LIFE CYCLE ASSESSMENT OF A PAPER E-COMMERCE BAG

A report to Nordic Paper

2024-03-21

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SUMMARY

Nordic Paper is a global supplier of pulp and paper. Their products are used in various settings, one example is their kraft paper being used for e-commerce bags.

Nordic Paper was interested in gaining more knowledge on the environmental performance through a Life Cycle Assessment (LCA) of the one type of e-commerce bag which is made from Nordic Paper's unbleached kraft paper.

This report covers the LCA of an e-commerce paper bag produced in Sweden. The declared unit in this study is 1 piece of paper e-commerce bag and the weight of the bag is 38.61 g.

The paper e-commerce bag is made of several raw materials, with the main raw material being unbleached kraft paper which is produced at the Nordic Paper Bäckhammar site in Sweden. Other raw materials are either produced at the site (the wood pulp) or sourced from European suppliers (chemicals and other consumables). The production in the integrated mill in Bäckhammar consists of different process steps before the final paper product is delivered to the converter Jonsac where the paper e-commerce bag is converted.

According to the assumptions made in this analysis, the result from the study shows that the paper e-commerce bag produced with paper from Nordic Paper has a fossil climate impact of 23.4 g CO_2-eq. Climate impact from the transport for the distribution of the bag could have a larger or smaller impact, depending on the final location of both the paper and plastic e-commerce bags.

The environmental impact of the paper used in the e-commerce paper bag could be reduced by using chemicals that have a lower climate impact and energy efficiency at the plant producing the paper.

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1. INTRODUCTION

Nordic Paper is a global supplier of pulp and paper. Their products are used in various settings, such as their paper being used in the production of paper e-commerce bags. Nordic Paper was interested in gaining more knowledge on the environmental performance through a Life Cycle Assessment (LCA) of one type of e-commerce bag which is made from Nordic Paper's unbleached kraft paper. Additionally, Nordic Paper was interested in understanding what the potential benefits are with the use of paper e-commerce bags instead of plastic e-commerce bags through a scenario analysis of a generic plastic e-commerce bag.

1.1 Introduction to Life cycle assessment (LCA)

Life Cycle Assessment (LCA) is a methodology for assessing the environmental impact of a product, service, or process. The LCA methodology is standardised according to ISO 14040 (ISO - International Organisation for Standardisation, 2006) and ISO 14044 (ISO - International Organisation for Standardisation, 2006) and consists of the steps Goal and scope definition, Inventory analysis, Impact assessment and Interpretation.

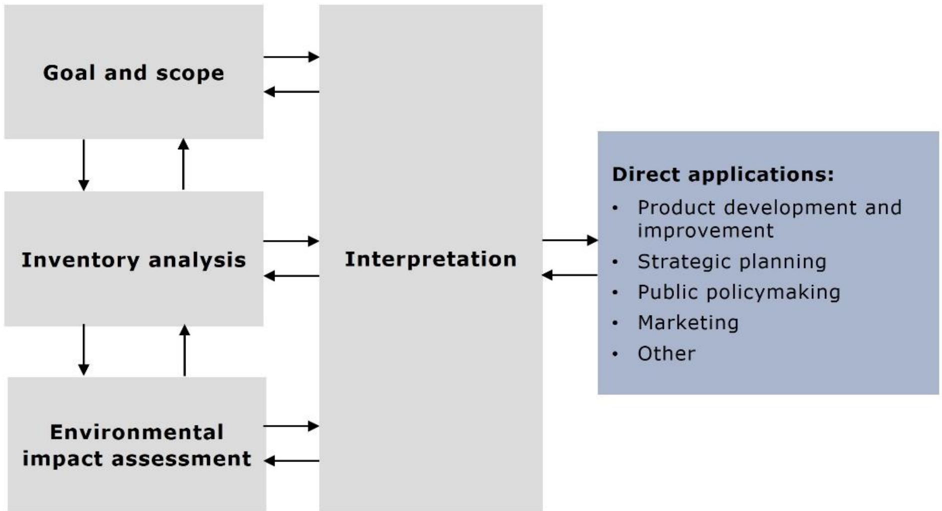


Figure 1: Framework for life cycle assessment (ISO - International Organisation for Standardisation, 2006).

1. Goal and scope definition: The goal of the study describes the intended application, the reasons for carrying out the study and the intended audience. The scope of the LCA is described with the product system being studied, the functional unit, the system boundaries, possible allocations, the methodology for environmental impact assessment and subsequent interpretation, limitations, data quality requirements, type of critical review if applied and type and format of report required for the study.

2. Inventory analysis: Information on materials and processes is collected including resources needed for and emissions and waste from each process. This is done for all phases in the product’s life cycle.
3. Environmental impact assessment: The environmental impact assessment evaluates the significance of the environmental effects that the product's life cycle potentially contributes to. It is important to be aware that it is the potential environmental impact that is being described.
4. Interpretation: An interpretation of the results is made by, among other things, analysing the impact of the method choice and the underlying assumptions on the result. The significance of data gaps and used data quality must also be described in the interpretation section. The results of sensitivity analyses and uncertainty analyses performed in other parts of the study must appear in the interpretation.

Life cycle assessment is an iterative methodology meaning that the different phases of the study may need to be adjusted as the study is carried out and more information is collected.

A complete LCA comprises all phases of a product’s life cycle (“cradle to grave") and includes extraction of raw materials, manufacture of materials, components and products, transport, use phase and waste management. It is also possible to only include a few life-cycle phases, the most common approach being a so-called cradle to gate-LCA, in which the assessment often ends after the manufacturing phase with the finished product ready to use.

When generating an LCA, the goal is to quantify environmental inputs and outputs to the defined system. Such inputs and outputs are, for instance, raw materials, different types of energy, water and emissions to air, soil, and water of different substances such as CO_2, NO_x, metals, and other pollutants.

Several emissions and resources used can contribute to the same environmental impact category. Therefore, resources and emissions are multiplied with so called characterisation factors to calculate the environmental impact in different categories such as climate change, eutrophication, resource use and toxicity. In this way, several resources and emissions contributing to environmental impact within a certain category can be added to or compared with each other. Resulting environmental impact is often expressed in “equivalents”. One example is the impact category climate change in which other emissions contributing to climate change such as methane or nitrous oxide are recalculated to CO_2-equivalents.

2. GOAL AND SCOPE DEFINITION

2.1 Purpose of the study

The purpose of this study is to assess the environmental performance of the paper e-commerce bag produced in Sweden by Nordic Paper and Jonsac. Additionally, a scenario analysis of the potential benefits of using a paper e-commerce bag instead of a generic plastic e-commerce bag was examined. The study is intended to be communicated externally to customers and stakeholders, the results from the scenario analysis with the generic plastic e-commerce bag is however not meant for external communication to state the benefits of one bag over another. This study will also be used internally at Nordic Paper in the process of developing products with a lower environmental impact.

2.2 Target Audience

The target audience for this report is Customers, Stakeholders and Nordic Paper themselves.

2.3 Commissioner of the LCA Study and Other Influential Actors

The study is commissioned and fully financed by Nordic Paper. Nordic Paper and Jonsac has also provided the data necessary for performing the study. LCA practitioners performing the study are employees at AFRY. AFRY do not have any conflict of interest in the execution of the study.

2.4 Product description

The product that is analysed in this LCA is a paper e-commerce bag. The specification for the paper e-commerce bag can be seen in Table 1 below:

Table 1: The weight and dimensions of the e-commerce bags

Product	Weight (g)	Dimension (mm)	Weight of paper
Paper e-commerce bag	38.61	300 x 420/80	100 gsm

The paper e-commerce bag

The paper e-commerce bag is made of several raw materials, with the main raw material being the unbleached kraft paper which is produced at Nordic Paper Bäckhammar site in Sweden. Raw materials are either produced at site (the wood pulp) or sourced from European suppliers (chemicals, other consumables). The production in the integrated mill in Bäckhammar consists of different process steps, as the mill produces both pulp and kraft paper, before the final paper product is delivered to the converter Jonsac.

Three different products are produced at Nordic Paper's site in Bäckhammar during the production of the kraft paper, for which an allocation has been made. More information on the allocation can be found in section 2.9.

The unbleached kraft paper is converted to the e-commerce bag at Jonsac's Otterbäcken site in Sweden. Raw materials, such as coating and chemicals, are bought from European suppliers. The manufacturing of the paper e-commerce bag consists of different process steps before the final product is delivered to the customer.

The kraft paper is then transported over the Jonsac's Otterbäcken site in Sweden where the conversion of the kraft paper to the e-commerce bag takes place. The paper bag is then transported to the various customers within Sweden. The system boundaries of the paper e-commerce bag can be seen in section 2.7 below.

2.5 Declared Unit

The declared unit in this study is 1 piece of e-commerce bag, based on 100 gsm kraftpaper, see Table 1. The reference flow is 38.6 g paper e-commerce bag.

2.6 LCI Modelling Framework

This study follows an attributional LCA framework following ISO 14040 (ISO - International Organisation for Standardisation, 2006) and ISO 14044 (ISO - International Organisation for Standardisation, 2006).

2.7 System Boundaries

The study is performed as a cradle-to-grave study, and for the paper e-commerce bag, it includes the production of raw materials, transportation of raw materials to the production sites, production at both Nordic Paper and Jonsac's sites, distribution and waste management of the final product according to the system showed in Figure 2. The use phase of the product is thus not included in the study. Additionally, activities such as manufacturing of equipment, buildings and other capital goods are excluded as well as business travel and travel to and from work by personnel.

In Figure 2, the general system boundaries of the study are shown. The system is divided in the modules:

- **Production of unbleached kraft paper at Nordic Paper site**: Including production and transport of raw materials, other chemicals and production processes that are used in the production of unbleached kraft paper at Nordic Paper's Bäckhammar site.
- **Production of paper e-commerce bag at Jonsac site**: Including production and transport of raw materials, other chemicals and production processes that are used in the production and conversion of the e-commerce paper bag at Jonsac's Otterbäcken site.

- **Distribution and EoL (End-of-Life)**: Including transport to distribution centre, transport to final client and waste handling of the final product.

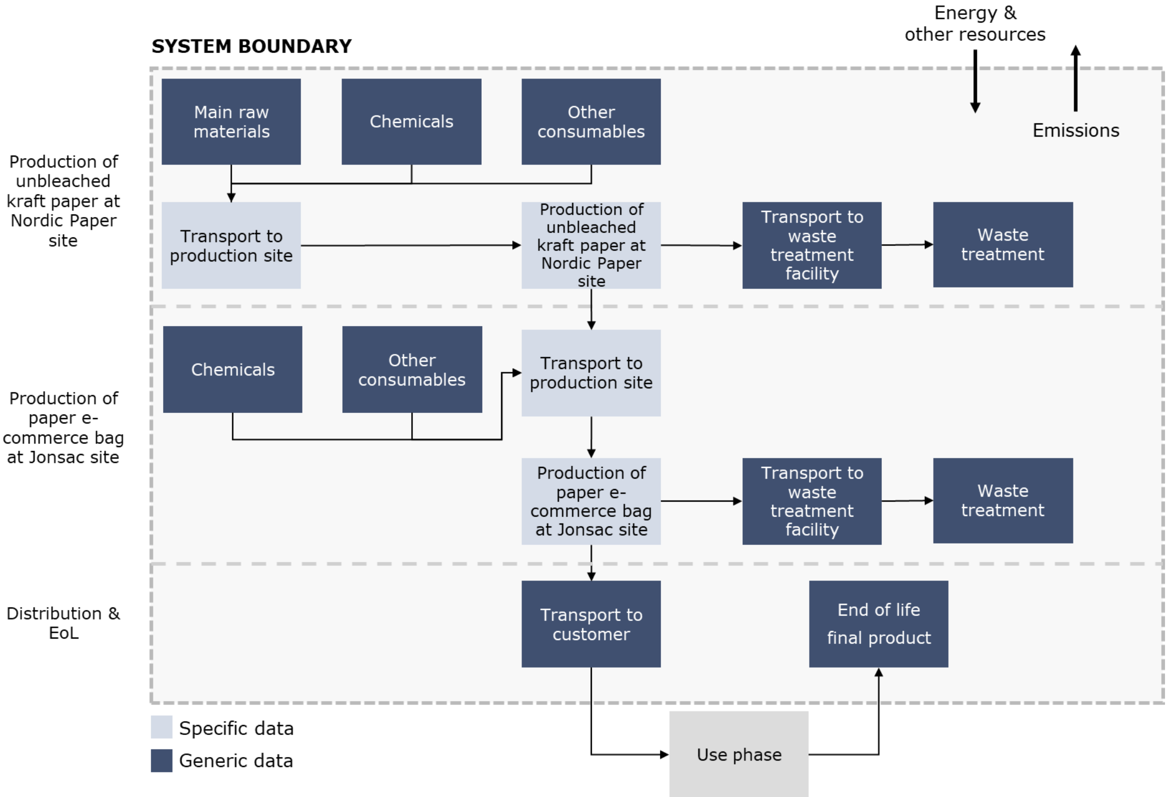


Figure 2: General system boundaries of the study

2.8 Cut-off criteria

All known mass and energy flows are included in the study.

2.9 Allocation

In the following section the allocation choices related to the LCI-analysis are presented.

An allocation has been done in relation to the produced unbleached kraft paper from Nordic Paper Bäckhammar site. The production process of kraft paper generates output of dried virgin pulp, wet virgin pulp, and kraft paper. As this LCA study analyses the impact of the paper e-commerce bag, which is predominantly made from the unbleached kraft paper, an allocation based on mass has been done. Table 2 shows the allocation ratio for the kraft paper.

Table 2: Allocation ratio for the LCA, based on mass (of kraft paper)

Output from production	Amount (air dried Ton)	% of total output
Dried virgin pulp	13 000	6 %

Wet virgin pulp	54 000	25 %
Unbleached kraft paper	*148 641*	*69 %*
Total	**215 641**	**100%**

2.9.1 *Allocation of burdens between products*

Allocation of manufacturing utilities, emissions and waste have been made as several products are produced in the same production site. The allocation is made based on the total amount of pulp and paper produced.

2.9.2 *Allocation of recycled content*

Allocation of recycled materials has been set according to the polluter pays principle. This means that the generator of waste carries the full environmental impact until the point of the product's life cycle at which the waste is transported to a waste disposal facility or the gate of a waste processing plant. The subsequent user of the waste shall carry the environmental impact from the processing and refinement of the waste but not the impact caused in the earlier life cycles.

2.10 Software and database

The LCA model was created using Simapro software (v.9.5.0.2). Generic data comes primarily from Ecoinvent, 3.9.1 (Wernet, o.a., 2019). In the case where data from the Ecoinvent database wasn't available, other databases (e.g. Industry data 2.0) were considered during the modelling. The geographical information of the data has been prioritized.

2.11 Representativeness of LCI Data

The quality of the generic data used has been assessed according to geographical, time-related, and technical representativeness of the datasets used in this analysis. The datasets were selected from Ecoinvent 3.9.1. In general, the overall representativeness of the data is good when the three criteria are assessed. In the following sub-sections, the data quality according to the three criteria is described.

2.11.1 *Geographical Representativeness*

The datasets used in the analysis have been chosen to best represent geographically where the production of the products takes place. If possible, datasets from the specific country where the production takes place has been chosen. This is the case for the pulpwood and fuelwood, as well as the sawmill chips, which account for the largest share of the total raw materials used in the production of the kraft paper used in the production of the paper e-commerce bag. For the modelling of the electricity for the paper e-commerce bag, a Swedish average electricity mix from Ecoinvent was used as a starting point and modified according to specific information of electricity used during the production. If datasets were not available on materials or processes in the right geography, regional datasets, such as "Rest-of-Europe", "Global", or

"Rest-of-World" were used instead, these are the cases for the chemicals used in the production, for which global generic datasets have been used.

2.11.2 Time-Related Representativeness

The time-related representativeness of the data is considered good. All specific inventory data is from year 2022 and based on production data for the entire year. The generic data was based on Ecoinvent version 3.9.1 (Wernet, o.a., 2019) which was released in January 2023.

2.11.3 Technical Representativeness

Datasets representing the stated technology were selected from Ecoinvent 3.9.1 (Wernet, o.a., 2019). In cases where the technology was unknown or uncertain, datasets representing an average or conventional method were prioritised. This is the case for modelling of the chemicals and additives used during the production, where organic and inorganic chemicals were used to represent the unknown chemicals. Alternatively, datasets for similar product types or more general datasets were utilised. This was done for modelling of the sawmill chips, but the generic data was modified to account for an electric stationary woodchipper instead of a diesel-driven mobile woodchipper to give a better technical representativeness of the actual process for sawmill chips.

2.12 Impact Assessment Method

In this study, the impact categories climate change, acidification potential, particulate matter and abiotic depletion – fossil fuels have been assessed. The rationale for choosing these categories is that they are pointed out as the most relevant for intermediate paper products in PEFCR (European Commission, 2020). Water use was also assessed in addition to the categories mentioned above. Even though the paper e-commerce bag is not an intermediate product, these impact categories have been considered as relevant also for that product since pulp and paper production is the dominant production process.

Impact assessment categories from EF 3.1 as implemented in SimaPro has been used.

Table 3 shows impact categories. Characterisation factors for the included impact categories can be found on the European Platform on Life Cycle Assessment (European Commission, 2019).

Table 3: Environmental impact categories from EN 15804:2012 + A2:2019

Impact category	Indicator	Unit	Model
Climate change - total	Radiative forcing as global warming potential (GWP100)	kg CO2eq.	Baseline model of 100 years of the IPCC based on IPCC 2021
Climate change - fossil	Global Warming Potential (GWP-fossil)	kg CO2eq.	Baseline model of 100 years of the IPCC based on IPCC 2021

Impact category	Indicator	Unit	Model
Climate change - biogenic	Global Warming Potential (GWP-biogenic)	kg CO2eq.	Baseline model of 100 years of the IPCC based on IPCC 2021
Climate change – land use and land use change	Global Warming Potential (GWP-luluc)	kg CO2eq.	Baseline model of 100 years of the IPCC based on IPCC 2021
Acidification	Acidification potential, Accumulated Exceedance (AP)	mol H+ eq.	Accumulated Exceedance, Seppälä et al. 2006, Posch et al., 2008
Resource use, fossils	Abiotic resource depletion – fossil fuels (ADP-fossil)	MJ, net calorific value	CML 2002, Guinée et al., 2002, and van Oers et a. 2002.
Particulate matter emissions	Potential incidence of disease due to PM emissions (PM)	Disease incidence	SETAC-UNEP, Fantke et al. 2016
Water use	User deprivation potential (deprivation-weighted water consumption)	m3 world eq.	Available WAterREmaining (AWARE) Boulay et al., 2016

2.13 Limitations

This study should not be used as to make general claims on whether the products are environmentally friendly or not. The LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks. The quality of the results depends on the quality of the LCI given by Nordic Paper and Jonsac and on the quality of the datasets used.

2.14 Critical Review

As this report is to be communicated externally, an independent third-party review is to be performed. This review is done by Katrin Molina-Besch at Miljögiraff. In addition, AFRY assigns an internal quality reviewer in all its projects.

3. LIFE CYCLE INVENTORY ANALYSIS

In the following section the methodological choices related to the LCI-analysis are presented.

3.1 Data Collection

Inventory data has been collected from the companies Nordic Paper and Jonsac. All specific inventory data is from year 2022 and based on production data for the entire year. Data connected to the production at Nordic Paper's and Jonsac's facilities, and transportation of raw materials is specific while data for raw materials, waste transport and management, transport to customers and EoL are generic. Generic data comes from Ecoinvent 3.9.1 (Wernet, o.a., 2019). The energy use, amount of waste, chemicals and direct emissions have been allocated to the product by mass.

3.2 System Modelling Paper E-commerce bag

The system modelling of the paper e-commerce bag has been divided into three modules: 1) Production of unbleached kraft paper at Nordic Paper site, 2) Production of paper e-commerce bag at Jonsac site, and 3) Transport to customer and EoL of final product. The system modelling and input and output for the paper e-commerce bag will be presented in the following sections.

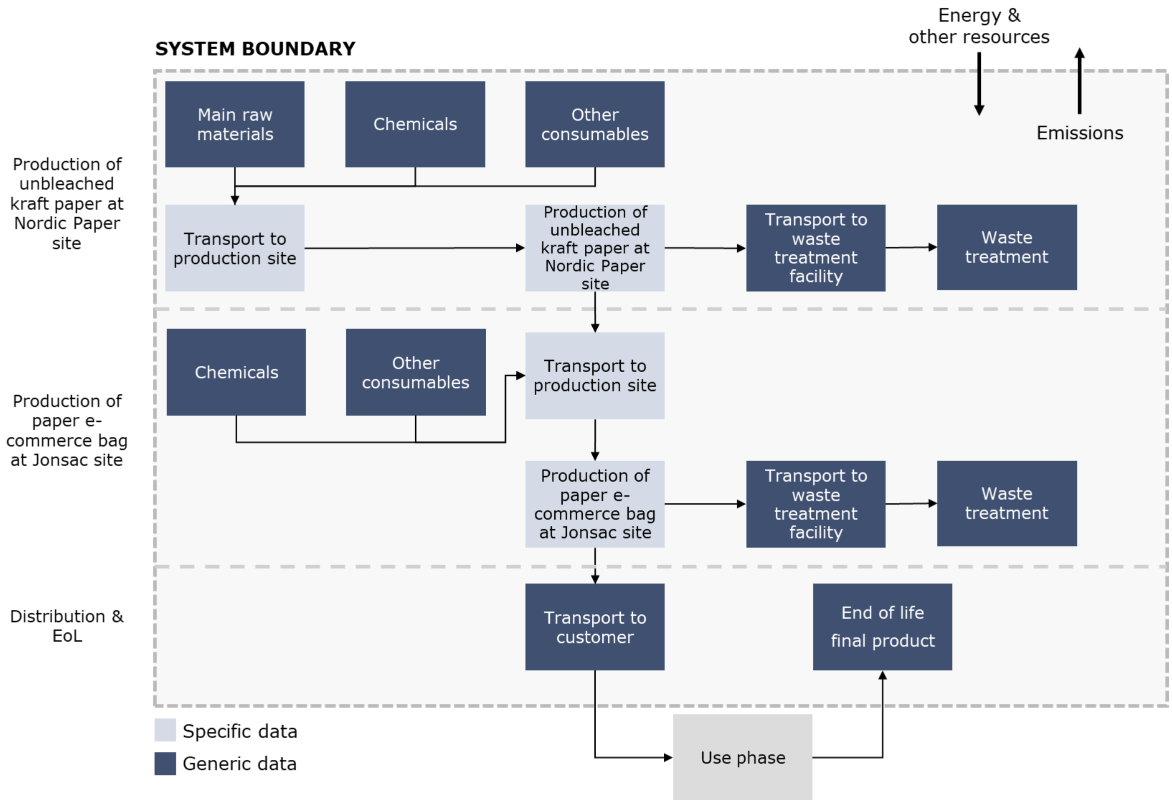


Figure 3: System model

3.2.1 Production of unbleached kraft paper at Nordic Paper site

The *Production of unbleached kraft paper at Nordic Paper site* module includes the raw materials (along with transport to the manufacturing facility), chemicals and other consumables used in production and the production processes of the paper e-commerce bag at Nordic Paper's Bäckhammar site. Nordic Paper has shared comprehensive information on their environmental impact, including data on their emissions, energy use, chemical usage, water consumption, waste generation and transportation. The data also covered waste generated through spillage during production, as well as chemicals used in the different process stages. The following sections explain the generic data modified for this specific study, as well as explaining the thought process for the system modelling done in Simapro.

The full life cycle inventory (input and output data as well as used generic datasets) for the production at Nordic Paper Bäckhammar site for 1 paper e-commerce bag can be found in Table 11 in Annex B.1.

3.2.1.1 Raw materials

The main raw materials used in the production of the unbleached kraft paper are pulp wood, fuel wood and sawmill chips.

The pulp and fuel wood consists of 50% spruce wood and 50% pine wood, and generic data sets for pulpwood was used for the system modelling.

The modelling of the sawmill chips process required modifications of a generic Ecoinvent dataset in order to account for the use of electrical woodchipper at the sawmill instead of mobile chipper that is in the original dataset from Ecoinvent. The saw- and veneer log used to model the sawmill chips consists of 50% spruce wood and 50% pine wood. As the process in Simapro requires the amounts of sawmill chips in kg, a conversion was done to convert the input amount of m^3fub to kg. The density factor for the spruce sawmill chips wood was 421 kg/m^3fub, and for the pine sawmill chip wood was 404 kg/m^3fub.

There is a lack of publicly available information on density factors converting wood from m^3fub to kg, and a relevant source that was available on the density and conversion factors for industrial and pulpwood chips was from 2001 (Lindblad & Verkasalo, 2001). The use of the density factor was confirmed and agreed on by Nordic Paper.

3.2.1.2 Chemicals

The safety data sheets of the chemicals were provided by Nordic Paper. The European Chemical Agency database was then used to gain information on the specific data on the substances in the chemicals.

For the data sheets that disclosed very small amounts of the substances in the chemicals, generic data sets from Ecoinvent (either organic or inorganic chemicals) were used to model those chemicals.

3.2.1.3 Energy and water use

Electricity

Nordic Paper's manufacturing facility in Bäckhammar both self-produces electricity, and purchases electricity from the company Vattenfall, who generates electricity from different sources.

Excess heat from pulp production, more specifically from the boilers, can be recovered and utilized for energy generation which is done at Nordic Paper's Bäckhammar site. The emissions for the self-produced energy are included in the direct emissions reported by Nordic Paper and can be seen in Table 11 in Annex B.1.

For the purchased energy from Vattenfall, the share of the different sources has been provided by the company, with the largest source in the electricity mix being nuclear energy with 61% share, followed by hydro energy with 39% share in the electricity mix. Swedish average electricity mix from Ecoinvent was used as a starting point during the system modelling for the electricity and has been modified according to Vattenfall's electricity mix that Nordic Paper purchases. The certificate of origin can be found in Annex D.2.

Water

The water used at the Nordic Paper Bäckhammar site comes from a nearby lake.

3.2.1.4 Packaging

The produced unbleached kraft paper is rolled up, and packaged with a wrapping paper which is a PE-laminated wrapping paper. The short sides of the rolls are then covered with dishes made from kraft paper.

The wrapping paper consists of 10% PE-plastic and 90% paper.

3.2.1.5 Transport

Transport distances for raw materials were provided by Nordic Paper. Raw materials from Europe are transported by truck, train or boat. In Table 12 in Annex B.1, the distances, transport types and data sets are presented.

3.2.1.6 Direct emissions (to air and water)

The direct emissions stemming from the production of Nordic Paper's unbleached kraft paper were provided by Nordic Paper and are the direct emissions (to air and water) registered at Naturvårdsverket for the year 2020. The direct emissions can be found in Table 11 in Annex B.1.

3.2.1.7 Manufacturing waste

Waste from the manufacturing process is divided into hazardous and non-hazardous waste and sent to waste treatment processes. Based on information from Nordic Paper, the waste goes to incineration or recycling. The amounts of manufacturing waste, as well as the respective waste treatment methods can be found in Table 11 in Annex B.1

An average transport distance of 250 km with truck was added to the model.

3.2.2 Production at Jonsac site

The *Production at Jonsac site* module includes the raw materials (along with transport to the manufacturing facility), other chemicals used in production and the conversion processes of the paper e-commerce bag at Jonsac's Otterbäcken site. Jonsac has shared comprehensive information on their environmental impact, including data on their emissions, energy consumption, chemical usage, water consumption, waste generation and transportation. The data also cover waste produced through spillage during production, as well as chemicals used in the different process stages.

The following sections explain the generic data used in this specific study, as well as explaining the thought process for the system modelling done in Simapro.

The full life cycle inventory (input and output data) for the production at Jonsac's Otterbäcken site for 1 paper e-commerce bag can be found in Table 13 in Annex B.2.

3.2.2.1 Raw material

The main raw material to produce the e-commerce paper bag is paper (E-pack NP brun) from Nordic Paper. The other materials used in the production are other paper, adhesive, adhesive stripe, and print.

3.2.2.2 Transport

Transport distances for raw materials was provided by Jonsac. Raw materials from Europe are transported by truck. In Table 14 in Annex B.2 the distances, transport types and data sets are presented.

3.2.2.3 Energy and water use

Electricity

The manufacturing facility in Otterbäcken purchases electricity from the company Skellefteå Kraft, which provides an electricity mix from different sources, the share of the different sources has been provided by the company. The largest share in the electricity mix is hydro with 76.72% followed by wind with 20.44% and combined heat and power from biofuels with 2.83%. The certificate of origin can be found in Annex D.1.

Heat

The manufacturing facility in Otterbäcken purchases pellets that are used for heat.

3.2.2.4 Packaging

The produced paper e-commerce bags are packed in cardboard boxes. The boxes are stacked on EUR pallets and wrapped in plastic packaging film before they are shipped to the customer.

3.2.2.5 Direct emissions

There are no direct emissions stated by the converter of the paper e-commerce bag.

3.2.2.6 Manufacturing waste

Waste from the manufacturing process is non-hazardous waste and it is sent to waste treatment processes. Based on information from Jonsac, the waste is assumed to go to recycling.

An average transport distance of 15 km with a truck was added to the model. The total amount of manufacturing waste per raw material input is 6% for the e-commerce paper bag.

3.2.3 Distribution and End of Life

3.2.3.1 Distribution

The distribution of the e-commerce bag is divided into two steps. The first step is from the converter (Jonsac) to the first customer which is a distribution centre (DC). The second step is from the DC to the final client.

In this study, the first distance is assumed to be on average 300 km and the second distance on average 500 km. All transports are assumed to be by road.

3.2.3.2 End-of-Life

The end-of-life scenario for the paper e-commerce bag includes recycling, incineration and landfill. It is assumed that the end-of-life scenario takes place in Sweden and the share for the different processes is presented in Table 4.

Table 4: End-of-life scenario for paper e-commerce bag

Process	Percentage	Comment
Recycling	78%	(Förpackningsinsamlingen, 2023)
Incineration	21.4%	Split between energy recovery and landfill, based on 2022 Avfallshantering (Avfall_Sverige, 2023)
Landfill	0.6%	Split between energy recovery and landfill, based on 2022 Avfallshantering (Avfall_Sverige, 2023)

The transport from the final client to the recycling station is assumed to be by car and on average 1km. It is difficult to assess the distance and allocation for transport to the recycling station for the e-commerce bag. In some instances, individuals will take a trip with the primary purpose to drop of waste to the recycling station, while in other instances, dropping off waste to the recycling station will be done in connection with something else, e.g., going for groceries, or on the way home from work. It is therefore assumed that 1% of the car journey is allocated to the transport for the recycling of an e-commerce bag.

4. RESULTS AND INTERPRETATION

The estimated impact results are only relative statements which do not indicate the end points of the impact categories, exceeding threshold values, safety margins or risks.

4.1 LCIA results for the paper e-commerce bag

In Table 5, the LCIA results for the following impact categories for the paper e-commerce bag is presented.

Table 5: LCIA results per 1 e-commerce bag (weighing 38.61 g)"

Impact category	Unit	Production of unbleached kraft paper at Nordic Paper site	Production of 1 paper e-commerce bag at Jonsac site	Distribution and EoL	Total
Climate change – Fossil	kg CO2 eq	7.46E-03	5.95E-03	9.98E-03	2.34E-02
Climate change – Biogenic[1]	kg CO2 eq	-3.73E-02	-2.12E-03	1.35E-02	-2.59E-02
Climate change – Land use and LU change	kg CO2 eq	9.26E-05	1.77E-04	4.56E-06	2.74E-04
Climate change (total)[1]	kg CO2 eq	-2.98E-02	4.01E-03	2.35E-02	-2.28E-03
Acidification	mol H+ eq	1.19E-04	3.31E-05	3.43E-05	1.86E-04
Resource use, fossils[2]	MJ	2.54E-01	9.96E-02	1.36E-01	4.90E-01
Water use[2]	m3 depriv.	3.79E-03	5.15E-03	9.41E-04	9.88E-03
Particulate matter	disease inc.	2.10E-09	9.22E-10	6.84E-10	3.70E-09

[1] Note that results for climate change-biogenic and climate change-total include CO2 taken up by trees while growing and stored in paper. This CO2 will eventually be released back to the atmosphere. Thus, results in these impact categories shall be used with care.

[2] The results of this environmental impact indicator shall be used with care as the uncertainties on these results are high or as there is limited experience with the indicator.

4.1.1 Environmental impact of the different life cycle stages

Figure 4 shows the relative environmental impact of 1 paper e-commerce bag, for the following environmental impact categories: climate change – fossil, acidification, resource use, water use and particulate matter. The results are shown according to the three modules presented above. Climate change (total) is the sum of the other three climate change categories (Land use and land use change, biogenic and fossil).

In this analysis, a decision was made to focus on the fossil climate impact to avoid creating a confusion for the reader. The rationale for this decision is that trees that are the main raw material for paper absorbs biogenic carbon when they grow. This carbon is then stored in the bags and finally emitted to the atmosphere when the bags are incinerated. As we in this study are looking at different end-of-life scenarios, including recycling that does not lead to release of the biogenic carbon, we want to avoid the impression that paper e-commerce bags are carbon sinks by focusing on fossil impact.

The figure shows that the production at Jonsac has a higher impact for the impact category Water Use. This is connected to the production of the raw materials used during the conversion of the paper bag at Jonsac's site, more specifically the coating and the adhesive.

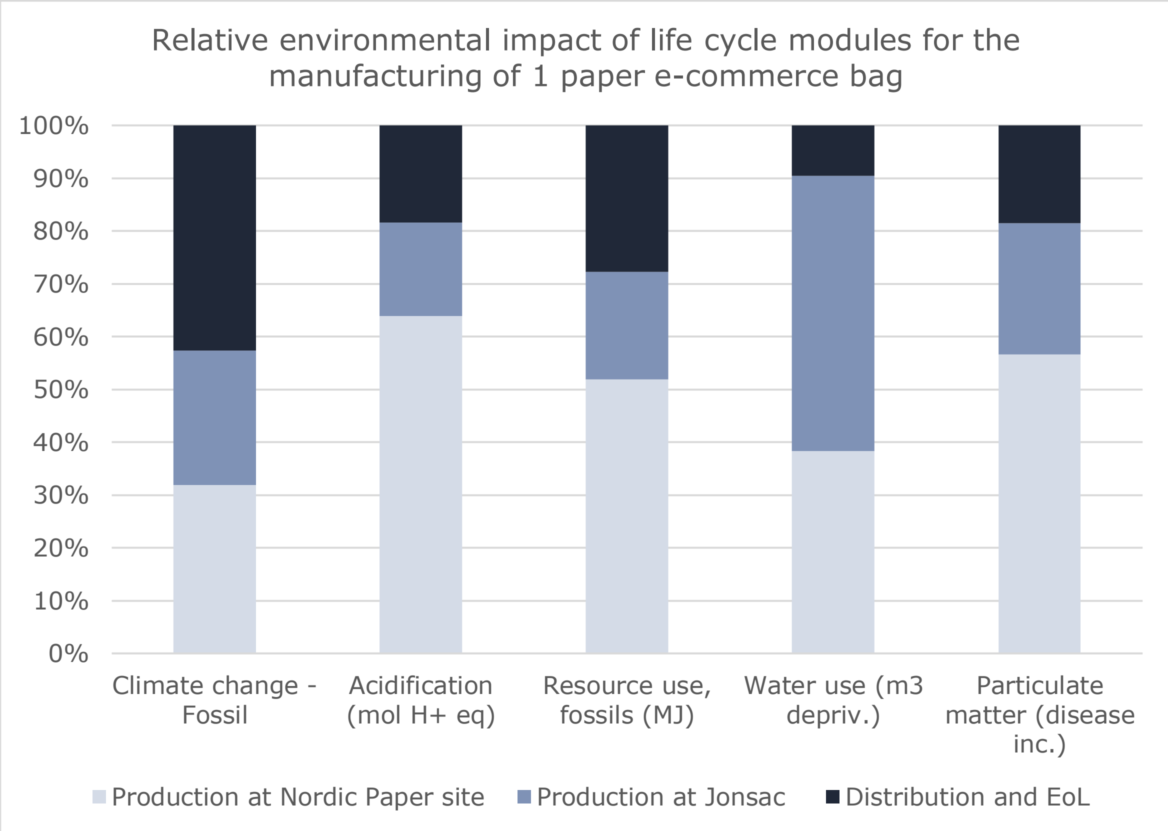


Figure 4: Environmental impact of life cycle modules for the manufacturing of 1 paper e-commerce bag

4.1.2 Climate change – fossil

4.1.2.1 Production of Nordic Paper

This section presents the fossil climate impact from the module *Production of unbleached kraft paper at Nordic Paper site* to produce 1 paper e-commerce paper bag. The results are shown according to production of 0.037595 kg of Nordic Paper's unbleached kraft paper, which is the amount needed for production of 1 e-commerce bag. In Annex C below, the results for production of 1 tonne of Nordic Paper's unbleached kraft paper are presented.

Figure 5 shows the results according to the different input materials and processes in the manufacturing, while Figure 6 shows the results as presented in the SimaPro software. The results from SimaPro are shown as a tree, and the thicker the arrow is, the more impact that process has.

The results for the unbleached kraft paper show that the pulpwood and chemicals have the largest impact, while the direct emissions to air have also a significant contribution. The reason for the large impact of the pulp wood is due to the large amounts of wood needed for the manufacturing of the kraft paper, the pulpwood accounts for 67% of the total wood input for the production. The large impact from the chemicals is due to the extraction of the raw materials for the manufacturing is considered carbon-intensive process.

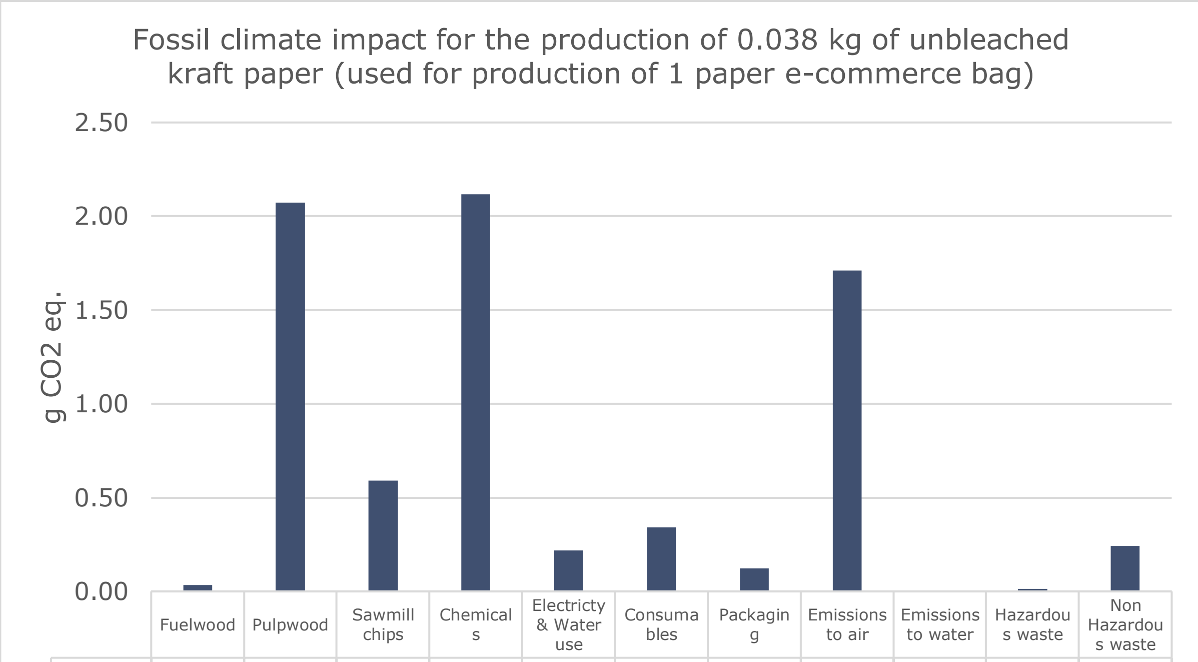


Figure 5: Fossil climate impact for the production of 0.038 kg of unbleached kraft paper

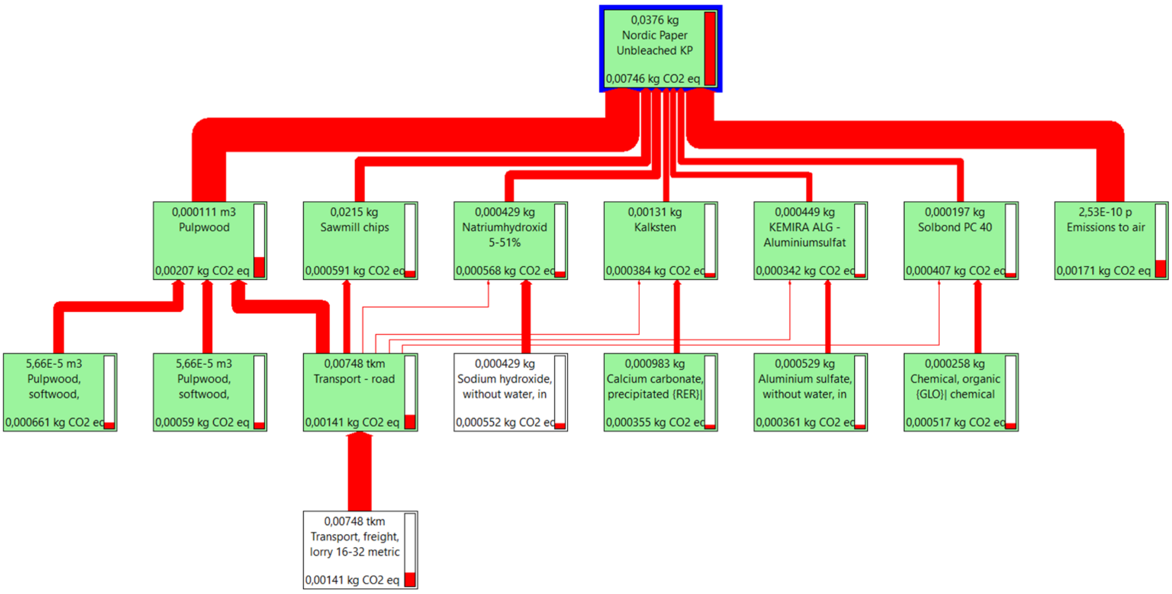


Figure 6: Fossil climate impact to produce 0.038 kg of unbleached kraft paper. Results from SimaPro software. Cut-off; 3.96 %

4.1.2.2 Production at Jonsac

This section presents the fossil climate impact from the module *Production of unbleached kraft paper at Nordic Paper site* to produce 1 paper e-commerce paper bag. The results do not include the raw materials connected to the manufacturing of Nordic Paper's unbleached kraft paper. The paper bag weighs 38.61 g, and the fossil climate impact is shown in g CO_2-eq.

Figure 7 shows the results according to the manufacturing process and the packaging, while Figure 8 shows the results as they are presented in the SimaPro software.

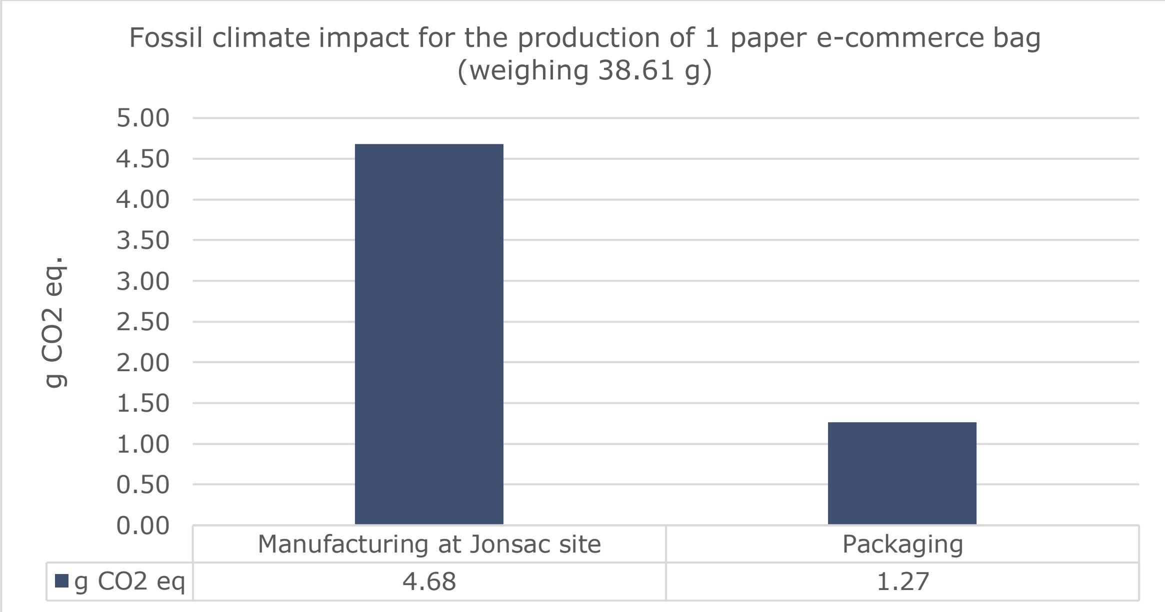


Figure 7: Fossil climate impact to produce 1 paper e-commerce bag

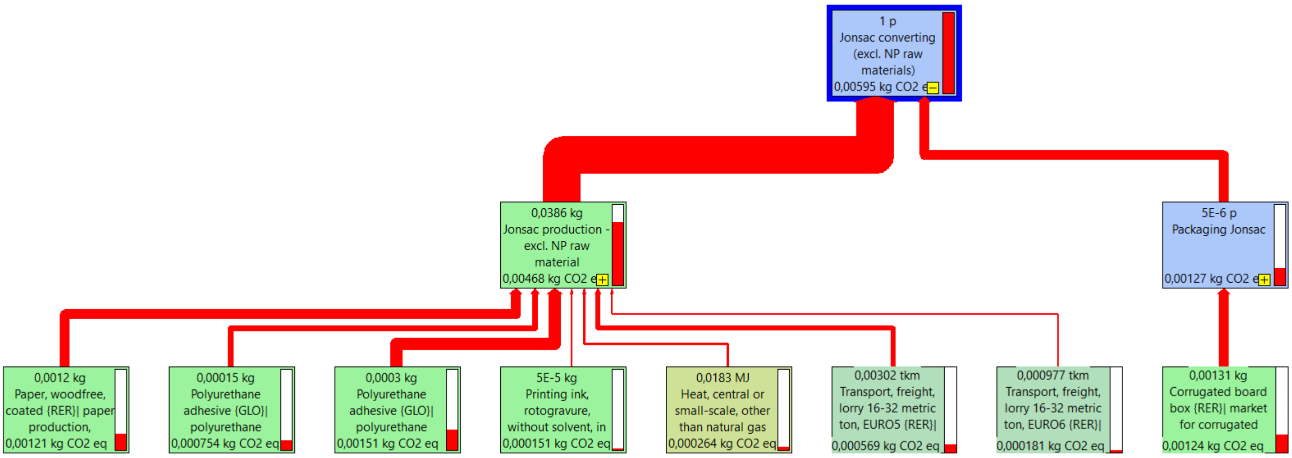


Figure 8: Fossil climate impact for the production of 1 paper e-commerce bag. Results from SimaPro software. Cut-off: 0.315 %.

4.1.2.3 Distribution & EoL

This section presents the fossil climate impact from the module Distribution and End-of-life for the paper e-commerce paper bag. The paper bag weighs 38.61 g, and the fossil climate impact is shown in g CO_2-eq.

Figure 9 shows the results according to the distribution process and the EoL process, while Figure 10 shows the results as they are presented in the SimaPro program. Figure 9 shows that the transportation during the distribution, and the EoL, has the largest impact of these two processes. That is due to the combustion of fossil fuels during the transport by road.

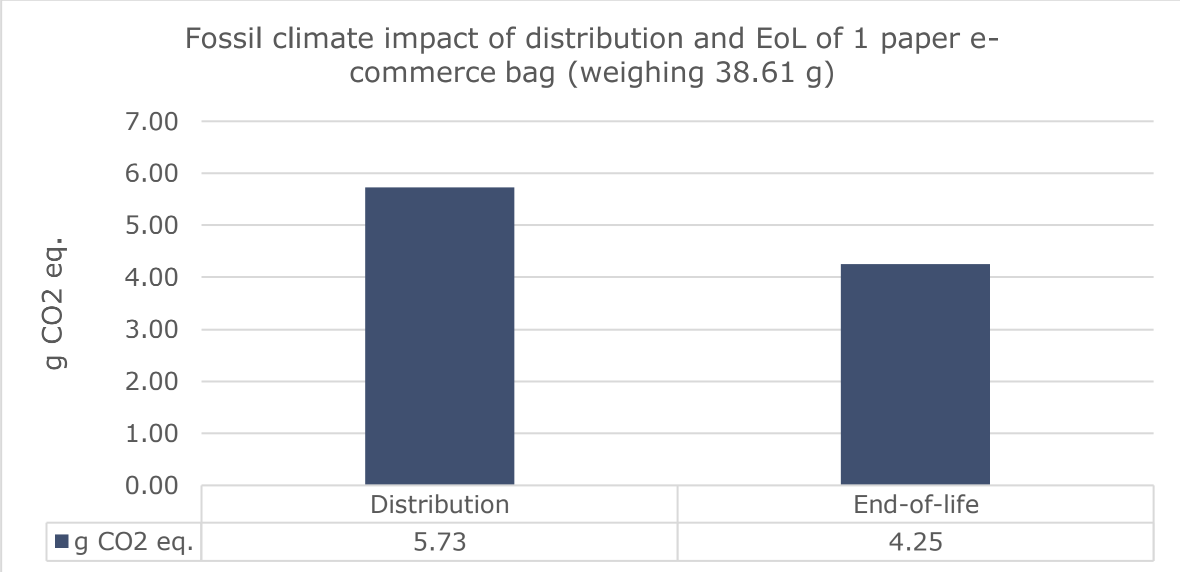


Figure 9: Fossil climate impact of distribution and EoL of 1 paper e-commerce bag

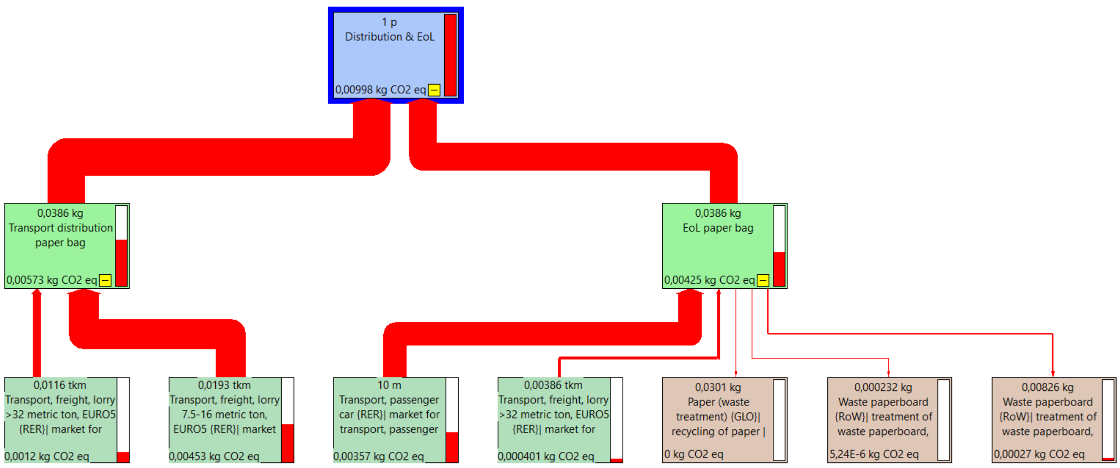


Figure 10: Fossil climate impact of distribution and EoL of 1 paper e-commerce bag. Results from SimaPro software. Cut-off: 0 %.

5. SCENARIO ANALYSIS

Nordic Paper was interested in understanding what the potential benefits are with the use of a paper e-commerce bag instead of use of a generic plastic e-commerce bag. In this chapter, an analysis of the scenario of a generic LDPE plastic e-commerce bag of similar size and properties as the paper e-commerce bag is presented and the potential benefits and challenges connected to use of paper or plastic e-commerce bag are showcased.

5.1 The scenario of a plastic e-commerce bag

The plastic e-commerce bag is a generic low-density polyethylene (LDPE) bag with a weight of 21g which is based on database data and assumptions. No specific data has been used in the modelling of the plastic e-commerce bag.

The plastic e-commerce bag is assumed to be produced in Sweden and has the same type of print, adhesive stripe and packaging as the paper e-commerce bag. As there are several producers of plastic bags in Sweden, the assumption of Sweden produced plastic e-commerce bag considered a relevant scenario for this scenario analysis.

The dimensions of the plastic e-commerce bag are 310 x 490 mm, and it was chosen as an appropriate scenario for this evaluation because it is the same size as the paper e-commerce bag, and the customer considers it to be a comparable option for the evaluation. The weight and dimensions used for the scenario of the plastic e-commerce bag can be seen in Table 6 below.

Table 6: The weight and dimensions of the plastic e-commerce bag

Product	Weight (g)	Dimension (mm)
Plastic e-commerce bag	21	310 x 490

5.1.1 System boundaries

The system boundaries of the plastic e-commerce bag are assumed to be similar to the paper e-commerce bag, where the main raw materials are transported to the product site, and the production of the plastic bag takes place. The plastic e-commerce bag is then distributed to the customer, and the use phase is excluded. End-of-life of the bag is included in the system boundaries, as well as transport of waste and waste management from the manufacturing process.

5.1.2 Data collection

Data inventory for the scenario of plastic e-commerce bags is made on assumptions regarding raw materials and manufacturing methods. Weights and dimensions have been provided by Jonsac and represent an e-commerce bag with the same function as the assessed paper e-commerce bag. It should be noted that a plastic e-commerce bag modelled with specific data might have a lower or higher environmental impact than the fictive plastic e-commerce bag assessed in this study. Generic data comes from Ecoinvent 3.9.1 (Wernet, o.a., 2019) and Industry data 2.0.

5.2 System Modelling Scenario Plastic E-commerce bag

The system modelling is based entirely on database data and assumptions. For the plastic e-commerce bag the system modelling has been divided into two modules: 1) Production of plastic e-commerce bag and 2) Transport to customer and EoL of the final product. The system modelling and input and output for the plastic e-commerce bag will be presented in the following sections.

5.2.1 The plastic e-commerce bag

The plastic e-commerce bag is assumed to be produced in Sweden with a Swedish electricity mix. The plastic e-commerce bag is 21g in 60my low-density polyethylene (LDPE) with the dimensions 310x490 mm.

The following sections explain the generic data used for this specific scenario analysis, as well as explain the thought process for the system modelling done in Simapro.

The full life cycle inventory (input and output data) for the production of 1 plastic e-commerce bag can be found in Table 17 in Annex B.4.

5.2.1.1 Raw material

The main raw material to produce the e-commerce plastic bag is LDPE. The other materials assumed to be used in the production are other, adhesive stripe, and print.

5.2.1.2 Manufacturing

The manufacturing process for the plastic e-commerce bag is assumed to be an extrusion process. When modelling this process in Simapro, a plastic film extrusion process has been used and modified to use a Swedish average electricity mix instead of the European average electricity mix. See Annex B.4 for detailed information regarding the datasets used.

Based on data from Ecoinvent manufacturing process for extrusion it is assumed that 1kg of plastic granulates gives 0.976 kg of plastic film.

5.2.1.3 Packaging

The produced plastic e-commerce bags are assumed to be packed in the same way as the paper e-commerce bag, see section 3.2.2.4.

5.2.2 Distribution and End of Life

5.2.2.1 Distribution

The distribution for the plastic e-commerce bag is assumed to be same as for the paper e-commerce bag, see section 3.2.3.1.

5.2.2.2 End-of-Life

The end-of-life scenario for the plastic e-commerce bag includes recycling, incineration and landfill. It is assumed that the end-of-life scenario takes place in Sweden and the share for the different processes is presented in Table 7.

Table 7: End-of-life scenario for the scenario of plastic e-commerce bag

Process	Percentage	Comment
Recycling	33%	(Förpackningsinsamlingen, 2023)
Incineration	65.1%	Split between energy recovery and landfill, based on 2022 Avfallshantering (Avfall_Sverige, 2023)
Landfill	1.9%	Split between energy recovery and landfill, based on 2022 Avfallshantering (Avfall_Sverige, 2023)

The transport is assumed to be same as for the paper e-commerce bag, see section 3.2.3.2.

5.3 LCIA results for the scenario of plastic e-commerce bag

In Table 8, the LCIA results for the following impact categories for the scenario of a generic plastic e-commerce bag is presented.

Table 8: LCIA results for the scenario of plastic e-commerce bag.

Impact categories	Unit	Production of plastic e-commerce bag	Transport to customer and EoL	Total
Climate change – Fossil	kg CO2 eq	4.47E-02	4.83E-02	9.30E-02
Climate change – Biogenic	kg CO2 eq	-1.67E-03	3.53E-06	-1.67E-03
Climate change – Land use and LU change	kg CO2 eq	1.94E-04	3.30E-06	1.98E-04
Climate change (total)	kg CO2 eq	4.32E-02	4.83E-02	9.15E-02
Acidification	mol H+ eq	1.27E-04	2.85E-05	1.56E-04
Resource use, fossils[1]	MJ	1.73E+00	9.82E-02	1.82E+00
Water use[1]	m3 depriv.	7.80E-02	5.53E-04	7.86E-02

Impact categories	Unit	Production of plastic e-commerce bag	Transport to customer and EoL	Total
Particulate matter	disease inc.	1.63E-09	4.75E-10	2.10E-09

[1] The results of this environmental impact indicator shall be used with care as the uncertainties on these results are high or as there is limited experience with the indicator.

5.3.1 *Climate change – Fossil*

This section presents the fossil climate impact for the scenario of plastic e-commerce bag. The plastic bag weighs 21 g, and the fossil climate impact is shown in g CO_2-eq.

Figure 11 shows the results for the manufacturing of the plastic bags, the packaging, distribution and EoL, while Figure 12 shows the results are presented in the SimaPro program.

The results show that the EoL of the plastic bag has the highest fossil climate impact due to the release of the carbon stored in the plastic bag during incineration, as the bag is made of fossil based raw materials. The EoL scenario for the plastic bag is as following: 33 % ends up in recycling, 65.1 % goes to incineration and 1.9% ends up in landfill. It is therefore important to note that these results might change, showing less or more impact, depending on how the EoL scenario for the plastic bag looks like. That is, less amounts going to incineration could lead to lower fossil climate impact for the plastic bag. These differences in the climate impact of different EoL scenarios is explored further in the sensitivity analysis in Chapter 6 below.

The second largest fossil climate impact is of the use of virgin LDPE material, and that is due to the extraction of the raw materials is considered carbon-intensive process.

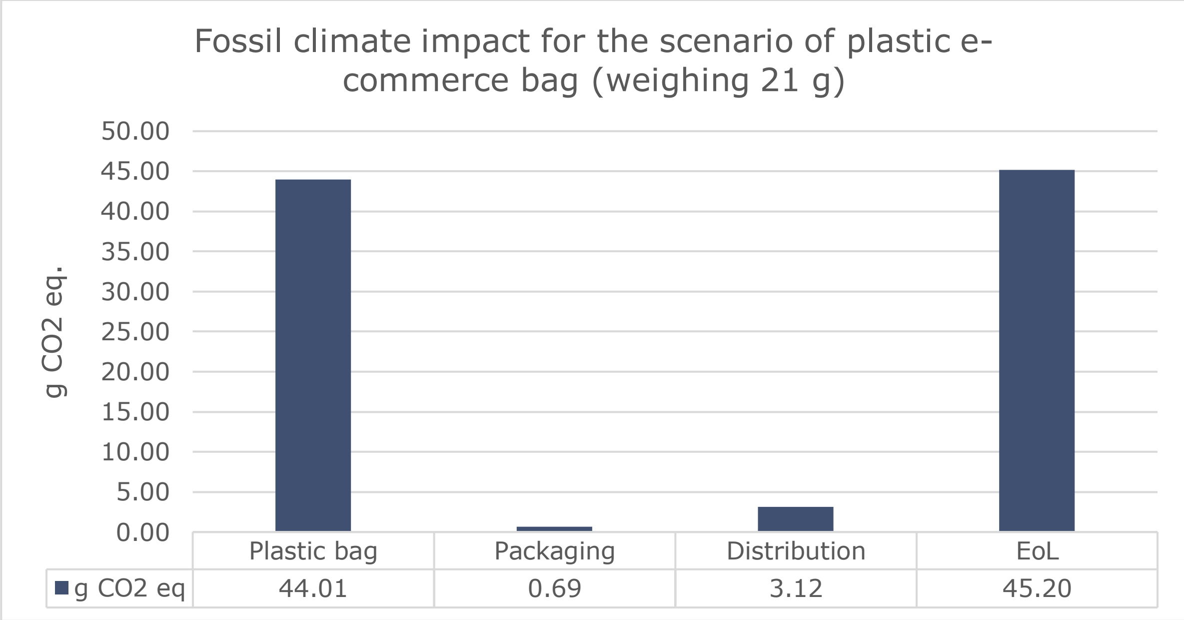


Figure 11: Fossil climate impact for the plastic e-commerce bag

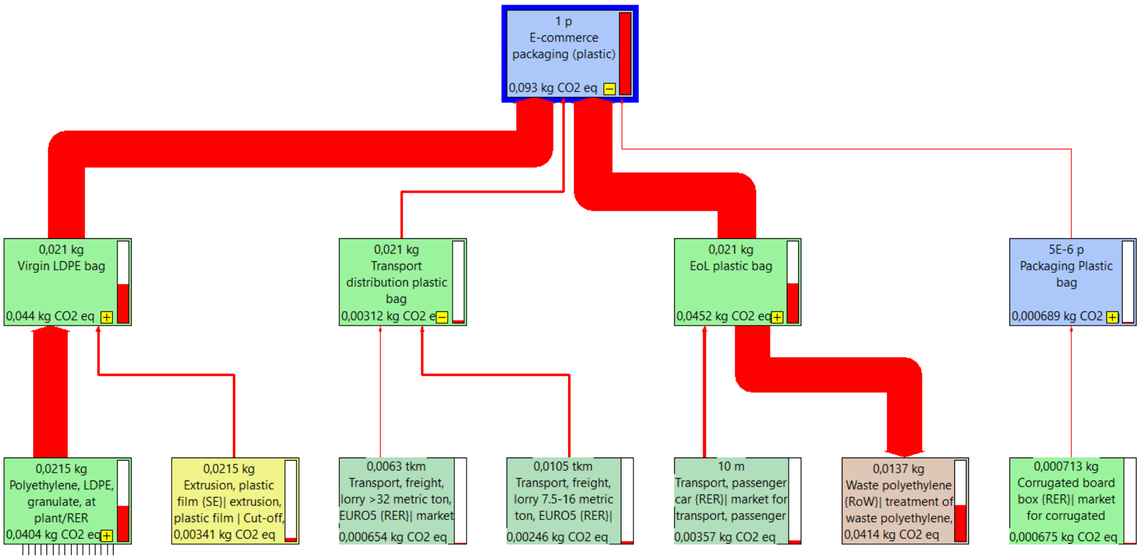


Figure 12: Fossil climate impact for the scenario of plastic e-commerce bag. Results from SimaPro software. Cut-off: 0.25 %.

5.4 Results from scenario analysis of paper and plastic e-commerce bag

This section shows the results for the paper e-commerce bag and the scenario of plastic e-commerce bag with regard to the different impact categories (see Table 8), as well as in more detail for the fossil climate impact.

It is important to note that the plastic e-commerce bas is modelled with generic data and several assumptions, such as the dimensions of the plastic e-commerce bag being slightly larger compared to those of the paper e-commerce bag. Therefore, the results may differ if specific data is used. However, it can be assumed that the generic data used for the modelling of the plastic bag give as generic representation of a probable reality.

The plastic e-commerce bag, in this study, is assumed to be produced from virgin material and the fossil climate impact could be reduced if it was produced from example recycled or bio-based material. How the plastic e-commerce bag and raw materials are produced also has an impact on the results and could be either lower or higher depending on the production process and place of production.

Table 9: LCIA results of the paper e-commerce and the scenario of plastic e-commerce bag

	Unit	Paper e-commerce bag	Scenario: Plastic e-commerce bag
Climate change – Fossil	kg CO2 eq	2.34E-02	9.30E-02
Climate change – Biogenic	kg CO2 eq	-2.59E-02	-1.67E-03
Climate change – Land use and LU change	kg CO2 eq	2.74E-04	1.98E-04
Climate change (total)	kg CO2 eq	-2.28E-03	9.15E-02
Acidification	mol H+ eq	1.86E-04	1.56E-04
Resource use, fossils[1]	MJ	4.90E-01	1.82E+00
Water use[1]	m3 depriv.	9.88E-03	7.86E-02
Particulate matter	disease inc.	3.70E-09	2.10E-09

[1] The results of this environmental impact indicator shall be used with care as the uncertainties on these results are high or as there is limited experience with the indicator.

In Table 9, the results of the different impact categories are shown for the paper e-commerce bag and the scenario of a plastic e-commerce bag. The results show that the paper e-commerce bag performs better for the impact categories of Climate change – fossil, biogenic, and total, resource use – fossil and water use. The results however show that the generic plastic e-commerce bag performs better for the impact categories of Climate change – land use and LU change (LULUC), acidification, and particulate matter. The emissions from LULUC are mostly related to forestry. For particulate matter, the direct emissions from the manufacturing process have the largest effect.

The reason for the lower results of the plastic bag for acidification is due to the direct emissions reported by Nordic Paper Bäckhammar mill, more specifically due to the pollutants of nitrogen dioxide and ammonia which together with its reaction products can lead to changes in chemical compositions of soils and surface waters when deposited. It is however important to note again that the results for the plastic bag might change, showing either more or less difference in the results, if specific data would be used instead of generic data for the modelling.

5.4.1 Climate change – fossil

This section shows the potential benefit in regard to fossil climate impact of using a paper e-commerce bag instead of the scenario of plastic e-commerce bag. The paper e-commerce bag weighs 38.61 g, while the plastic e-commerce bag weighs 21 g. The fossil climate impact is shown in g CO_2-eq.

Figure 13 shows the total fossil climate impact for both bags, while Figure 14 shows the results presented in the SimaPro program.

The results show that the plastic e-commerce bag has a higher fossil climate impact, and that is mainly due to the EoL of the plastic bag, as well as the use of virgin LDPE material in the production.

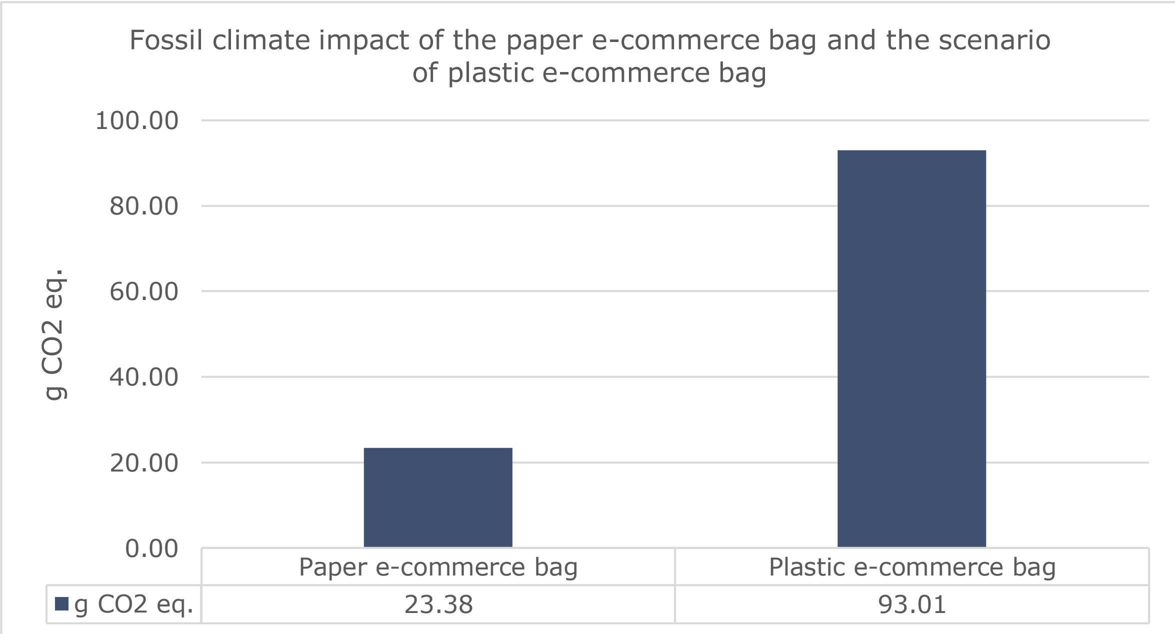


Figure 13: Fossil climate impact of the paper e-commerce bag and the scenario of plastic e-commerce bag

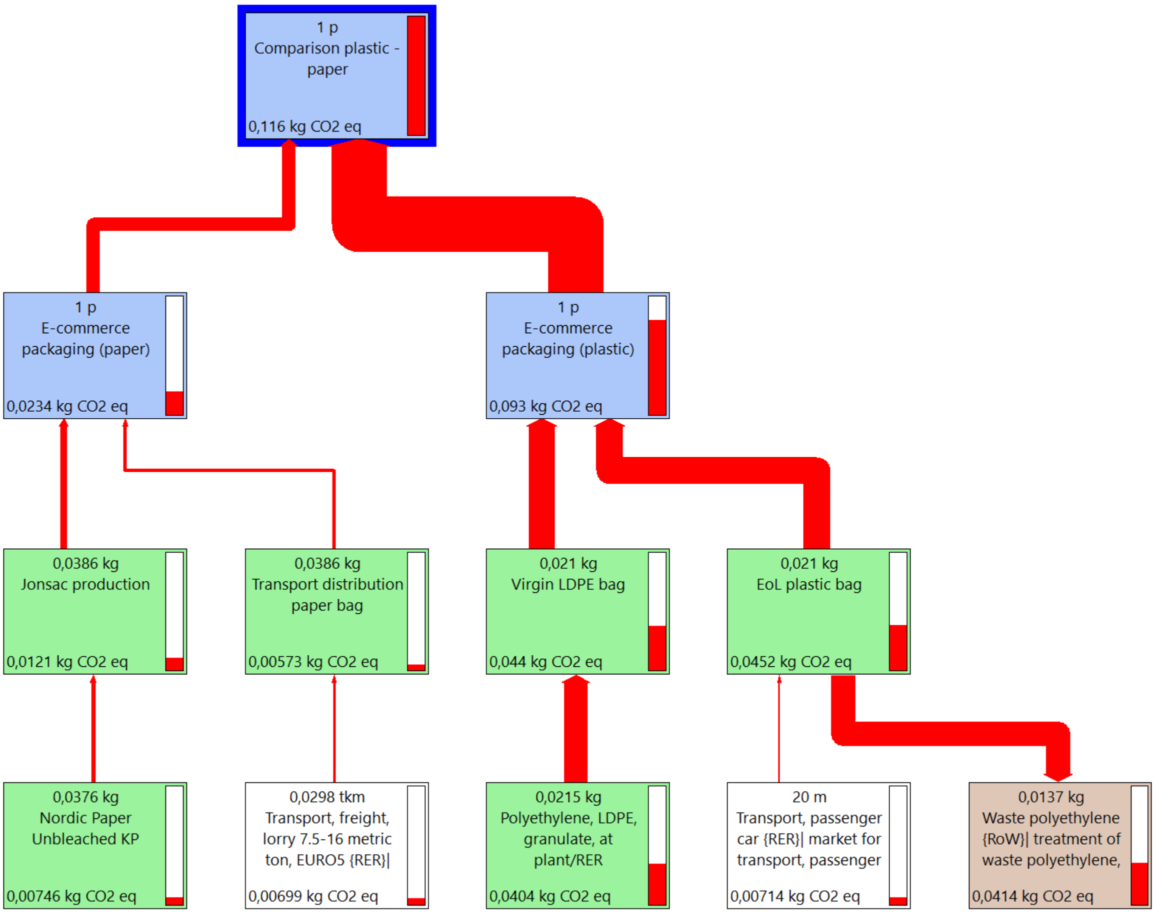


Figure 14: Fossil climate impact of the paper e-commerce bag and scenario of plastic e-commerce bag. Results from SimaPro software. Cut-off: 4.92 %.

6. SENSITIVITY ANALYSIS

A sensitivity analysis can be made to study the effects of certain modelling assumptions, or the effects of certain design/production/purchasing choices on the product's environmental performance. In the following section, the effects corresponding to the following scenarios are presented in more detail:

- Scenario 1 – The plastic e-commerce bag is produced in Europe and the customers for both bags are located in Europe.
- Scenario 2 – EoL of the paper and plastic e-commerce bag happens in Europe.
- Scenario 3 – EoL of both the paper and plastic e-commerce bag is only incineration.

These three scenarios have been chosen as interesting scenarios to analyse further as distribution and EoL have a major impact on the entire life cycle when it comes to fossil climate impact and therefore different scenarios for those parts have been investigated. Furthermore, it is interesting to see how the EoL and the location of the customers affect the fossil climate impact from the bag.

6.1 Plastic e-commerce bag produced in Europe

Plastic bag is produced in Europe and European average electricity mix is assumed. The customers are in Europe and that means that the transport distance to DC from converter will be longer for the paper bag (1500 km in total) and the distance for the plastic bag will be the same as base case (300 km). The distance from DC to final customer will be the same as base case (500km) for both paper and plastic e-commerce bag.

The change in production place for the plastic bag will give the plastic bag a bit higher fossil climate impact. But the paper e-commerce bag will have a longer transport distance to the DC and therefore also get a bit higher fossil climate impact. The results can be seen in Figure **15**.

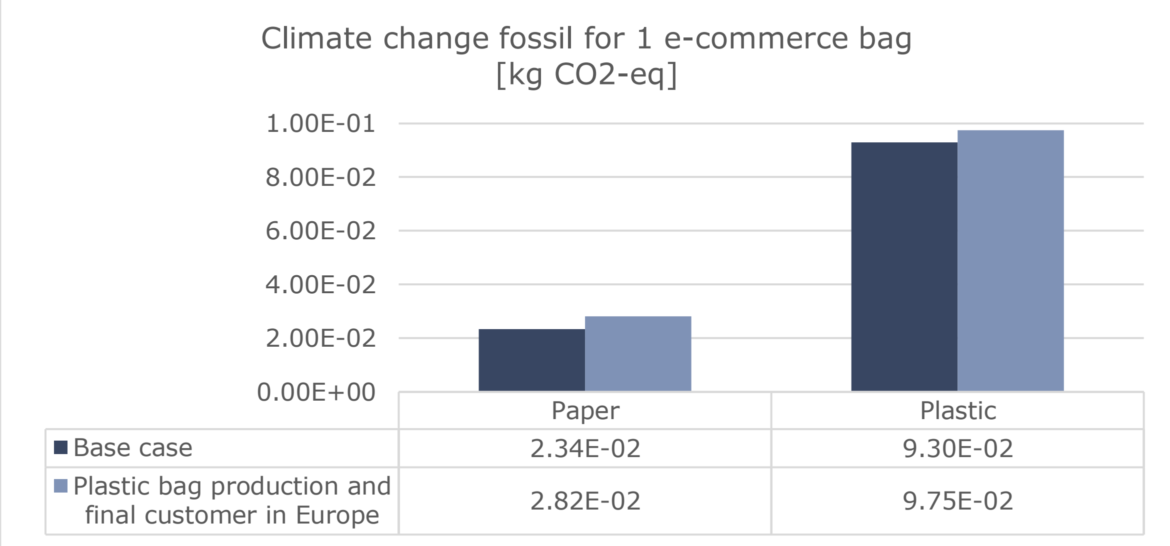


Figure 15: Fossil climate change for 1 plastic and paper e-commerce bag

6.2 Other End-of-life scenarios for e-commerce bags

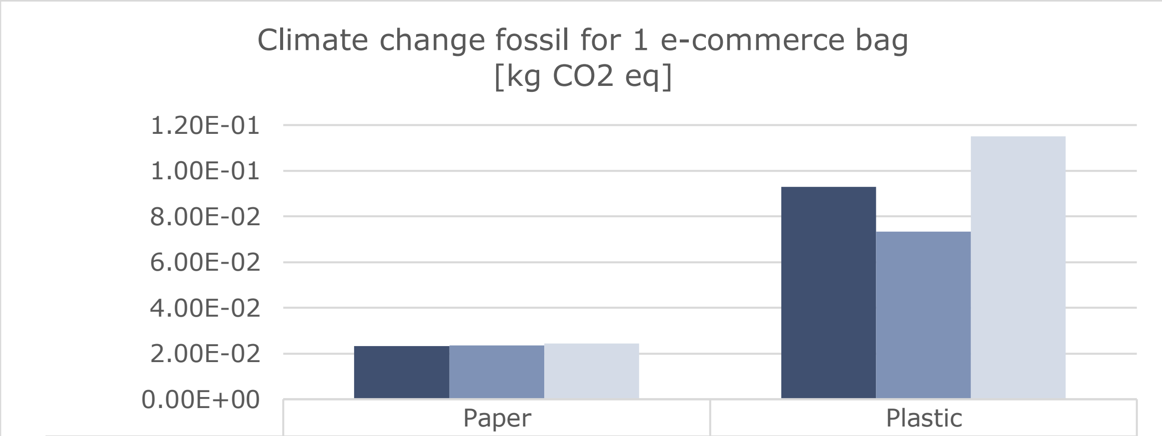
Two other EoL scenarios are compared to base case. The first one assumes that the end-of-life for both bags will take place in Europe instead of Sweden. The share of material being recycled, incinerated or go to landfill is changed to European average values according to Table 10.

Table 10: End-of-life scenarios for paper and plastic e-commerce bag

Process	Base case	EoL in Europe
Paper		
Recycling	78%	70.5% ((EPRC), 2023)
Incineration	21.4%	15.8% Split between incineration and landfill, based on Municipal waste statistics, 2023 (Eurostat, Municipal waste statistics, 2023)
Landfill	0.6%	13.7% Split between incineration and landfill, based on Municipal waste statistics, 2023 (Eurostat, Municipal waste statistics, 2023)
Plastic		
Recycling	33%	38% (Eurostat, Plastic packaging waste: 38% recycled in 2020, 2022)
Incineration	65.1%	33.1% Split between incineration and landfill, based on Municipal waste statistics, 2023 (Eurostat, Municipal waste statistics, 2023)
Landfill	1.9%	28.9% Split between incineration and landfill, based on Municipal waste statistics, 2023 (Eurostat, Municipal waste statistics, 2023)

The second scenario is that both bags will go only to incineration.

The results can be seen in Figure 16. The figure shows the total fossil climate impact of the total life cycle for one bag. There is a small change in the impact from climate change fossil in the different cases for the paper e-commerce bag, but it is not significant. However, for the plastic e-commerce bag there are a larger change in the fossil climate impact depending on how EoL is handled.



	Paper	Plastic
Base case	2.34E-02	9.30E-02
RER EoL	2.34E-02	7.34E-02
Incineration only	2.44E-02	1.15E-01

Figure 16: Fossil climate change for 1 plastic and paper e-commerce bag

7. CONCLUSIONS AND RECOMMENDATIONS

In this chapter the conclusions and recommendations from this study are presented.

7.1 Discussion

When interpreting the results of the study, it is important to consider the underlying assumptions and restrictions associated with both the methods and data used.

According to the assumptions made in this analysis, a source of uncertainty arises in connection with the measurement of wood, particularly concerning its moisture content, which can fluctuate depending on the time of year the wood is harvested or storage conditions. Therefore, it is not a common practice to measure round timber wood by weight. Instead, it is typically measured in volume, such as in solid volume under bark (m^3 fub, Swedish: kubikmeter fast under bark). During the modelling of the sawmill chips used in the production of Nordic Paper's kraft paper, the generic dataset used to represent the sawmill chips required the input amounts to be specified in weight. This required a conversion from m3 fub to kg, utilizing a density factor for pine and spruce sawmill chips. As a result, this introduced uncertainty regarding the quantities of used sawmill chips in the production of kraft paper, and therefore uncertainties surrounding the climate impact stemming from this process.

Additionally, it can be expected that the transport for the distribution of the bags could either have a larger or smaller climate impact. This factor depends on the final location of the bag, where longer distances could result in a higher climate impact compared to shorter distances, which could result in a smaller climate impact.

When looking at the potential benefits of the use of paper e-commerce bag instead of a generic plastic e-commerce bag studies in the scenario analysis, the results shows that the paper e-commerce bag produced with paper from Nordic Paper has a lower fossil climate change impact. However, the plastic e-commerce bag performed better for the impact categories acidification and particulate matter. Note that the results from the scenario analysis with the generic plastic e-commerce bag is not meant for external communication to state the benefits of one bag over another.

Finally, as could be seen from the results, the chemicals employed in the production process of the paper e-commerce bag made a large contribution to the fossil climate impact. Therefore, a recommendation is to use chemicals with a lower climate impact or to reduce the quantities of chemicals used during the production process.

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QUALITY AND DOCUMENT CONTROL

Quality control

Role	Name	Date
Author(s):	Linnéa Termén Jóhanna Wium Pálmarsdóttir	2024-03-21
Approved by:	Kristin Fransson	2024-03-21
QC review by:	Kristin Fransson	2024-03-21

Document control

Version no.	Principal changes	Date
Version 1	Initial client release	2024-01-23
Version 2	Updated after review comments	2024-02-25
Version 3	Updated after review comments	2024-03-14
Version 4	Updated with review report	2024-03-21

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