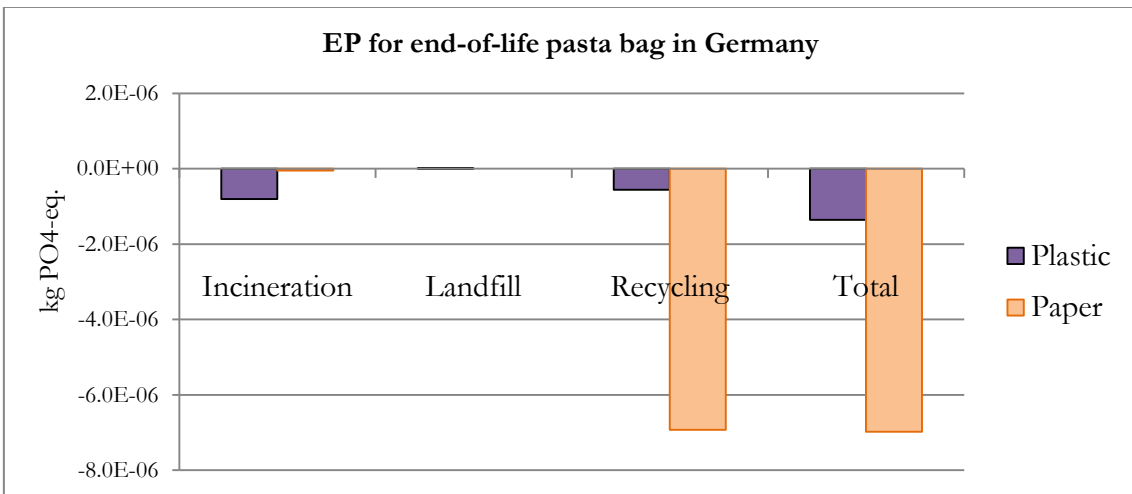


Figure 60. Impact on EP due to the different waste treatment methods during end-of-life.

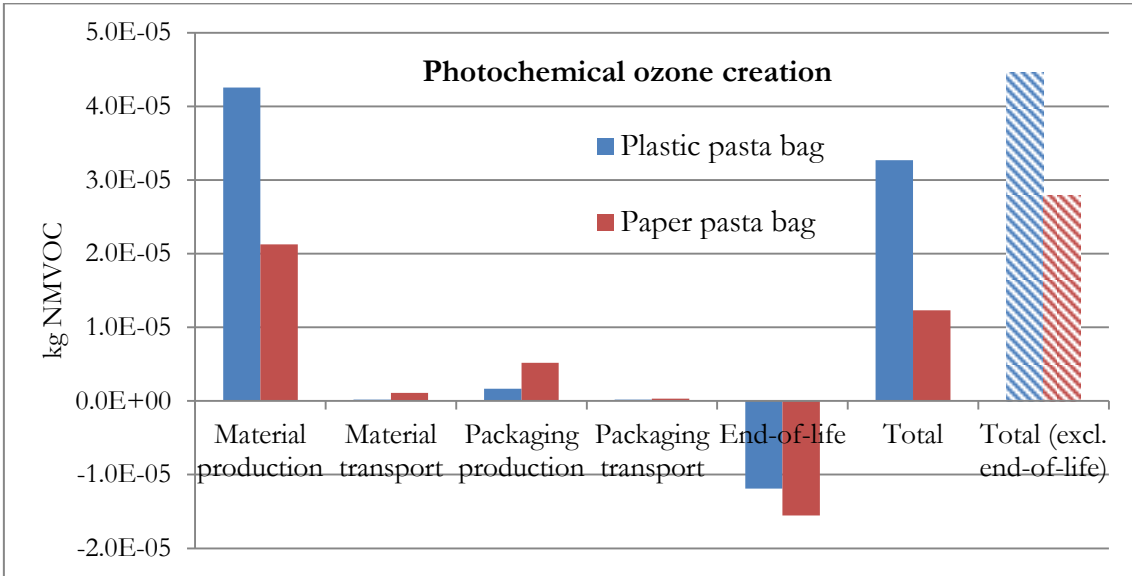


Figure 61. POCP results due to system expansion (incl. end-of-life) for the pasta bag.

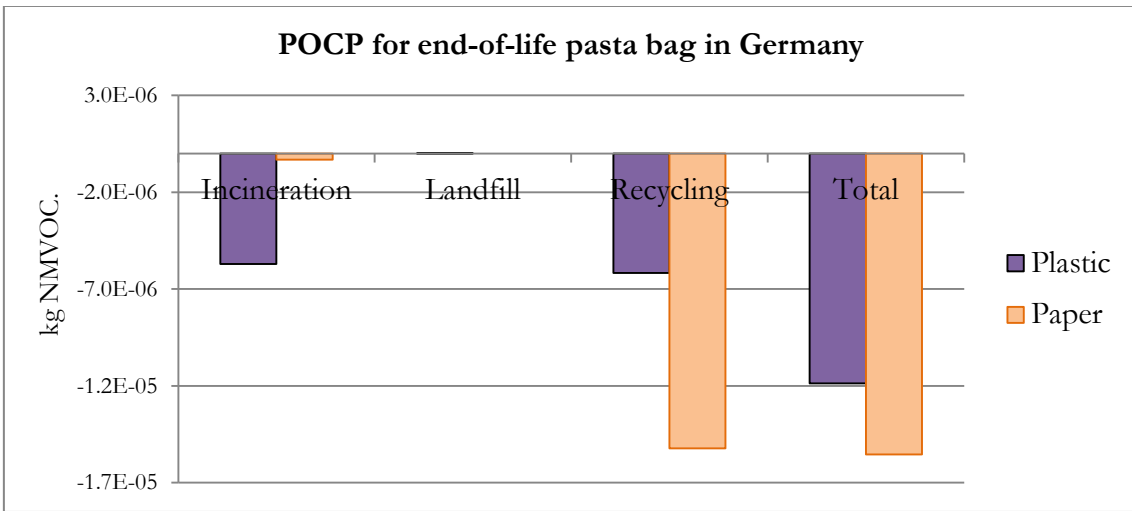


Figure 62. Impact on POCP due to the different waste treatment methods during end-of-life.

#### 4.3.4 Grocery bag

In the UK, 65 % of plastic waste is put on landfill; however, the degradation process is much slower than for paper, therefore, emissions (such as greenhouse gases) will be released after a long time (longer than what is within the 100 year-system boundary of the study), the effect on regard to GWP is therefore smaller than compared to landfill of paper. However, the remaining plastic in the landfill after 100 years will also here be a potential emission source in the future.

The part of paper which is incinerated will give a credit for all KPIs, the same is true for plastic with the exception of GWP, since the greenhouse gases emitted from the incineration plant is larger than the avoided emissions, which increases the GWP in total.

Most of the paper waste in the UK is recycled (85 %), hence, the impact of this will dominate the end-of-life results for paper. Recycling of paper reduces all KPIs except GWP since the greenhouse gases emitted from the recycling facility is larger than the avoided emissions, which increases the GWP in total.

The impact over the entire life cycle for the plastic grocery bag, when including end-of-life decreases all KPIs, except GWP and EP, the effect on EP, which instead is increased, although, not by much. The impact over the entire life cycle for the paper bag when including end-of-life decreases all KPIs drastically, except GWP which is increased. Comparing this to the plastic bag, the advantage on regard to EP is now seen for the paper bag and the previous, almost insignificant difference for paper and plastic bag on POCP, now gives an advantage for paper bag.

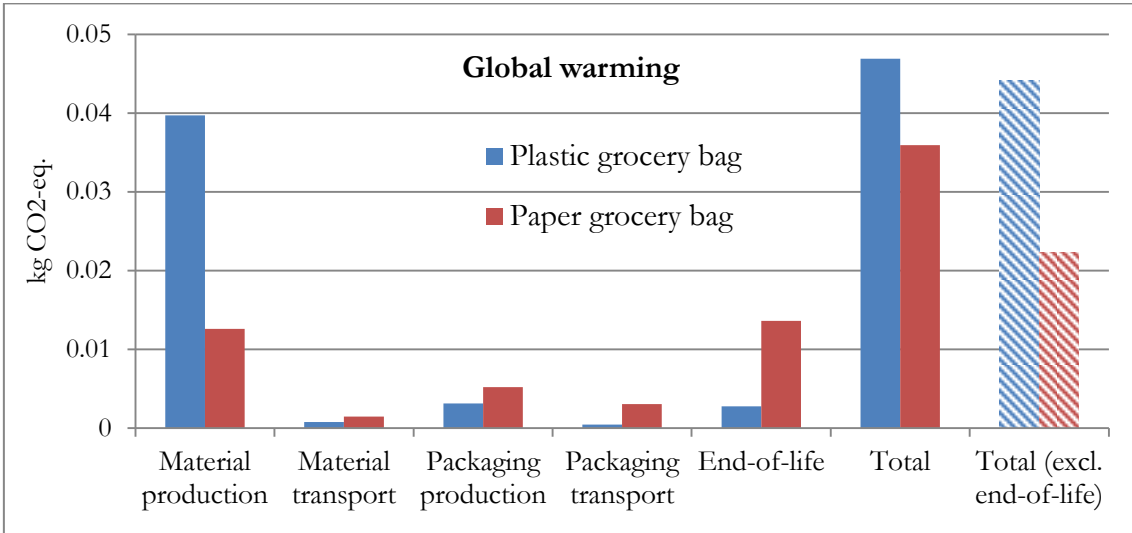


Figure 63. GWP results due to system expansion (incl. end-of-life) for the grocery bag.

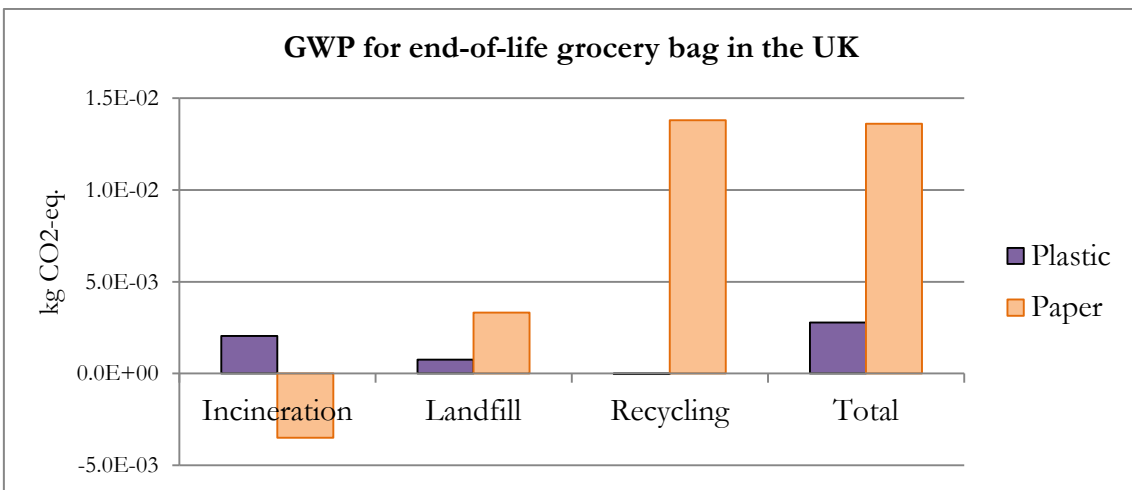


Figure 64. Impact on GWP due to the different waste treatment methods during end-of-life.

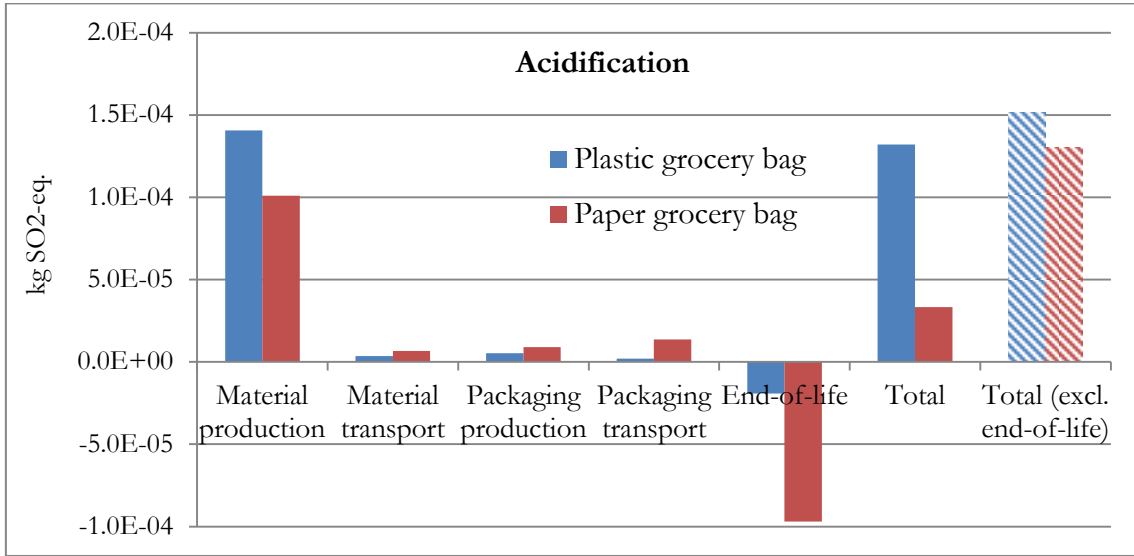


Figure 65. AP results due to system expansion (incl. end-of-life) for the grocery bag.

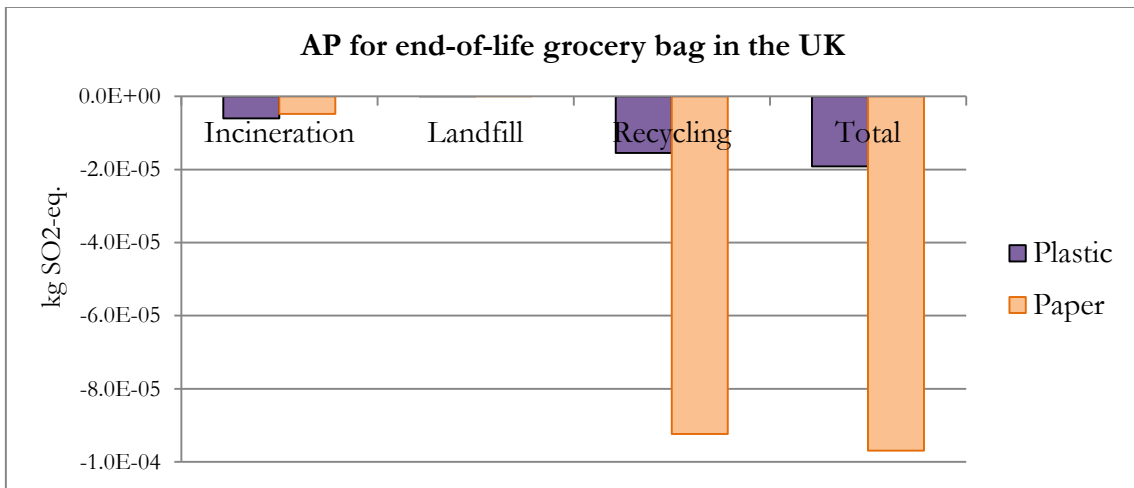


Figure 66. Impact on AP due to the different waste treatment methods during end-of-life.

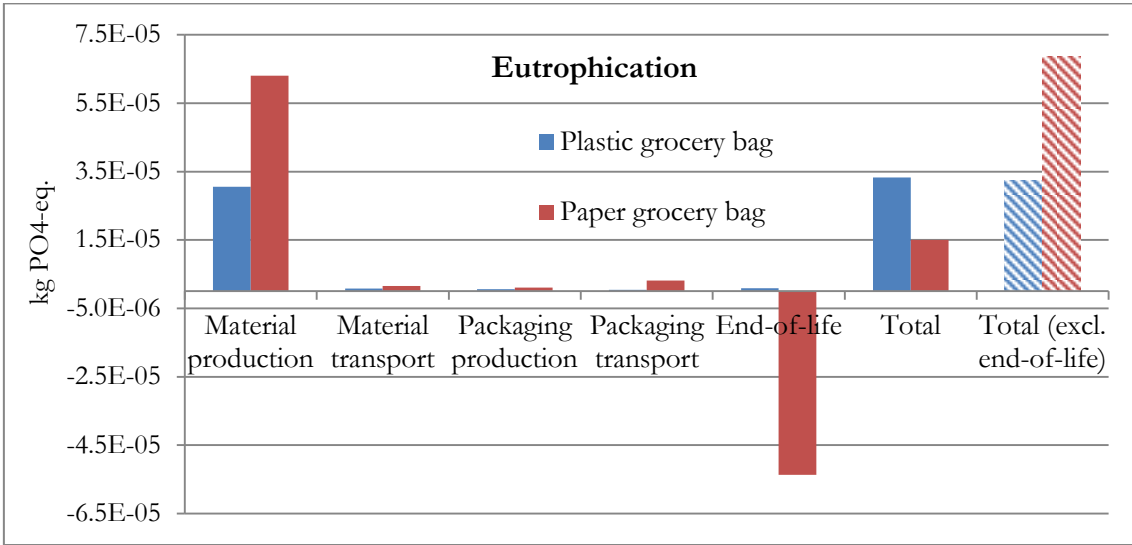


Figure 67. EP results due to system expansion (incl. end-of-life) for the grocery bag.

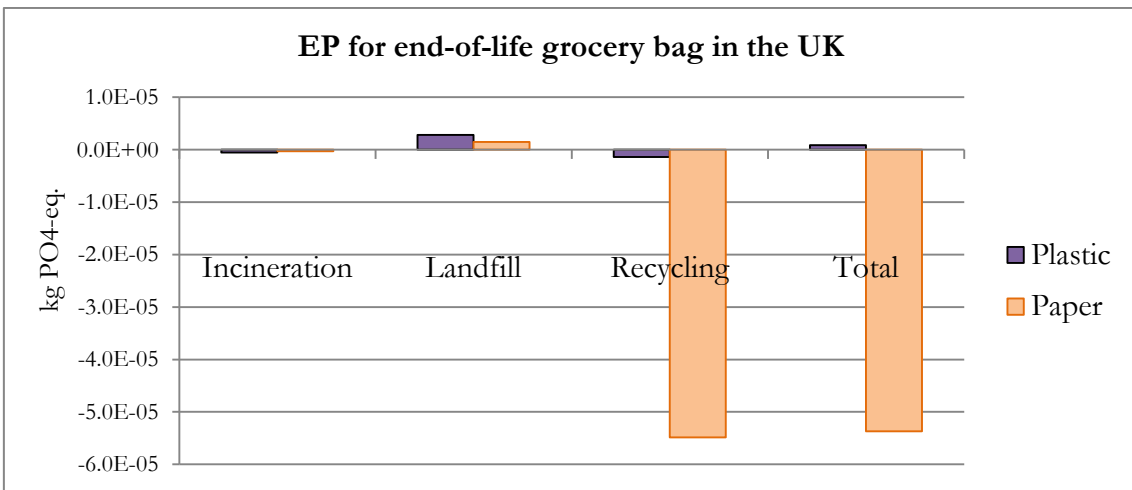


Figure 68. Impact on EP due to the different waste treatment methods during end-of-life.



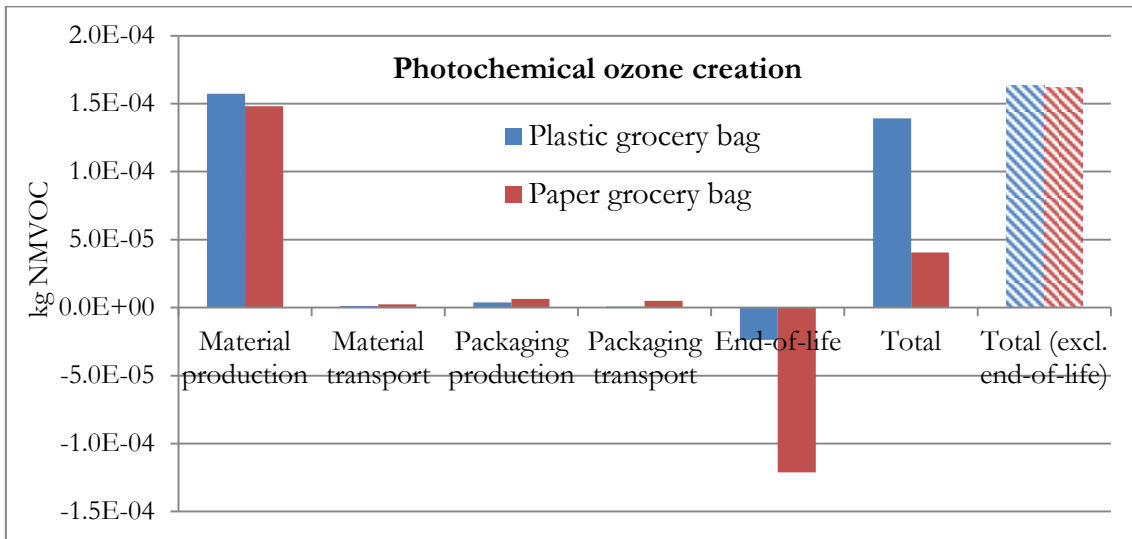


Figure 69. POCP results due to system expansion (incl. end-of-life) for the grocery bag.

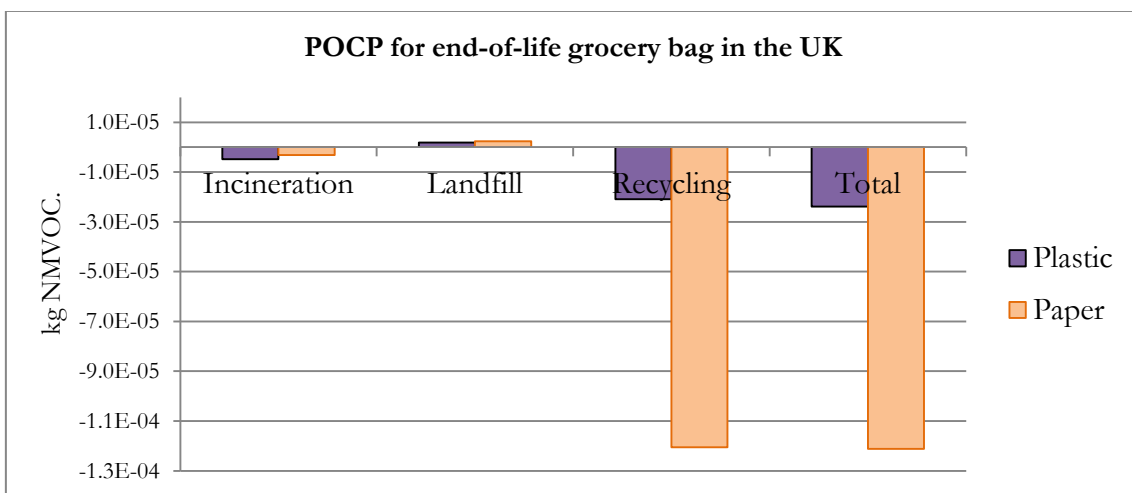


Figure 70. Impact on POCP due to the different waste treatment methods during end-of-life.

#### 4.3.5 Bottle

The effect of putting both the plastic and paper waste product on landfill is negligible, since only 0.5 % of plastic and 0 % paper are landfilled in Germany.

Most of the plastic waste in Germany are recycled or incinerated with energy recovery. For the PET bottle; recycling generates a credit for all KPIs, since those emissions effecting GWP, AP, EP and POCP, which are avoided due to recycling, are larger than the emissions from the actual recycling facility. The same is true for incineration, with the exception that the greenhouse gases which are

emitted from the incineration plant are larger than the avoided emissions, increasing the GWP for PET.

For FibreForm Packaging bottle; both recycling and incineration generates a credit for AP, EP and POCP, since the avoided emissions, effecting these KPIs, are larger than the emissions from the actual recycling facility and incineration plant. This is however not the case for GWP. This is mainly because CO<sub>2</sub> is emitted during incineration of the plastic details (caps, PE-laminate and LDPE-ring) of the FibreForm Packaging bottle. Likewise, the paper recycling process is energy demanding, and in the model this originates from fossil fuels which during combustion emits CO<sub>2</sub> and increases the GWP. These CO<sub>2</sub> emissions are larger than the avoided emissions from alternative energy production as well as from virgin material production.

The impact over the entire life cycle when including end-of-life decreases all KPIs except GWP, both for PET and FibreForm Packaging bottle. However, in comparison between the two products when end-of-life is included, FibreForm Packaging bottle still have an advantage over the PET bottle.

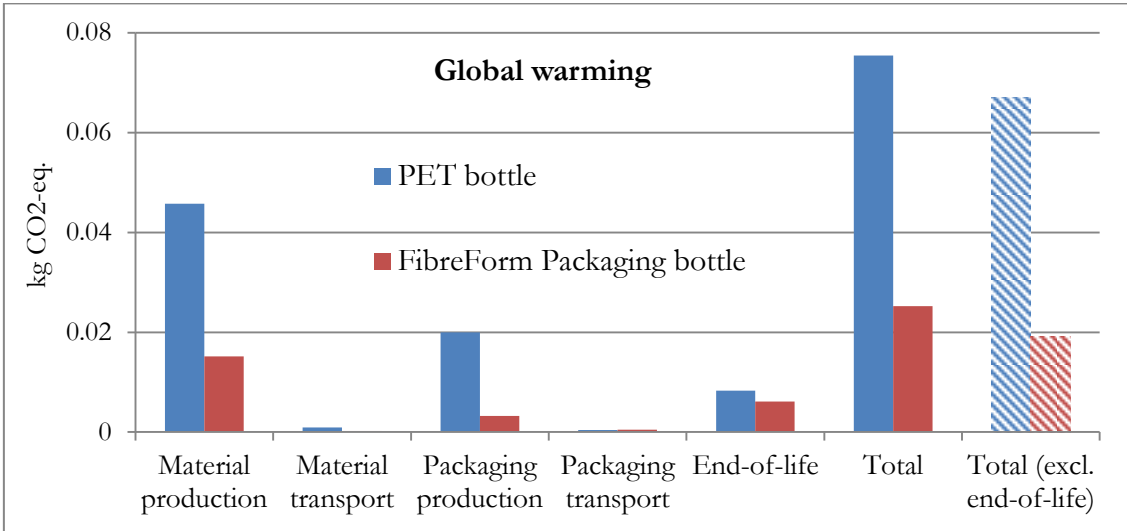


Figure 71. GWP results due to system expansion (incl. end-of-life) for PET/FibreForm packaging bottle.

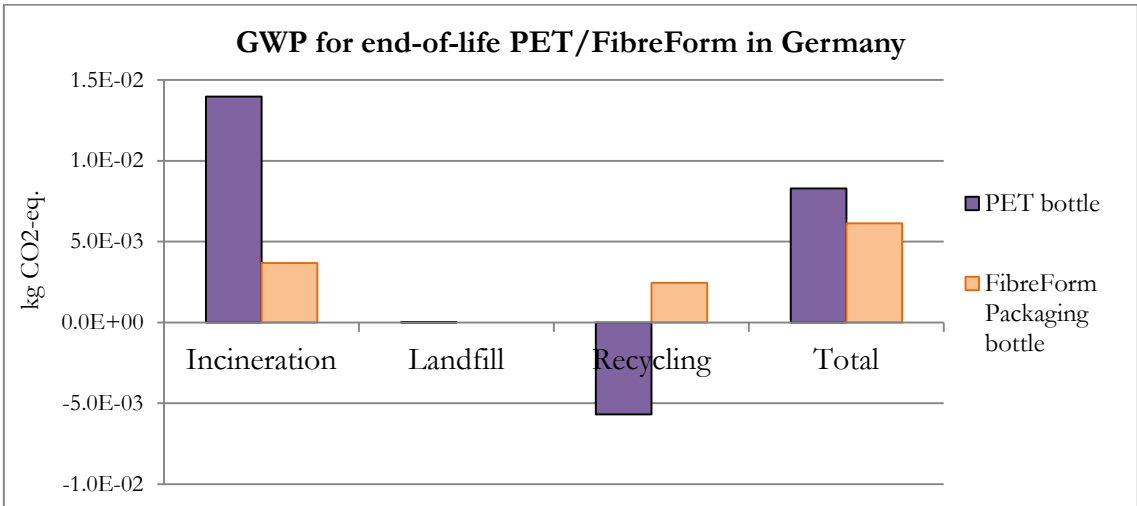


Figure 72. Impact on GWP due to the different waste treatment methods during end-of-life.

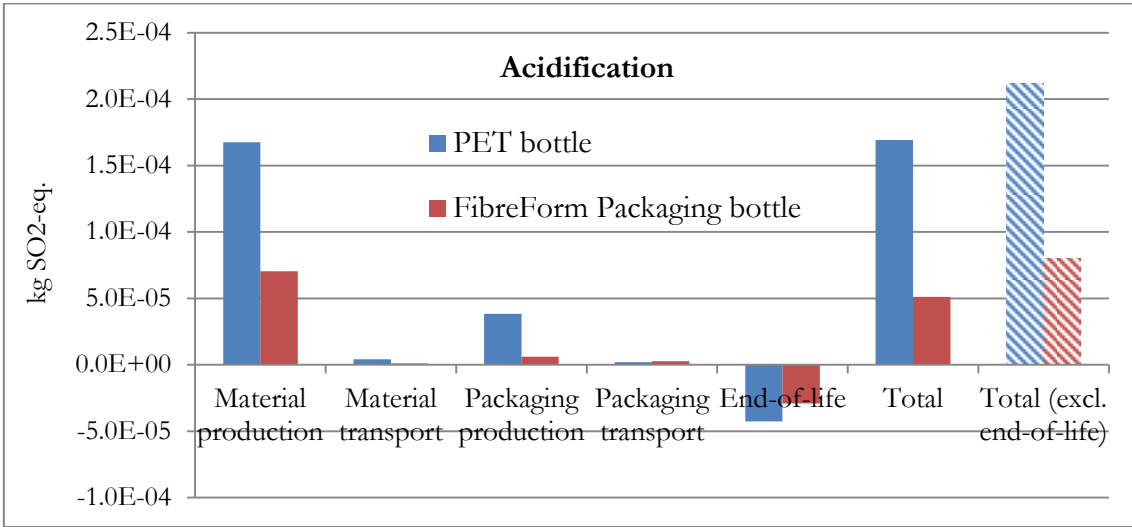


Figure 73. AP results due to system expansion (incl. end-of-life) for PET/FibreForm Packaging bottle.

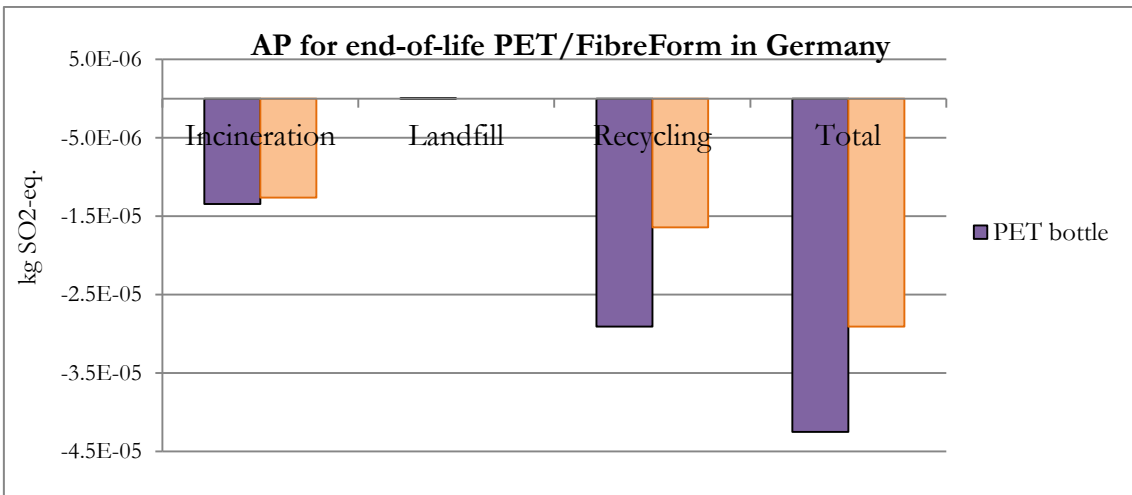


Figure 74. Impact on AP due to the different waste treatment methods during end-of-life.

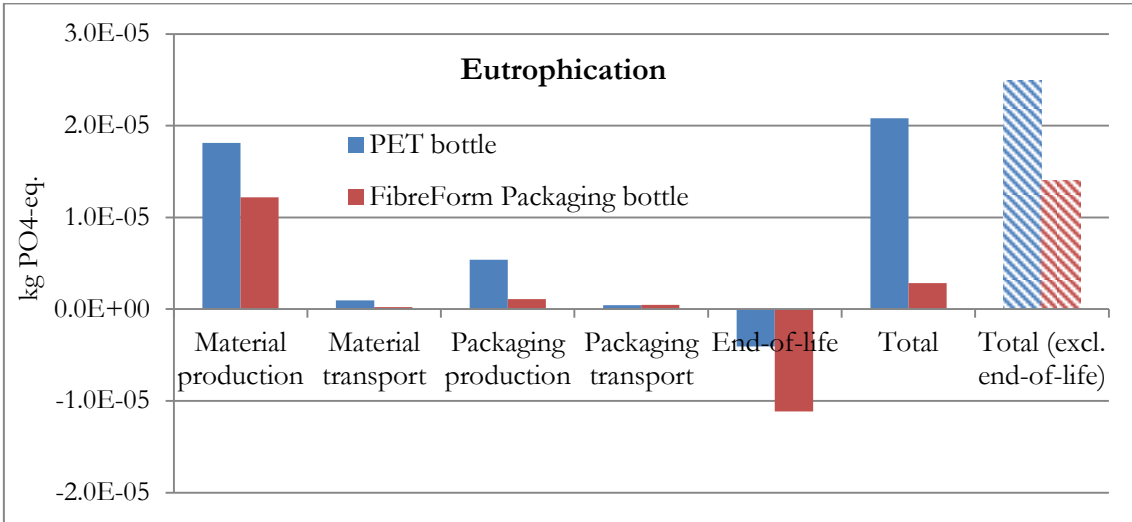


Figure 75. EP results due to system expansion (incl. end-of-life) for PET/FibreForm Packaging bottle.

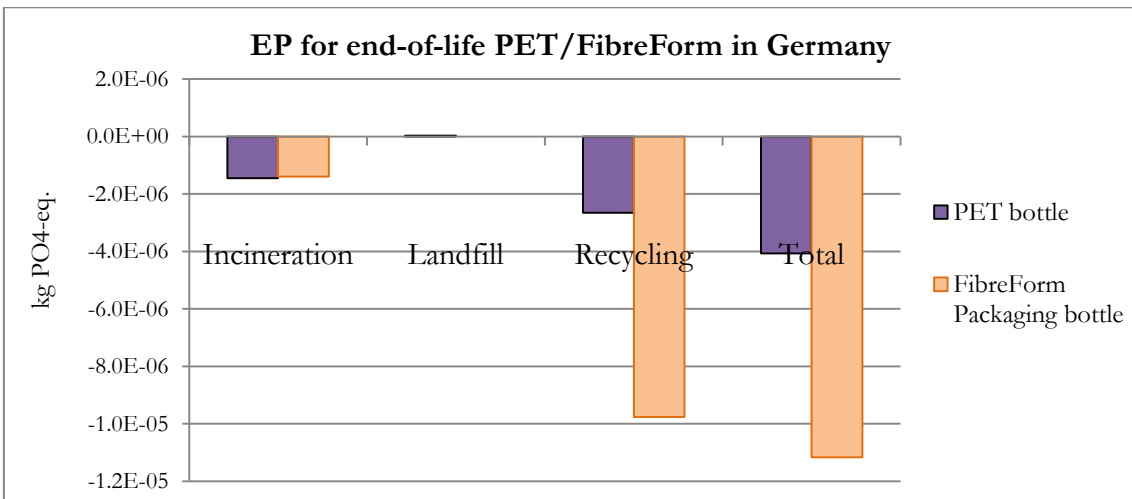


Figure 76. Impact on EP due to the different waste treatment methods during end-of-life.

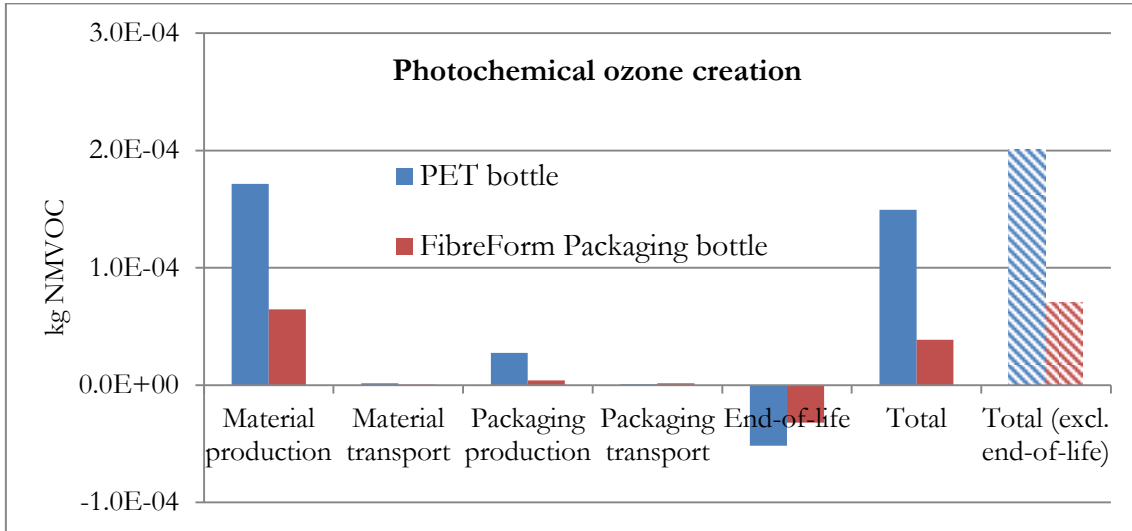


Figure 77. POCP results due to system expansion (incl. end-of-life) for PET/FibreForm Packaging bottle.

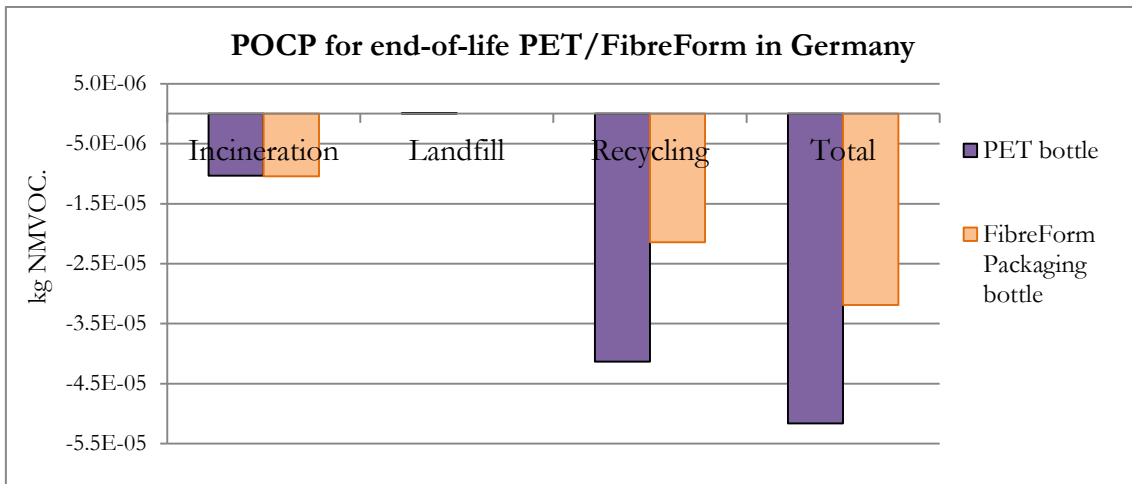


Figure 78. Impact on POCP due to the different waste treatment methods during end-of-life.

#### 4.3.6 District heating at the mills

System expansion was also made to include the excess energy generated at Gruvön and Skärblacka mills, which is utilized for district heating in the close-by society. This was considered, under the assumption that district heating will substitute heavy fuel oil as energy source, hence generating an environmental credit which is seen in the resulting figures.

GWP for Gruvön and Skärblacka is shown in Figure 79 and Figure 80. The impact on all KPIs for Gruvön and Skärblacka is shown in Table 8, also, figures for this can be seen in appendix II.

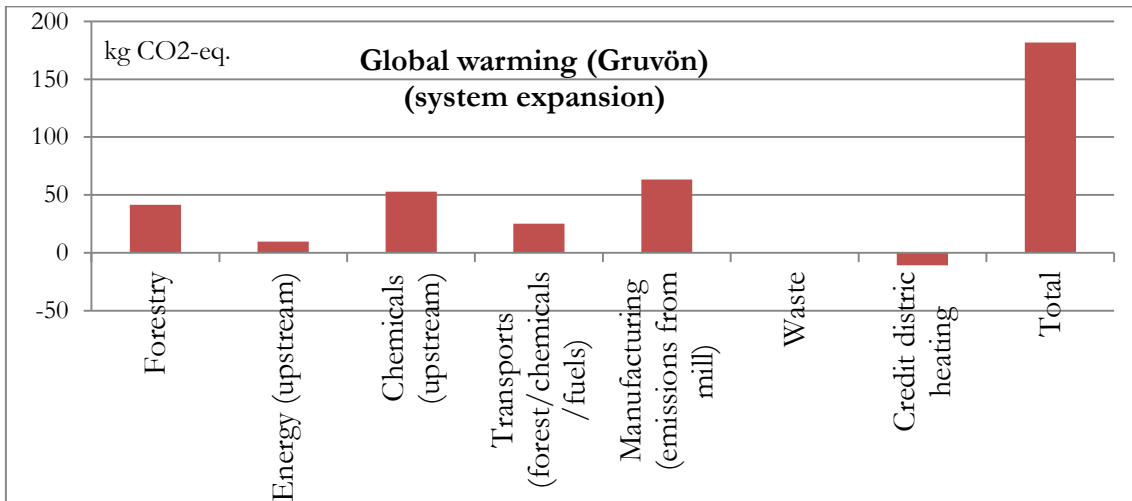


Figure 79. GWP results due to system expansion (incl. credits from district heating) for Gruvön mill.

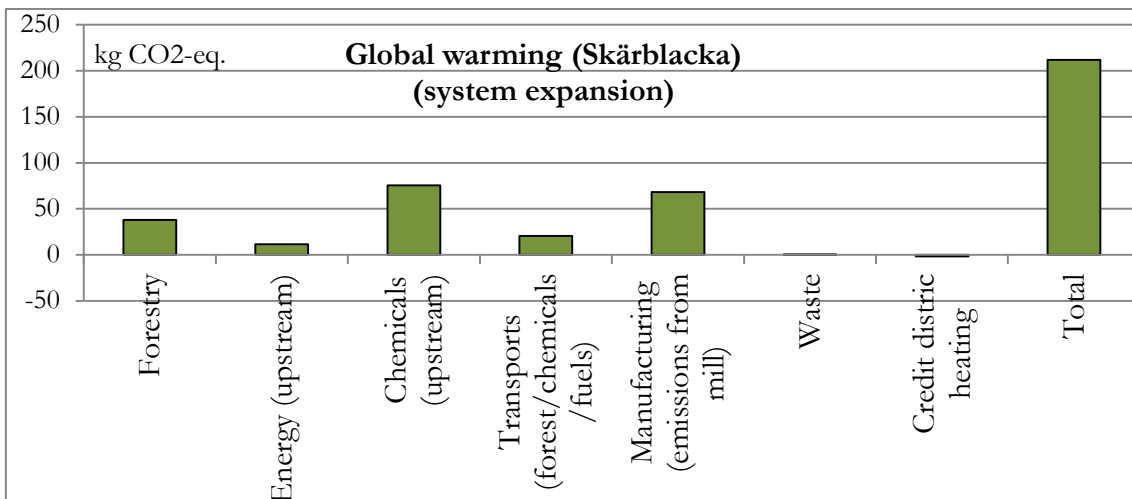


Figure 80. GWP results due to system expansion (incl. credits from district heating) for Skärblacka mill.

**Table 8. The impact of the KPIs when also including credit from generated excess energy at Gruvön and Skärblacka, which is utilized for district heating, and assumed to replace heavy fuel oil.**

KPI	Gruvön	Skärblacka
GWP	-5.6 %	-0.7 %
AP	-3.4 %	-0.6 %
EP	-0.4 %	-0.1 %
POCP	-1.5 %	-0.3 %

The effect of utilizing the excess energy at the mills in the district heating system has a negligible effect on the KPIs, especially for EP, which is decreased by 0.4 % for Gruvön and 0.1 % for Skärblacka.

An explanation for this almost insignificant effect is that the excess energy which is delivered to the close-by societies as district heating is dependent on the actual demand. The excess energy generated from the mills are actually quite large, however, only a small amount of this can be recovered in the close-by system for district heating, since the societies which utilize district heating are relatively small societies, both for Gruvön and Skärblacka sites, hence; the assumed credit has a small effect on the overall results for the mills. However, it should be mentioned that this energy utilization has a positive effect on the energy system and hence the GWP for the local societies.

Since the effect of district heating was so small, this credit was not taken into account for the packaging products, since this wouldn't change the outcome of the overall results when compared to the plastic products. This is true for both Gruvön and Skärblacka.

## 5 Conclusions

The results showed that emissions from the mills are an important factor for all KPIs, but also, production of chemicals for some KPIs. Hence, how and where the chemicals are manufactured might be an essential aspect for the environmental performance of the mills. For many chemicals, the electric energy used in the production is significant and thus also the production mixes of the country producing the chemical.

Examining the packaging products, material production is in general the most important factor, having a significant impact to all KPIs, both for plastic and paper products. Plastic material production is, generally, more dominating than the Kraft paper production, on the total life cycle of the product. This is true for all products except the cement sack, for which the material transport distance, and the packaging production become important contributors to the environmental performance of the product.

In general, Kraft paper production in both Skärblacka and Gruvön, show a higher EP than for the competing plastic materials. The reason for this is mainly because of COD and nitrogen oxides emissions from the mills. However, an exception of this trend is the case for FibreForm Packaging/PET bottle, for which EP for the PET bottle is higher than for the FibreForm



Packaging bottle, due to high nitrogen oxides to air and phosphates to water from the PET raw material production.

The transportation of the different packaging products is of minor importance for the different KPIs, except for AP and POCP for the paper cement sack. This is because of the long distance transportation with ship from Sweden to Indonesia, which causes nitrogen oxides and sulphur dioxide emissions.

For the cement sack, the influence of the packaging production is most significant, especially for GWP, EP, and AP, for both the paper and plastic product. This is due to the relatively energy intense manufacturing process but also due to the high amount of fossil energy in the Indonesian electricity mix.

The type of processes for the end-of-life and the utilization of the gained materials and energy are important factors that have to be modelled carefully. The system expansion made in this study showed that credits were gained for AP, EP and POCP for all products made in plastic, GWP was however always increased. For the products made in paper, credits were gained for AP and EP, for all products, likewise for POCP with the exception of the cement sack, where POCP was increased due to high emissions from the landfill. GWP for all the paper products was however continuously increased.

The results showed that GWP was consistently higher for the plastic products than for the paper products, this was true both when end-of-life were included or not.

Credit from utilizing the excess energy generated at both Gruvön and Skärblacka sites for district heating, under the assumption that it replaces heavy fuel oil, seem to have little effect on the overall results since the utilized amount in the district heating system is relatively small due to the geographical location of the mills, which allows only for the small near-by societies to utilize district-heating. However, it should be mentioned that this energy utilization has a positive effect on the energy system and hence the GWP on the local societies level.

## **6 Third-party review**

This study has been critically reviewed and approved by third-party; Göran Brohammer, Bureau Veritas, Sweden.

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## Appendix I: Chemicals

**Table 9. Production sites of the chemicals used at Gruvön and Skärblacka**

Chemicals	Gruvön	Skärblacka
Aluminum sulphate	n/a	Helsingborg, Sweden
Carbon dioxide	n/a	Surahammar, Sweden
Hydrogen peroxide	Bohus, Sweden	n/a
Kaolin	Cornwall, UK	n/a
Calcium carbonate (limestone)	Knarrevik, Norway	n/a
Liquid oxygen	Surahammar, Sweden	n/a
Polymer (epichlorohydrin-dimethylamine copolymer)	n/a	France
Polymer (polyacrylamide)	n/a	Cleckheaton, UK
Lime (Quicklime)	Mo I Rana, Norway	Köping, sweden
Sodium chlorate	Bohus, Sweden	n/a
Sodium hydroxide	Stenungsund, Sweden	Rotterdam, Holland
Starch	Mjälby, Sweden	Lestrem, France
Sulphuric acid	Piteå, Sweden	n/a

Modifications of the database data for some chemicals were, when necessary, made by substituting European average electricity mix, for country specific electricity, also from database. The influence of this is shown for sodium hydroxide in Table 10.

**Table 10. GWP for different data for Sodium hydroxide and for the electricity used in each dataset.**

Sodium hydroxide		
	GWP NaOH (kg CO <sub>2</sub> -eq./kg NaOH)	GWP country specific electricity (kg CO <sub>2</sub> -eq./kWh)
<b>Ecoinvent (with European average electricity)</b>	1.1	0.531
<b>Ecoinvent (with Dutch electricity)</b>	1.35	0.683
<b>Ecoinvent (with Swedish electricity)</b>	0.259	0.0871

## Appendix II: System expansion including district heating utilisation at Gruvön and Skärblacka mill

This appendix shows the results for all KPIs from the system expansion, when credit from district heating has been included for Gruvön and Skärblacka mill.

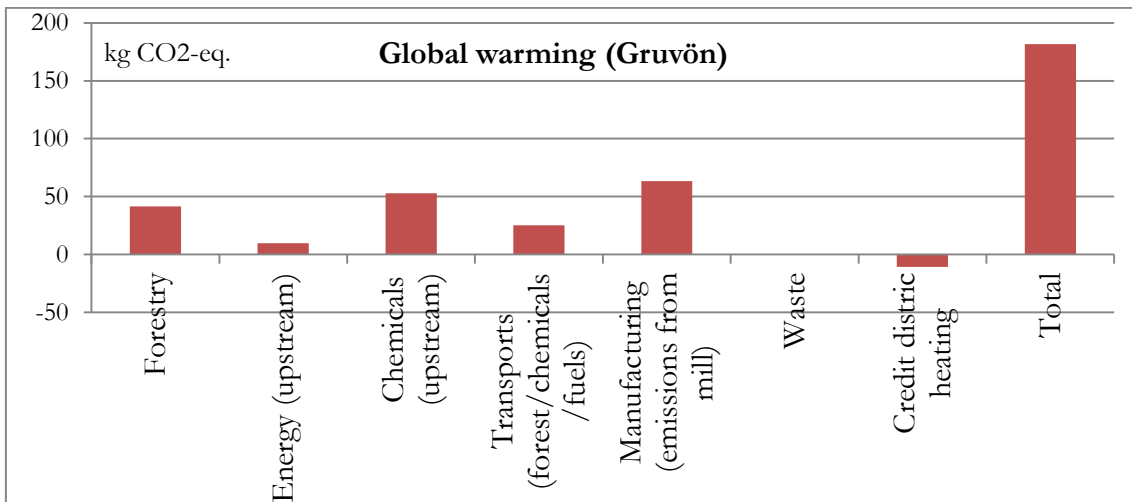


Figure 81. GWP for the production of one tonne bleached Kraft paper at Gruvön mill including credit from district heating utilization in the close-by society.

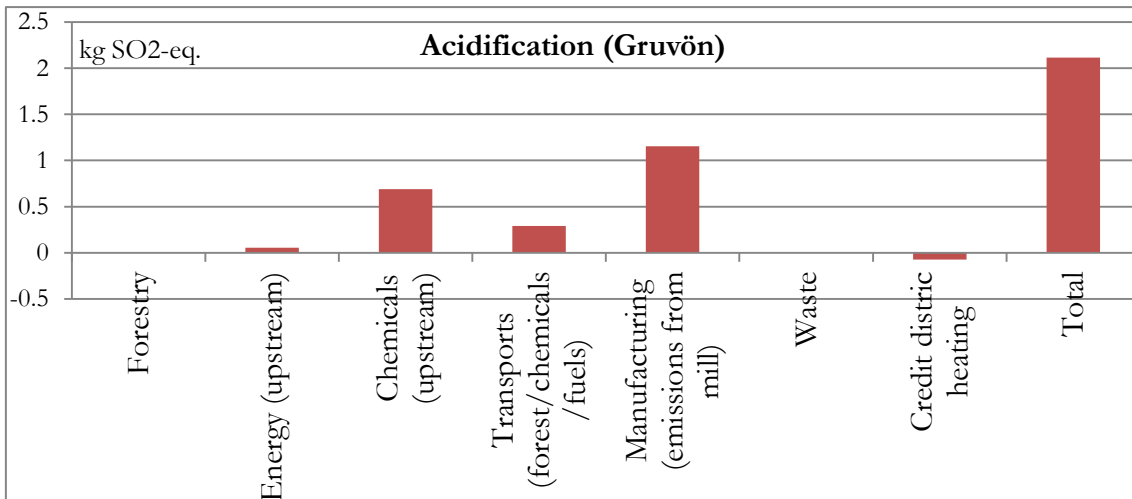


Figure 82. AP for the production of one tonne bleached Kraft paper at Gruvön mill including credit from district heating utilization in the close-by society.

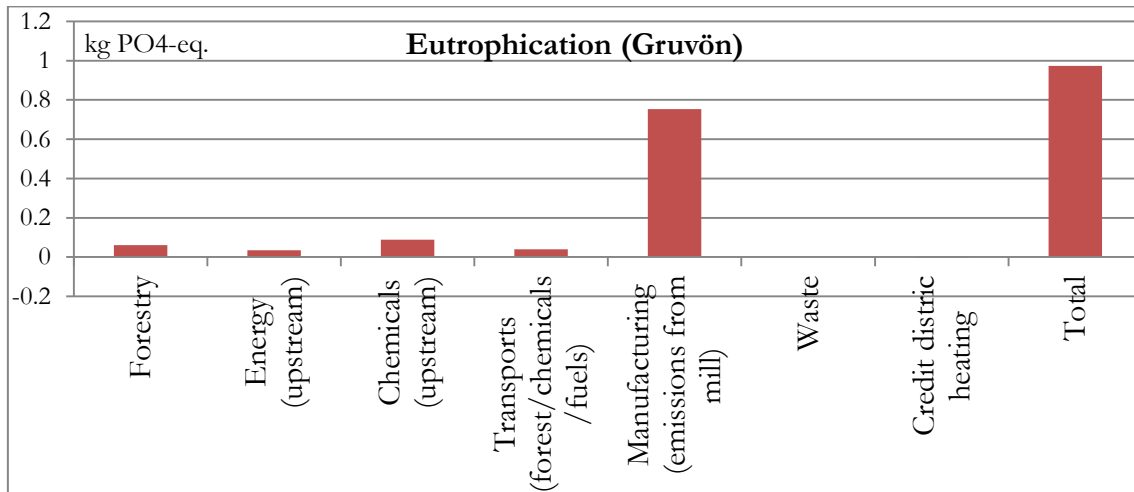


Figure 83. EP for the production of one tonne bleached Kraft paper at Gruvön mill including credit from district heating utilization in the close-by society.

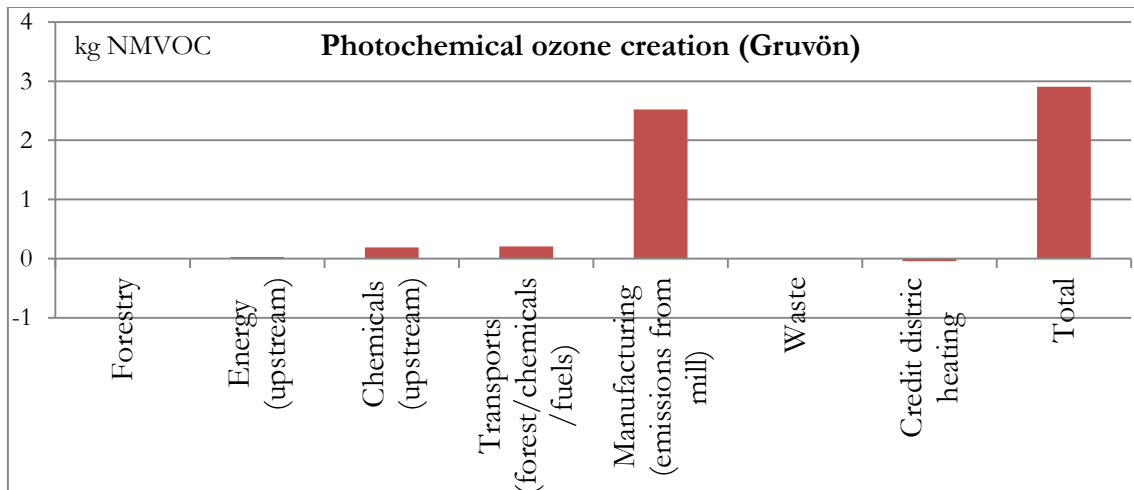


Figure 84. POCP for the production of one tonne bleached Kraft paper at Gruvön mill including credit from district heating utilization in the close-by society.

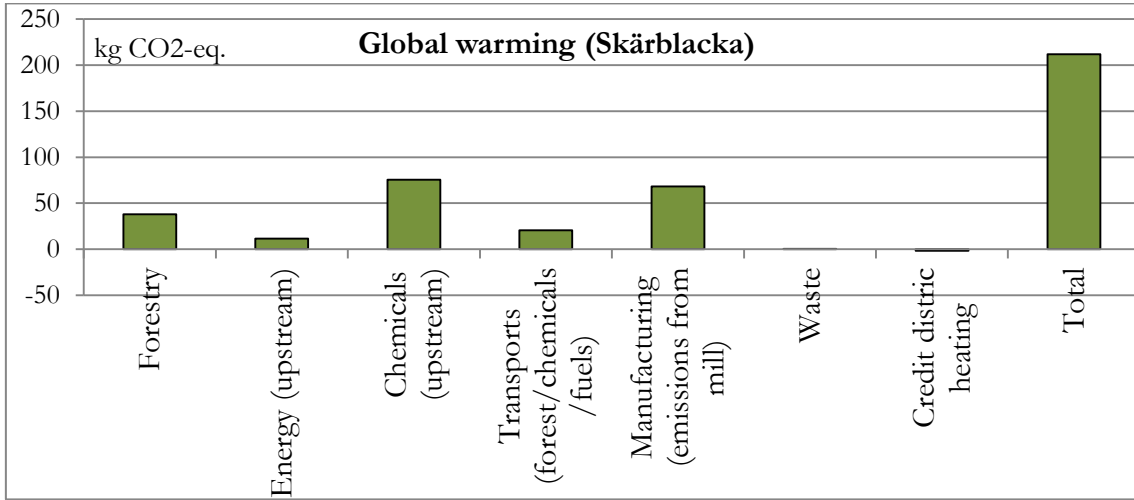


Figure 85. GWP for the production of one tonne bleached Kraft paper at Skärblacka mill including credit from district heating utilization in the close-by society.

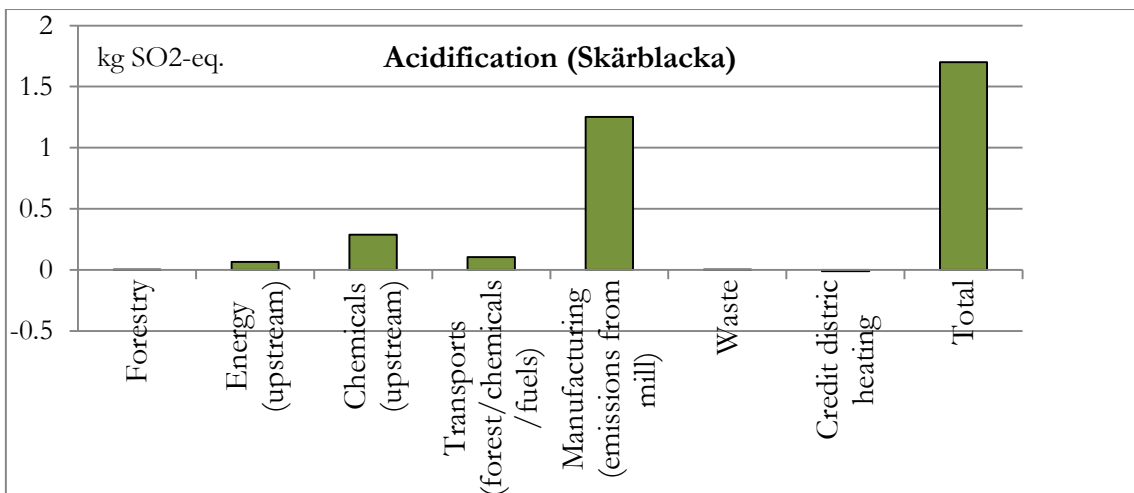


Figure 86. AP for the production of one tonne bleached Kraft paper at Skärblacka mill including credit from district heating utilization in the close-by society.

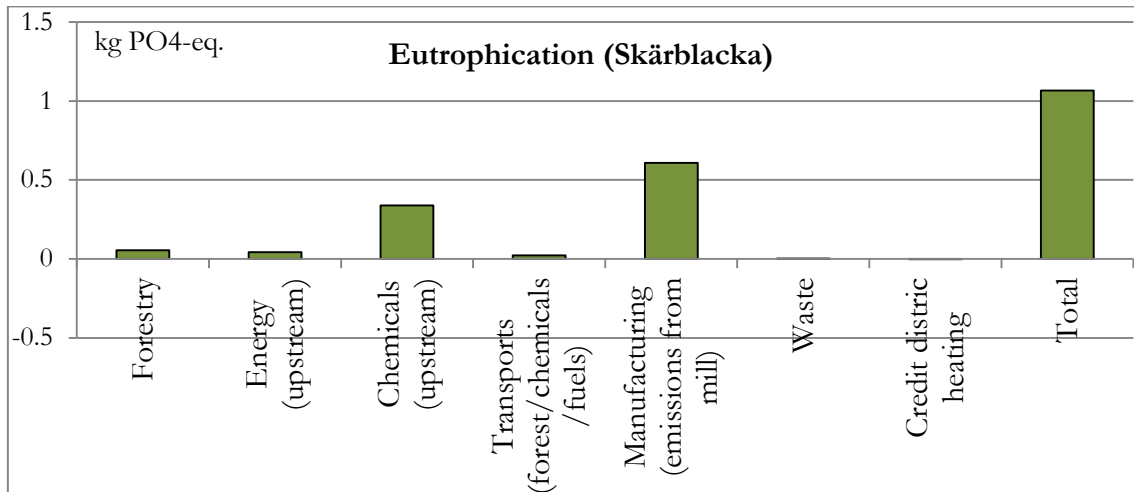


Figure 87. EP for the production of one tonne bleached Kraft paper at Skärblacka mill including credit from district heating utilization in the close-by society.

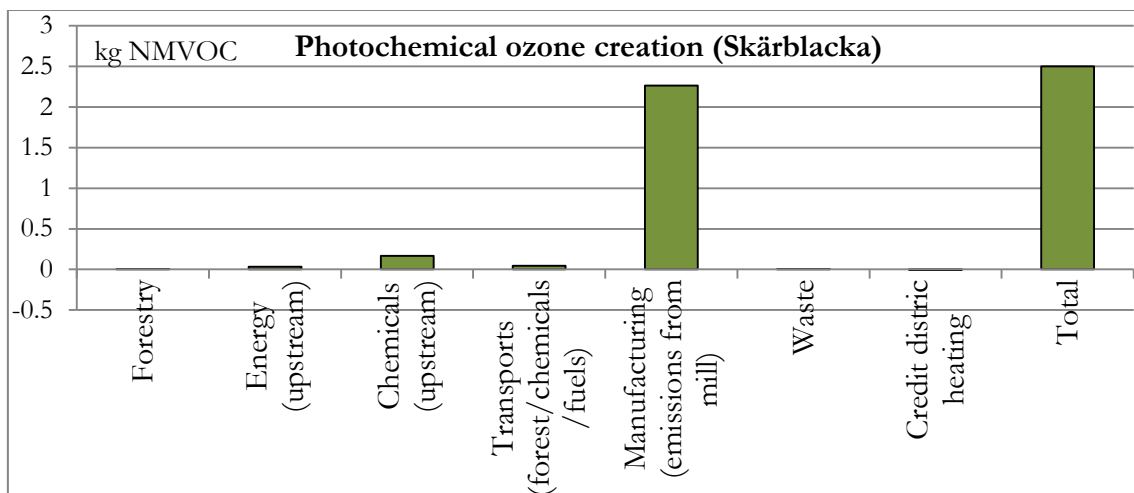


Figure 88. POCP for the production of one tonne bleached Kraft paper at Skärblacka mill including credit from district heating utilization in the close-by society.



## Appendix III: The results presented in tables

Table 11. Results for Gruvön mill

Bleached kraftpaper - Gruvön				
	AP	EP	GWP	POCP
	[kg SO <sub>2</sub> -eq.]	[kg PO <sub>4</sub> -eq.]	[kg CO <sub>2</sub> -eq.]	[kg NMVOC]
Forestry	9.41E-04	6.06E-02	4.14E+01	6.51E-04
Energy (upstream)	5.56E-02	3.44E-02	9.60E+00	2.86E-02
Chemicals (upstream)	6.87E-01	8.82E-02	5.28E+01	1.92E-01
Transports (forest/chemicals/fuels)	2.91E-01	4.05E-02	2.52E+01	2.07E-01
Manufacturing	1.15E+00	7.54E-01	6.34E+01	2.52E+00
Waste	8.19E-05	1.86E-05	1.83E-02	3.00E-05
<b>Total</b>	<b>2.19E+00</b>	<b>9.77E-01</b>	<b>1.92E+02</b>	<b>2.95E+00</b>

Table 12. Results for Skärblacka mill

Unbleached sackpaper - Skärblacka				
	AP	EP	GWP	POCP
	[kg SO <sub>2</sub> -eq.]	[kg PO <sub>4</sub> -eq.]	[kg CO <sub>2</sub> -eq.]	[kg NMVOC]
Forestry	8.63E-04	5.56E-02	3.80E+01	5.97E-04
Energy (upstream)	6.60E-02	4.21E-02	1.14E+01	3.39E-02
Chemicals (upstream)	2.88E-01	3.40E-01	7.54E+01	1.65E-01
Transports (forest/chemicals/fuels)	1.04E-01	2.19E-02	2.06E+01	4.45E-02
Manufacturing	1.25E+00	6.09E-01	6.81E+01	2.26E+00
Waste	6.92E-05	1.57E-05	1.54E-02	2.54E-05
<b>Total</b>	<b>1.71E+00</b>	<b>1.07E+00</b>	<b>2.14E+02</b>	<b>2.51E+00</b>

**Table 13. Results Acidification for all products**

Acidification Potential [kg SO <sub>2</sub> -Equiv.]					
	Material production	Material transport	Packaging production	Packaging transport	Total
Plastic pasta bag	8.44E-05	4.82E-07	2.13E-06	4.63E-07	8.75E-05
Paper pasta bag	1.58E-05	2.98E-06	7.33E-06	8.40E-07	2.69E-05
Plastic grocery bag	1.41E-04	3.54E-06	5.21E-06	1.98E-06	1.51E-04
Paper grocery bag	1.01E-04	6.59E-06	8.96E-06	1.37E-05	1.30E-04
Plastic cement sack	1.03E-03	1.85E-05	1.07E-03	1.85E-06	2.13E-03
Paper cement sack	2.22E-04	9.19E-04	7.37E-04	4.70E-06	1.88E-03
PET bottle	1.67E-04	4.20E-06	3.83E-05	1.94E-06	2.12E-04
FibreForm Packaging bottle	7.03E-05	9.99E-07	6.01E-06	2.78E-06	8.01E-05

**Table 14. Results Eutrophication for all products**

Eutrophication Potential [kg PO <sub>4</sub> -Equiv.]					
	Material production	Material transport	Packaging production	Packaging transport	Total
Plastic pasta bag	6.26E-06	1.10E-07	2.55E-07	1.05E-07	6.73E-06
Paper pasta bag	7.04E-06	6.79E-07	8.91E-07	1.92E-07	8.80E-06
Plastic grocery bag	3.05E-05	8.05E-07	6.32E-07	4.51E-07	3.24E-05
Paper grocery bag	6.30E-05	1.55E-06	1.09E-06	3.11E-06	6.87E-05
Plastic cement sack	7.67E-05	3.23E-06	8.24E-04	3.23E-07	9.05E-04
Paper cement sack	1.39E-04	9.30E-05	5.66E-04	8.24E-07	7.99E-04
PET bottle	1.81E-05	9.56E-07	5.38E-06	4.41E-07	2.49E-05
FibreForm Packaging bottle	1.22E-05	2.28E-07	1.09E-06	4.73E-07	1.40E-05

Table 15. Results Global warming for all products

Global Warming Potential [kg CO <sub>2</sub> -Equiv.]					
	Material production	Material transport	Packaging production	Packaging transport	Total
Plastic pasta bag	1.69E-02	1.08E-04	1.46E-03	1.04E-04	1.86E-02
Paper pasta bag	1.39E-03	6.62E-04	4.30E-03	1.86E-04	6.53E-03
Plastic grocery bag	3.97E-02	7.91E-04	3.14E-03	4.43E-04	4.41E-02
Paper grocery bag	1.26E-02	1.46E-03	5.21E-03	3.05E-03	2.23E-02
Plastic cement sack	2.07E-01	3.17E-03	1.49E-01	3.17E-04	3.59E-01
Paper cement sack	2.78E-02	3.03E-02	1.02E-01	8.00E-04	1.61E-01
PET bottle	4.58E-02	9.39E-04	2.00E-02	4.33E-04	6.71E-02
FibreForm Packaging bottle	1.52E-02	2.23E-04	3.22E-03	4.58E-04	1.91E-02

Table 16. Results Photochemical Ozone Creation for all products

Photochemical Ozone Creation Potential [kg NMVOC]					
	Material production	Material transport	Packaging production	Packaging transport	Total
Plastic pasta bag	4.26E-05	1.77E-07	1.66E-06	1.70E-07	4.46E-05
Paper pasta bag	2.13E-05	1.09E-06	5.20E-06	3.08E-07	2.79E-05
Plastic grocery bag	1.57E-04	1.30E-06	3.76E-06	7.27E-07	1.63E-04
Paper grocery bag	1.48E-04	2.42E-06	6.32E-06	5.02E-06	1.62E-04
Plastic cement sack	5.22E-04	5.50E-06	2.97E-04	5.50E-07	8.25E-04
Paper cement sack	3.26E-04	7.78E-04	2.04E-04	1.40E-06	1.31E-03
PET bottle	1.71E-04	1.54E-06	2.74E-05	7.11E-07	2.01E-04
FibreForm Packaging bottle	6.46E-05	3.66E-07	4.02E-06	1.62E-06	7.06E-05