Zero Waste within the food sector and an evaluation of the package-free distribution of two different food products

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MASTER THESIS

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The environmental impact of different packaging models of oats and rapeseed oil: a case study of a Danish package-free retail store compared to a reference, packaged scenario

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Abstract

This study investigates the zero-waste concept applied to the food industry, and how the environmental impact differs between a package-free scenario found at a specialised Danish retail-store and a conventional scenario, using two reference products typically found in normal retail stores in Sweden. In the Danish store, the oats are sold in gravity dispensers, and the rapeseed oil is sold in glass bottles intended to be brought back to the store by the consumer to be cleaned and reused.

Based on previous literature – both in regards to the zero-waste concept and about packaging logistics within the food sector – a zero-waste framework is presented intended to be used by the practitioners. The purpose of the framework is to give general guidance to anyone aiming to offer products according to the zero-waste principles, making sure that the products and their distribution are designed in a way that ensures zero-waste across every parameter that exists. This shall hopefully mitigate the risk that stores employ a zero-waste model but generates more waste, as they for instance reduce packaging material but in turn increase food waste generation or creates very long and inefficient transportation.

Then, a life cycle assessment of rolled oats and rapeseed oil is performed, evaluating the package-free model found at the Danish retail store to the conventional scenario found in Sweden. The results for oats show that even if package-free stores offer disposable paper bags in the store – much like the system with plastic bags at the vegetable department in most stores – the savings across most impact categories are still large. The margin for how much food waste increase would be tolerated given the savings is calculated, differing between about 1% for eutrophication and acidification to 8% for climate change. For rapeseed oil, the potential savings are not as high as for oats, and they are bound to how many times the glass bottle is reused. If the concept were to be scaled up and the cleaning of the glass bottle centralised, the total distance between the store and the cleaning facility should not extend 400 kilometres, as that makes the conventional model preferable in all categories except for freshwater eutrophication. In practise, it is advisable that the distance does not exceed 100 kilometres to motivate the shift, as the savings otherwise are small.

Keywords: Zero waste, package free, life cycle assessment, food waste, oats and rapeseed oil.

Sammanfattning

Här studeras konceptet ’zero waste’, ungefär ’inget avfall’, applicerat på livsmedelsindustrin, och hur den miljömässiga påverkan skiljer sig mellan ett förpackningslöst scenario som kan ses i en nischad, dansk livsmedelsbutik, och ett konventionellt scenario, där två typiska produkter i vanliga matbutiker används som referenser. I den danska butiken säljs havregryn i gravitationsmatare (gravity dispenser), och rapsolja säljs i glasflaskor ämnade att återföras till butiken av konsumenten för att sedermera diskas och återanvändas.

Baserat på tidigare studier – både kopplat till ’zero-waste’-konceptet och till förpackningslogistik inom livsmedel – så presenteras ett ramverk för ’zero waste’, vilket är ämnat att användas av de som menar sig utöva det. Syftet med ramverket är att ge generella råd och riktlinjer till den som påstår sig erbjuda produkter enligt principerna för ’zero waste’, samt utifrån bästa förmåga försäkra sig om att distributionen utformas på sätt som ser till att inget avfall uppstår i något led av varken produktion, distribution eller avfallshantering. Detta ska förhoppningsvis minska risken för att ’zero-waste’-butiker anammar ett tänk som i slutändan leder till att mer avfall genereras, som att de till exempel reducerar mängden förpackningsmaterial men vilket i sin tur leder till att mängden matavfall ökar.

Vidare så genomförs en livscykelanalys av havregryn och kallpressad rapsolja, där den förpackningslösa modellen som återfinns hos den danska livsmedelsbutiken jämförs med det konventionella scenariot i Sverige. Resultaten för havregryn visar att även om butiken erbjuder engångsförpackningar – i likhet med de plastpåsar som erbjuds i grönsaksavdelningen i de flesta butiker – så minskas miljöpåverkan stort i samtliga påverkanskategorier. Marginalen för hur mycket mer matsvinn som skulle kunna tillåtas utan att den konventionella modellen blir att föredra är olika stor. För övergödning och försurning är marginalen ungefär 1%, medan den för global uppvärmning är 8%. För rapsolja så är de potentiella besparingarna inte lika höga som för havregryn, och de är tätt kopplade till hur många gånger glasflaskan återanvänds. Skulle konceptet genomföras i större skala och diskanläggningen för glasflaskor centraliseras, så får inte det totala avståndet mellan butiken och anläggningen överstiga 400 kilometer, eftersom detta leder till att den konventionella modellen är att föredra för alla påverkanskategorier utom sötvattensövergödning. I praktiken är det önskvärt att avståndet inte överstiger 100 kilometer för att motivera ett skifte.

Nyckelord: Zero waste, förpackningslös distribution, livscykelanalys, matsvinn, havregryn och kallpressad rapsolja.

Acknowledgments

After being involved in several different projects concerning topics within the food sector, it has been very rewarding to use my engineering degree and investigate such a current topic as the package free distribution of food.

Firstly, I want to thank Løs Market, Gunnarshögs Gård and Saltå Kvarn for their invaluable contribution to this study. Without their help, this thesis would not have been possible.

Secondly, I would like to thank RISE Agrifood and Bioscience (previously SP) for their input on life cycle assessments, both in terms of knowledge and resources.

I hope this thesis can bring more clarity to the current debate about package free distribution of food and to help retail stores to further decrease their environmental impact.

Lund, February 2017

Vilhelm Sjölund

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1 Introduction

1.1 Background

During the last decade, retail stores marketing themselves as ‘zero-waste’ or ‘unpackaged’ have emerged at an increasing pace. This has led to a debate as to whether this is the environmentally preferred direction for the food industry. Still today, close to the end of this study, it is still a current topic in media with experts commentating the role of packaging in food distribution (Pettersen & Hægermark, 2016; The Economist, 2016). However, few studies have evaluated the performance of these package-free distribution models. Two noteworthy examples include Nessi, Dolci, Rigamonti & Grosso (2016), where the authors evaluated the model for rice, pasta and breakfast cereals, with varying results but mostly in favour of package-free distribution, and Cleary (2013), who researched refillable wine bottles with a centralised solution, stating that the transport distance to the washing facility is the critical success factor.

Distributing food requires packaging, be it disposable or reusable. Even stores aiming to minimise packaging will be bound to use it to some extent, leaving us with different possible scenarios. Larger containers – disposable or reusable – can be bought and used to refill smaller, reusable consumer packaging. If retail stores use reusable packaging even at the supplier stage a reverse supply chain takes place, adding a layer of complexity as they now also must manage outbound logistics of the packaging containers. Because of this variety of packaging supply chain options, it is difficult to give a definite answer as to what package free distribution of food entails. Substituting primary packaging for reusable options is what many stores market, but for secondary and tertiary packaging such as corrugated boxes, shrink wrap and wooden pallets, less knowledge exists as to how the stores operate.

A central question of package free distribution is whether it is justified when food waste is considered, as packaging can serve to protect the food product and therefore reduce waste generation. No previous studies have evaluated a package free food distribution and at the same time quantifying the effects on food waste generation. To answer the question which packaging model is preferable in terms of environmental performance, one must both calculate the impacts of the packaging itself and differences in performance. But obtaining robust data is difficult and collecting a few samples would not lead to satisfying results.

1.2 Research purpose

1.2.1 **Purpose of the study**

The primary purpose of this study is to further the understanding of the potential benefits or drawbacks that could come from redesigning the supply chain model in the food sector towards removing packaging in favour of reusable, ‘package-free’ options. The study shall also provide a comprehensive review of the emerging concept where stores offer customers the possibility to buy food without packaging. The concept shall be described in its current state, compared to research within the area, evaluated based on environmental performance and produce a framework that can be used by the stores which both could unify the concept and increase the potential environmental benefits from their operations.

1.2.2 **Research questions**

The following research questions shall be answered:

> *RQ1:* Which definitions of ‘zero waste’ currently exist within food distribution; are they contradicting each other, and can a general definition be found which can be used as a framework for the practitioners?
>
> *RQ2:* For rolled oats and cold pressed rapeseed oil, what is the difference in environmental impact between the ‘package-free’ distribution model and the conventional, packaged distribution?
>
> *RQ3:* In terms of environmental performance, which positive and negative aspects exist when grocery stores adopt a package-free model and in which ways could a store benefit by combining the different models?

1.3 Document structure

First, the methodology of this thesis is presented. Then, in chapter three, the results from the literature review used to answer both the first and third research questions is presented. In chapter four, the inventory data from the studied supply chain systems are illustrated, and the impact assessment results are presented in chapter five.

Chapter seven is dedicated to provide an answer to the first and third research question. To answer the third, results from both the life cycle assessments, the survey and the literature review are used, and therefore all discussion relating to this can be found in this chapter.

Finally, the main conclusions are presented along with recommendations for further research.

2 Methodology

2.1 Research strategy

When assessing the environmental impact of a system, the life cycle approach is the preferred methodology, standardized by ISO (ISO, 14040:2006) and with methodological recommendations from the European Commission (European Commission , 2010). The life cycle methodology is closely related to that of a case study, both ensuring quality through validity, reliability and with sound generalization principles (Yin, 2014; European Commission , 2010). Many studies apply both terminologies, either describing their research as a case study with a life cycle approach (Paolotti, Boggia, Castellini, Rocchi, & Rosati, 2016), as a case study including a multi-method approach which includes life cycle assessment (Väisänen, et al., 2016) or as a general life cycle study with a regional case study approach (Yay & Suna, 2015). However, common to these studies is that the methodology is a life cycle approach and not affiliated with case study research. This study will therefore build upon this convention, applying the life cycle approach with a case study of the zero-waste model in a Danish and Swedish context.

A summary of the chosen research strategy is illustrated in Figure 1. The first research question will be answered by reviewing literature combined with a survey to the stores. The second research question will be answered through four independent life cycle assessments. The third research question will be answered by combining the results from the two previous studies, combined with additional literature findings. Results from the life cycle assessments are tied to a single store, as they do not address several zero-waste stores and how they operate. By combining these results with findings from the survey, more general conclusions can be drawn about the zero-waste model at large and which effects on environmental performance can be expected if a store chooses to deliver products accordingly.

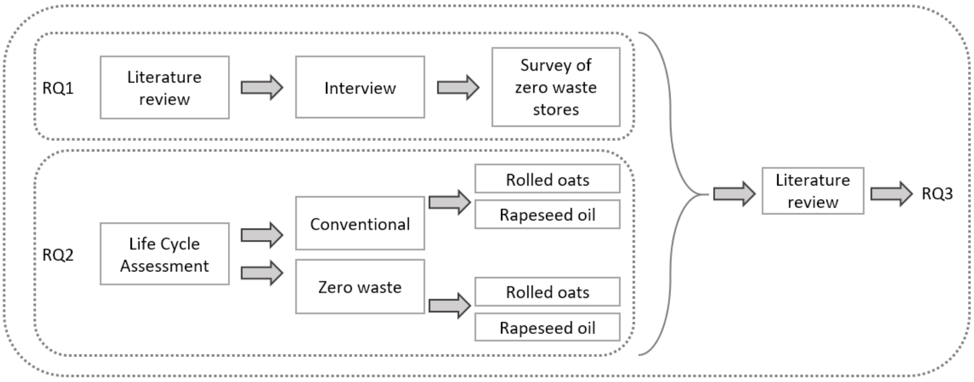


Figure 1: Summary of research methodology

2.2 Literature review

In Figure 2, the initial search strategy is summarised. The purpose of this literature review was to get an initial understanding of the field and create a theoretical frame of reference. In the beginning, it was unclear which keywords were relevant as no clear definition of the concept exists. To overcome this issue, a citation pearl growing was conducted (Rowley & Slack, 2004), involving an unstructured search for a few key articles and identifying relevant keywords for further search from these.

For the first research question, a comprehensive review of previous zero waste research was found during the first literature search process. The articles listed were evaluated based on their appropriateness to food packaging logistics, presented as inclusion criteria in Figure 2.

However, over the course of this study, literature was searched for continuously and collected from various sources. Several articles have been provided by the supervisors, combined with input from other person from academia and the industry. Furthermore, the bibliography from articles found during the primary search in Figure 2 have been examined to improve the theoretical framework.

Source		***Inclusion criteria: either or***	
Databases	LUB Search	RQ1	Relates to zero waste frameworks within retail or with generalizable applicability Relates to economic theories with a focus on sustainability
		RQ3	Relates to unpackaged distribution of food Relates to the conflict between food and packaging waste

RQ	***Keywords***	***Results***	***After exclusion***
RQ1	Zero waste & waste management	120	8
RQ1	Circular economy & packaging	47	2
RQ3	Waste prevention & packaging	256	16
RQ3	Food waste & retail & packaging	30	10

Note: Several other keywords were used, including 'Life cycle assessment' and 'environmental impact'. These searches did not generate articles other than those listed above, and has therefore been excluded from the summary.

Figure 2: Overview of the search strategy for the literature review

2.3 Survey

2.3.1 **Designing a good survey**

A survey describes a population, either only by describing the population itself or by comparing it to some reference group (Sapsford, 2007). To ensure good quality, high participation, thorough reflection about chosen questions and generating answers that gives unambiguous results are vital parts of a successful survey (Sapsford, 2007). Since relatively little is known about the zero waste stores, the survey was sent out after both going through the literature and visiting the store to find out about relevant aspects to include. In addition, a qualitative interview with a researcher was done before sending out the surveys.

2.3.2 **Identifying key aspects to include**

To find out which questions that should be included, the literature review for the first research question was completed before working with the survey. Thereafter, an open-ended interview was conducted with Mattias Eriksson, who is a postdoc researcher at the institution for energy and technology at Sveriges Lantbruksuniversitet in Uppsala. The purpose of these steps was to gain a better understanding for which environmental pitfalls may exist if a store adopts the zero-waste model. The interview largely consisted of discussions around packaging and food waste, and whether the zero-waste stores would generate more food waste than a regular store. This resulted in the addition of several questions relating to packaging, such as if the zero-waste stores would consider using bio-degradable packaging if this improves the shelf life of a product, and whether the stores use reusable packaging further down the supply chain or just for the primary, consumer packaging.

The questions included in the survey were either value-based or related to how the store operated. Valued-based questions were included to see how similar the stores' concept is to the principle of zero-waste management as explained in chapter 3.1.1. Typical questions were if the store gave special prioritisation to locally produced food or if they only sell organic produce. The other questions related to how the stores operate. This information was collected to see if the Danish store that was the basis for this study represents how the other stores operate. The full results of the survey can be found in Appendix B.

2.3.3 Finding and identifying the stores

Locating the relevant stores for this study both included finding information about the store itself as well as ensuring that it could be characterized as a store within the description of system I, see chapter 2.4.2.4. A website called Bepakt have assembled a thorough list of package free stores around the world which was used as a base for this study (Muller & van Engeland, 2015). However, after evaluating the stores listed at this site, not all were in line with the scope of this study. Furthermore, several stores were found to be missing from this list based upon the author's previous knowledge, and therefore an independent search was conducted as a complement to earlier findings.

Keywords		***Languages***
Zero waste store	Bulk store	Swedish, Danish, Norwegian, Icelandic, Finnish, English, Irish, Dutch, French, German, Polish, Russian, Italian, Spanish, Portuguese, Korean, Japanese, Chinese.
Package free store	Unpackaged store	
Wholefoods store	Bio-based store	

Table 1: Search strategy for localising relevant stores

The evaluation process included visiting the stores' websites and social media platforms, looking for key markers. These were primarily images of food sold without packaging and information about their vision and whether they claim to be a store selling unpackaged food. In total, 52 stores were found. To further increase the accuracy, a control question was added to the survey: *"My store aims to remove disposable packaging as far as possible, offering customers bulk food and the possibility to bring their own, reusable packaging."*, with possible answers being "*yes", "no"* and "*we offer mostly unpackaged food but also sell certain food items packaged"*.

2.3.4 **Collecting responses**

The survey was written using Google Forms, and initially delivered through email to each of the stores. This resulted in a very low response rate, and several iterations were performed, contacting stores in different ways. This included contacting them through social media, texting and/or calling the store, and translating the messages to their respective language in case English was too foreign to them. Despite the efforts, only 16 stores filled out the survey. Out of these, 14 are in Europe and 2 in North America. Obtaining statistically significant results for a population of 52 requires a large degree of participation, which has not been obtained here.

2.3.5 **Interpretation**

As the survey received too few responses to be statistically significant, these results will not be used to validate theories about the zero-waste concept at large, as those conclusions would rely on very weak premises. This means that the results from this life cycle assessment cannot be generalised well to all other stores as they might operate in different ways, which would render different results. The results can however give some insight about the concept itself and how stores operate. This will be used in conjunction with results from previous studies to better understand the concept.

2.4 Life Cycle Assessment

The methodology for conducting life cycle assessments has been standardized by ISO, and the general approach is shown in Figure 3. The ILCD handbook (European Commission , 2010) offers a thorough methodological guidebook for conducting life cycle assessments. The research strategy for this study is largely based on this handbook, complemented with a few other sources of literature (Baumann & Tillman, 2004; Rydh, Lindahl, & Tingström, 2002).

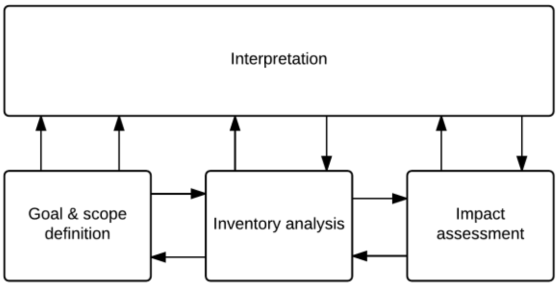


Figure 3: Overview of a life cycle assessment (ISO, 14040:2006)

In recent years, more emphasis has been put on the assessment as an iterative approach (European Commission , 2010). The general idea is to collect initial data and construct the life cycle model at an early stage. Thereafter, an analysis is performed to assess if the scope definition should be revised or if more accurate data from foreground processes are needed. Then another iteration is performed, validating the new data, and building an improved model. This study will be limited to one iteration, as both time and money for field visits are limited.

2.4.1 **Goal definition**

2.4.1.1 Intended applications

This study intends to perform four individual life cycle assessments, evaluating the environmental impact associated with two different supply chain systems for food distribution, namely:

1. System I, hereby denoted the ‘package-free model’, characterized by a far-reaching ambition to reduce waste by eliminating disposable packaging in favour of reusable packaging solutions. A niched type of small to medium sized retail store employ this model.
2. System II, hereby denoted the ‘conventional model’, characterized by a vision to not use more packaging than necessary while still maintaining the functions of packaging, e.g. to protect the product, provide information to the customer and market the product. This system comprises most western retail stores.

The purpose of the study is to evaluate how the environmental impact differ for the two different supply chain models. To determine superiority in terms of environmental impact, an externally reviewed comparative assertion is the recommended approach (European Commission , 2010). A comparative assertion intended to be disclosed to the public entails several mandatory requirements in terms of execution, documentation and reviewing (ISO, 14040:2006; ISO, 14044:2006). This study does not intend to perform an analysis which can be used as a foundation for claims of superiority between the two supply chain models, and the requirements dictated by ISO are not met.

The four individual assessments shall calculate the environmental impact of each system as is, meaning that no corrections will be made to adjust for different distances to packaging suppliers or in any way make the systems better resemble each other. To evaluate the impacts adjusted for differing variables, different theoretical scenarios will be computed in connection to the sensitivity analysis.

2.4.1.2 Limitations

Package-free stores target a specific customer segment and have a relatively small range of products, whereas conventional stores target a broad segment of customers and usually offer a wide range of products. The conclusions drawn based upon a niche market generally have poor generalisability to an industry at large, which is accounted for in this study (European Commission , 2010), and conclusions are generally limited to encompass other package-free stores. Despite these limitations, the question about which supply chain model is environmentally preferable still exists, and this study will provide valuable input to which system is better. The limited applicability mostly concerns that the concept may not appeal to a larger crowd, that customers may not bring their own packaging to the store and that customers may not fill their packaging properly, leading to increased food waste. In case the package-free model is preferable, overcoming these obstacles would make the results generalizable to a broader market.

2.4.1.3 Decision context and target audience

This study will create a micro level decision support for each of the two studied distribution models for the studied food products. It will determine the impact for each product flow with its corresponding processes and activities.

This decision support is intended to be used by the research field of packaging technology and the concerned industry parties: retail stores, primary food producers and packaging companies.

2.4.2 **Project scope**

2.4.2.1 Functional unit

Two different functional units are studied:

1. The packaging distribution of one kilo ready-to-eat rolled oats to the end consumer, including end-of-life treatment.
2. The packaging distribution of one litre ready-to-eat rapeseed oil to the end consumer, including end-of-life treatment.

The functional unit does not consist of the food product itself or the distribution of it, but the production and distribution of any packaging material that relates to the distribution of the food product itself, and the subsequent end-of-life management the packaging material. Any food waste generation is not accounted for, as no reliable data could be collected. For this discussion, see chapter 5.7.2.

2.4.2.2 Deliverables

For each of the studied food products, a life cycle assessment study will be delivered, including impact assessment and interpretation. Addition to this, theoretical scenarios, which seeks to answer under which circumstances each of the studied systems perform better than the other, shall be delivered.

2.4.2.3 Life cycle inventory (LCI) modelling framework

For all four of the studied systems, attributional modelling will be used as the inventory modelling framework. This means that all environmental inputs and outputs are summed up for processes that spans from raw material extraction to end-of-life treatment, or in easier terminology, attributes the sum of environmental burdens to a specific functional unit within a certain system boundary. The other common system model is called change-oriented or consequential LCA, which instead looks at which impact a change in a system would cause.

A central question in attributional modelling is how to handle cases of multifunctionality, for instance when the production of a product also generates several co-products. For the main processes, no multifunctionality exists as the functional units only provide a single function, i.e. to be delivered to the end consumer. However, within the processes themselves, cases of multifunctionality exist, where the actual production of a product generally leads to the production of several co-products. An example is the production of sodium hydroxide that stems from a chlor-alkali electrolysis process which also outputs chlorine. To handle this, Ecoinvent offers two different system models: allocation cut-off by classification and allocation at the point of substitution (Ecoinvent, 2014). For all assessments and processes in this report, the cut-off model has been used. In this model, recycled content is available burden-free for primary producers, or in other words, the recycled material only carries the impact of the recycling processes themselves. For most activities used, by-products are cut-off from their producing activities.

Other than multi-output activities, the waste management of packaging materials consists of several cases of multifunctionality, either in the form of electricity generation through municipal waste incineration, or raw material reuse through recycling. To correctly model recycling and to allocate avoided burden, one must consider recycling rates, which level of material downgrading occurs and the inventory and impact of the subsequent processes that relates to sorting, transporting, and processing the collected materials until they have achieved an equal quality to virgin materials (Baumann & Tillman, 2004; European Commission , 2010). For attributional modelling with net positive end-of-life products, the recommended approach is to determine an average inventory load based on infinite cycles of waste management. Each cycle will eventually converge to zero unless the system has both a perfect collection and zero downgrading, which in practise never occurs (European Commission , 2010). However, many studies adopt a simplified approach including only the first iteration (Gaudreault, 2012), which is adopted here as well. This choice was motivated based on the methodology proposed by ILCD, shown in equation 1, where *e* annotates the average inventory per unit of material, *p* the primary amount of material, *I* the amassed LCI impact for the total amount of materials based on the recycling grade, and *U* the total mass of all recycled content. *P*, *W*, and *R* annotates primary, waste and recycling LCI efforts. For instance, if we have one kilo of primary material (p), with a recycling grade of 90 %, the total mass would be 10 kg of material.

$$e = \frac{I}{U} = \frac{p * (P + W + R * (r - r^{n+1})}{(1 - r) * \sum_{i=0}^{n} p * r^{i}} \ (eq1)$$

However, when simplifying the expression, we end up with equation 2 (see Europan Commission (2010), annex C for a detailed description of the mathematic approach).

$$e = (P + W) * (1 - r) + R * r \ (eq2)$$

Modelling this would often be meaningful, but as R is defined as *“LCI of effort for reuse/recycling/recovery per unit of material, part or energy carrier”* (European Commission , 2010), W would be negligible for packaging processes considered since plastics and paper eventually end up in waste incineration plants (and therefore belong to R), and glass and steel have negligible leaching effects when sent to inert material landfill (Levova, 2016; Hischier, 2016). The impacts from the average inventory does not differ from a single recycle chain, since no further waste occurs, other than what is recycled in the first place.

Recycled material was assumed to replace the virgin production of materials in this study. Wherever the Ecoinvent cut-off model use recycled content as burden-free inputs, these activities have not been awarded recycling credits, as that would lead to double-counting. Another issue is when packaging is produced in one country and then exported to another country where it is recycled. Here, the numbers for the actual secondary material use in the production factory were used, meaning that no additional credits were awarded if the recycling rates in the country where the recycling takes place are higher. In practise, only polyethylene shrink film was awarded material credits.

In conclusion, a closed-loop recycling model - addressing downgrading and incomplete recycling rates - where materials are assumed to substitute the same production line has been assumed.

2.4.2.4 System boundaries

When using secondary data, it is important to control which upstream processes are included in the targeted process. For instance, the production of LDPE pellets – which can further be processes into stretch film – includes not only the actual production of the pellets but also the extrusion of crude oil, e.g. a cradle to gate perspective for this product (Plastics Europe, 2008). If the practitioner is not careful, this may lead to double-counting of processes, invalidating the results of the study. The Ecoinvent data provides a detailed description of what is included in a unit process to prevent double-counting on the form *"From reception of raw materials [possibly further specified] at the factory gate [possibly further specified]" or "Service starting with the input of [e.g. labour and energy]"* (Weidema, et al., 2013), making it easier to avoid this error.

The ILCD handbook strongly recommends a quantitative cut-off criterion (European Commission , 2010). This sounds good in theory, but presents several practical issues. The methodology is difficult to implement in its current form, because when initiating the assessment, no knowledge exists about the expected level of completeness or even which processes needs to be included to achieve this level. This can be overcome by adopting an iterative approach to the assessment, updating the judgement of completeness along the course of the assessment. However, a more severe issue is that the Ecoinvent database does not follow any strict quantitative cut-off rule (Weidema, et al., 2013). The datasets are as complete as the knowledge of the data providers allow. This means that even though a quantitative cut-off rule were to be adopted in this assessment, the uncertainty of the impacts would still be bound to the uncertainties found in the Ecoinvent dataset. To overcome this problem, the datasets of the two supply chain models will include as similar entries as possible for the different processes to avoid completeness irregularities between the models.

Initially, a cut-off criterion was intended to be used where sub-suppliers of packaging material would be cut off when the contribution did not exceed five percent. But over the course of the study, system expansion was used iteratively to enhance the accuracy of the model, rendering the cut-off unnecessary as the supply chain systems were modelled from cradle, or in other words that all packaging sub-suppliers were modelled. For remaining processes, a cut-off at one percent was used, and processes were evaluated to see if they could lead to a higher contribution. An example of processes cut off is the electricity consumed by the forklift in the warehouse. Even though a process might contribute with a small share of an impact factor, it might have a large contribution in some other aspect. An example is highly toxic materials that may be overlooked if a quantitative cut-off criterion is used. For the excluded processes, no risk for this error could be identified.

2.4.3 **Impact assessment**

The relevant midpoint impact assessment categories have been chosen based upon the recommendations set out by the European Platform on Life Cycle Assessment (Europan Commision, 2011). In Ecoinvent, the database layer computes the values for the different assessment categories, and the ILCD categories were added to the third version of the database (Hischier, et al., 2010).

Assessment category	*Unit*	*Quantitative analysis*	*Qualitative analysis*	*Not included*
Climate change	Kg CO_2-Eq	X		
Ozone depletion	Kg CFC-11	X		
Human toxicity			X	
Particulate matter	Kg $PM_{2.5}$	X		
Ionizing radiation – damage to human	kg U_{235}-Eq	X		
Ionizing radiation – damage to ecosystems				X
Photochemical ozone formation	Kg C_2H_4-eq	X		
Acidification	Mol H^+-Eq	X		
Terrestrial eutrophication	Mol N-Eq	X		
Freshwater eutrophication	Kg P-Eq	X		
Marine eutrophication	Kg N-Eq	X		
Land use				X
Depletion of abiotic resources				X

Table 2: List of the chosen impact assessment categories

The climate change category is based on the global warming potentials developed by the Intergovernmental Panel on Climate Change (IPCC). They calculate these based on three different time frames: a 20, 100 or 500-year cut-off period (Myhre, et al., 2013). Even though the 500-year period is the most robust and recommended praxis, the 100-year cut-off period is widely accepted and used as a basis for the Kyoto Protocol I . There is no scientific argument choosing a 100-year cut-off period over other periods, and IPCC stresses that this choice is a value based judgement (Myhre, et al., 2013). In this report, the 100-year cut-off period will be used since it is also used by previous research and therefore makes this report more comparable to these reports.

For the category *ionizing radiation damage to ecosystems* and *depletion of abiotic resources*, ILCD deems the underlying methodology to be interim, and it has therefore been excluded from this study. (Europan Commision, 2011; Garnier-Laplace, et al., 2006).

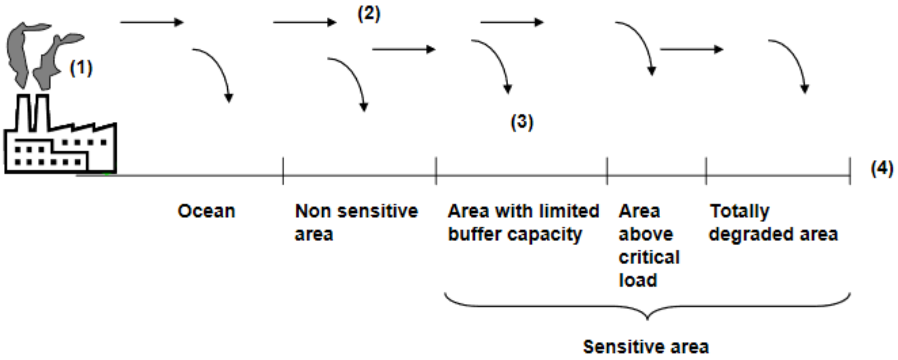


Figure 4: The difference between sensitive and non-sensitive areas as modelled in the AE method (Margni, et al., 2008).

The chosen methodology for measuring acidification is one called accumulated exceedance (Margni, et al., 2008). This method provides country-dependent characterization factors, which gives an average value for the buffer capabilities of a country. For Swedish conditions, the buffer conditions vary greatly. For instance, the limestone environment of Gotland has far greater buffer capabilities than the acid moors of Jämtland, but the methodology is still the most accurate to this date (Europan Commision, 2011).

2.4.4 Completeness check and sensitivity analysis

During the interpretation phase, a completeness check and a sensitivity analysis will be done.

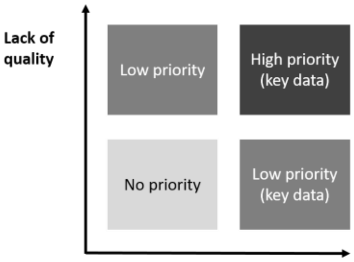


Figure 5: Sensitivity analysis matrix (European Commission , 2010)

The sensitivity analysis will be undertaken using the sensitivity matrix shown in Figure 5. The focus will be on high priority items where the underlying inventoried data has low quality and the value of the process largely affects the outcome of the study.

2.4.5 Constructing the theoretical scenarios

For both system models, theoretical scenarios were computed based on observations from the Danish retail store. In general, transport distances and emission classes of vehicles were normalised to not give benefit to either system. Firstly, car transports to the consumer were excluded as they contributed to a major share of all impacts, and do not relate to the difference between each system model. Secondly, electricity credits from waste incineration were excluded due to the different electricity composition between Denmark and Sweden. Including them greatly skewed results for carbon emissions in favour of Swedish management due to fewer coal plants, and ionizing radiation in favour to Denmark due to the nuclear power plants in Sweden.

The best-case scenarios were chosen based on a discussion with the owner of the Danish retail store owner. The poorer scenarios, for instance assuming fewer usage cycles of the glass bottle in the rapeseed oil system, were chosen by the author to shed light on relevant weaknesses in the package-free distribution model.

2.4.6 Methodological considerations for life cycle assessment

Even though it is highly recommended to include every impact assessment category available (European Commission , 2010), it is common that assessments performed on food products address a subset of these categories (Sonesson, Cederberg, Flysjö, & Carlsson, 2008; Wallman & Sonesson, 2010; Cederberg & Nilsson, 2004). This choice can be well motivated if the studied system is not affiliated with certain types of emissions (European Commission , 2010), but the relevant impact categories for a food product may not be the most relevant for the packaging itself (Silvenius, et al., 2014). It’s unclear how to evaluate the impacts between food products and packaging materials when they result in emissions for different impact categories, as no weighting between different impact categories could be identified (Europan Commision, 2011; Baumann & Tillman, 2004; Rydh, Lindahl, & Tingström, 2002). When looking at waste prevention initiatives of packaging, ecotoxicity, metal depletion, freshwater eutrophication and ozone depletion are the categories experiencing the most significant improvements (Cleary, 2014). For the production of food, it is unlikely that for instance metal depletion would contribute significantly, and evaluating which system would be preferable is then difficult as they perform well in different categories. The issue remains unresolved in this report as well.

2.4.7 Excluding food waste

To give a definite answer to which distribution model is preferable, one must consider differences in food waste generation. As will be discussed in chapter 3.3.2, previous studies have not quantified food waste when comparing different packaging solutions. For this study, it was decided not to include food waste as obtaining high enough quality of data was deemed too difficult given the project's time frame and the required efforts to complete the other parts. To overcome this limitation and still contribute to the academic research, the impact of the packaging will be evaluated against the impact of food production, and a tolerance for food waste will be computed. This means that given the reduction of emissions for either system, should it be accompanied by X percent increase in food waste, the overall impact would be higher even though the impact from the packaging itself is lower.

2.5 Combining methods

A life cycle assessment only looking at a single zero waste store is difficult to generalise, but employing a mixed method approach can partly overcome this limitation. General, epistemological issues are still unresolved as the dualism between subjectivism and objectivism collide when attempting to combine methods. A few philosophical theories are presented to overcome this dualism, such as adhering to the dialectic or pragmatic perspective (Greene & Hall, 2010). In this study, a pragmatic approach seemed most appropriate and in line with engineering conduct.

To answer the third research question, a combination of the results from the survey, the life cycle assessments and literature findings will be used. This means that the benefits and drawbacks of the zero-waste model when applied to conventional stores will be discussed, and how the results from this life cycle assessment can be interpreted given limitations to generalisability.

3 Theory

This section includes the literature findings used to answer the first and third research questions. The first section describes what zero waste means and how it is – or could be – applied in a food logistics context. The second and third chapter relates to the role of packaging within food logistics, describing the general purpose of packaging, how it's used, which unresolved issues still exist, and which end-of-life treatment options exist. Finally, findings from a study that specifically targeted zero-waste stores is summarised.

3.1 Zero waste

3.1.1 What does zero waste mean?

The zero-waste movement originates from the 1970s where it was coined by Paul Palmer, a doctor in chemistry from Yale University (Zaman, 2015; Palmer, 2007). It aims to minimize any waste generation, including emissions, by creating products that can essentially be reused indefinitely. However, the author agrees that this approach is infeasible and proposes a more pragmatic standpoint towards the life time of products by moving away from the current throwaway, consumeristic society (Palmer, 2007). Over the years, a variety of definitions have been used for zero waste, and even though attempts have been made to standardize the concept (ZWIA, 2009), many different definitions can be found. Notable examples include complete diversion from landfill and incineration (Welsh Assembly Government, 2010), diversion from landfill but permitting incineration ((Abbasi, Premalatha, & Abbasi, 2012; Björk, 2012; Premalatha & Tauseef, 2013) as cited in (Zaman, 2015)) or in conjunction with the concept circular economy (Europan Commission, 2014). A summary is given by Bartl (2014), proposing a further division of the term to avoid this ambiguity.

By subdividing 'zero-waste', implementing a zero-waste strategy enables the use of different phases depending on the current waste management situation. Different countries face different types of waste management challenges.

For some, a diversion from landfill strategy could be fruitful, whereas in a Scandinavian context where waste is incinerated or recycled rather than landfilled, moving further down towards a zero-waste society would be more important. Zaman (2015) proposes a three-phase implementation:

1. The first phase includes shifting industry to adopt cradle-to-cradle design and similar resource extraction principles.
2. The second phase targets consumer behaviour, endorsing customers both to consume consciously in terms of quantity and with regards to the impacts of each product's production and waste management.
3. The third phase involves a political shift towards the circular economy by creating green job opportunities and strategic plans.

Suggested term	***Definition***
Zero landfill	Total or almost total diversion of waste from disposal (e.g. landfill); Feasible options include other recovery (i.e. incineration) as well as recycling.
Zero incineration	Total or almost total diversion of waste from disposal as well as other recovery (e.g. incineration); All waste that is generated needs to be recycled.
Zero waste	Total or almost total avoidance of waste by excessive waste prevention and re-use; landfill, incineration as well as recycling must not take place.

Table 3: Suggestions for a precise wording in the field of zero waste (Bartl, 2013) as cited in (Bartl, 2014)

Palmer (2007) argues that the original intention of zero waste more closely resembles the current state of literature, but for decades the term has been used as diversion from landfill or seen as an inapplicable model due to the unreasonableness of a society entirely freed from waste. In previous years, the concept has regained its meaning in line with authors criticising earlier implementation strategies that usually interpreted zero waste as diversion from landfill. An example is Krausz (2012), who stresses how the local authorities are affected as the responsibility for end-of-life management generally falls on them. He argues that we need to localise production as local communities otherwise can't prevent hazardous waste from entering their waste streams; de-emphasise recycling due to the 'feel-good' aspect which hinders further transition towards zero waste; and ignore percentage diversion rates, instead introducing the new unit of measurement *per capita waste to landfill,* ultimately targeting 0 kg/person/year. Prioritising local production means that companies are affected by national laws which makes it easier for them to exert influence on companies.

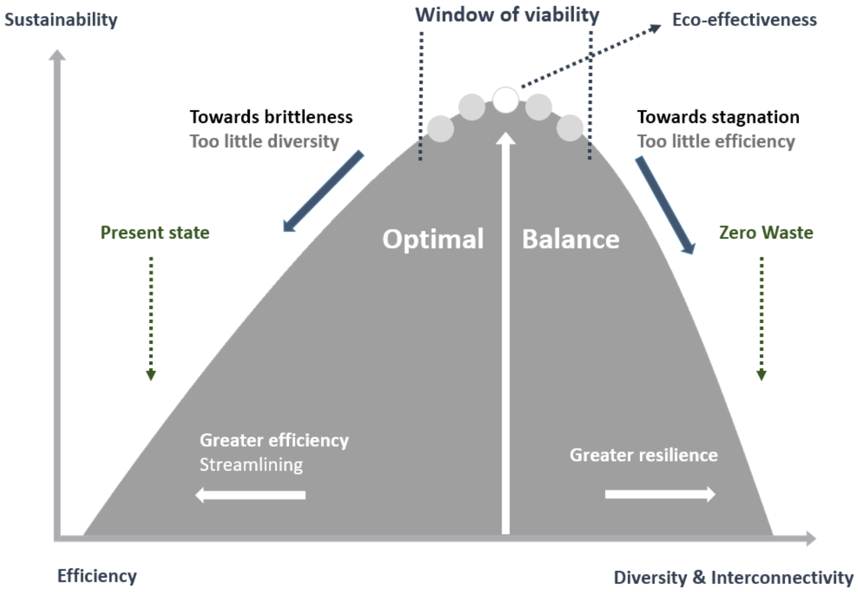
Scenarios	***Waste per capita***	***Diversion from landfill***	***Per capita waste to landfill***
Country A	250 kg	10 %	25 kg
Country B	500 kg	5 %	25 kg

Table 4: Illustrative example of the per capita measurement for diversion from landfill

This line of argument corresponds to the waste framework directive set out by the European Union (2008), where prevention and preparation for re-use are preferred alternatives to recycling, illustrated in Figure 9 in section 3.3.2.

3.1.2 Opposing theories of sustainability

While closing in on a consensus for what zero waste is, disagreement exists to whether it is the soundest strategy for future resource management. Another noteworthy concept is that of eco-effectiveness (Braungart, McDonough, & Bollinger, 2007; Dyllick & Hockerst, 2002). The critique against the zero waste concepts is that it decouples the relationship between economy and ecology, aggravating economic growth. Eco-effectiveness instead forms a supportive relationship with future economic growth by promoting upcycling, meaning that materials maintain their status as resources for a longer period. The authors advocate an increased producer responsibility for end-of-life treatment, synergistic effects from intelligent materials pooling which means that a central resource bank manages material flows and ensures that they are reused multiple times, and net positive inventions that effectively compensate for emissions by cleaning the environment upon usage. They argue that a zero-waste approach aims for a complete minimization of waste and emissions (ZWIA, 2009), whereas an eco-effectiveness approach seeks an optimum between economic growth and sustainability.



Note: Author's contribution marked in green.

Figure 6: The difference between eco-effectiveness and zero waste (Ellen MacArthur Foundation, 2012). Theory adapted from (Braungart, McDonough, & Bollinger, 2007).

In practice, the technology to shift towards these upcycling strategies exist, but as few producers adopt a cradle-to-cradle perspective products are wrapped in a mix of different packaging materials which obstructs this transition (Hopewell, Dvorak, & Edward, 2009; Aarnio & Hämäläinen, 2008). Advocates of zero waste and eco-effectiveness agree on the problem with sub-primary recycling and the principle of cradle-to-cradle design principles to overcome this issue, but goes to different lengths in reducing material input flows, illustrated in Figure 6 (Zaman, 2014; Braungart, McDonough, & Bollinger, 2007).

3.1.3 **Zero waste and the distribution of food**

Few studies have looked at food distribution in a zero-waste context, but Jurgilevich et al. (2016) provide an overview of the food sector in a circular economy perspective. It mostly addresses the production of food, but states that we need to shorten distribution distances and balance packaging in a way that balances mass reduction, prolonged shelf-life and protecting the food for safety reasons. But emphasizing cradle-to-cradle design or reusable products makes less sense in the case of food distribution, as food is downgraded once having been eaten by the final consumer (Ellen MacArthur Foundation, 2013). Still, a key aspect can be found that relates to zero waste and a circular economy, namely the cradle-to-cradle perspective of the food product itself (Genovese, Acquaye, Figueroa, & Lenny Koh, 2014; Halloran, Clement, Kornum, Bucatariu, & Magid, 2014). The authors highlight that a cradle-to-cradle perspective means converting waste to resources within the primary production of food, better distinguish between food surplus – which is unsellable food that is still edible – from food waste, and finding more effective end-of-life treatment options for food.

3.2 Packaging and food

'Packaging is a means of ensuring safe and efficient delivery of the goods in sound condition to the ultimate consumer, supplemented by efficient reuse of the packaging or recovery and/or disposal of the packaging material at minimum cost.' – The purpose of packaging (Leigh, Jonson, & Smith, 2006)

Packaging serves several purposes, including the protection of the product, as seen in the purpose listed above. But in general, three purposes can be identified: to protect the product, to be effective in terms of economic, environmental and convenience aspects, and to provide information, such as for marketing, distribution, or about additional service offerings (Leigh, Jonson, & Smith, 2006).

The protection is especially relevant for a perishable product such as food, where packaging can aid in reducing product waste (Lindh, 2016).

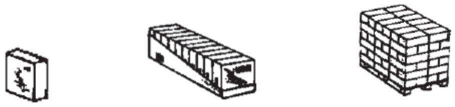


Figure 7: The three levels of packaging (Lindh, 2016)

Figure 7 illustrates the three level of packaging that exists. The first serves to directly protect the product, and the two additional levels provide extra protection, stability and makes handling of a single product more efficient. Packaging systems are generally organised in this way.

Within the food industry, packaging logistics both entail the packaging itself and the distribution of the product, with main process stages illustrated in Figure 8. The packaging shall protect the product throughout all stages illustrated, ensure a long durability in storage – both in the store and at the final consumer - as this aids in mitigating product loss, and it should be convenient to use for the consumer. The scope of the packaging purpose goes beyond aspects related to environmental performance. The disagreement between conventional supply chain models and zero-waste stores exists both in how much packaging is necessary to minimise food waste, and whether packaging should be motivated from an economic perspective such as in the case for marketing. The zero-waste concept aims to minimise any packaging that flows through this network and de-emphasize recycling in favour of reusable materials, as discussed in chapter 3.1.1.

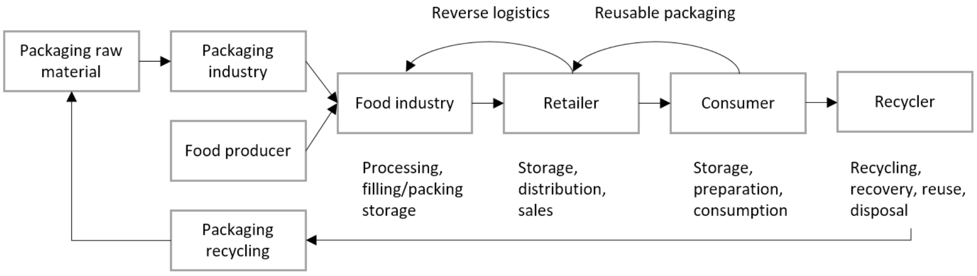


Figure 8: Overview of activities linked to packaging logistics of food. Adapted from (Lindh, 2016) with input from (Dias & Braga Junior, 2016) & (Beitzen-Heineke, Balta-Ozkan, & Reefke, 2016).

3.3 Perspectives on waste reduction

3.3.1 **Quantifying packaging reduction benefits**

		Environmentally preferable scenario			***Includes food waste discussion***	
Source	***Food product***	***Baseline***	***Neither***	***Prevention***	***No***	***Yes***
(Nessi, Dolci, Rigamonti, & Grosso, 2016)	Pasta		X		X	
(Nessi, Dolci, Rigamonti, & Grosso, 2016)	Rice			X	X	
(Nessi, Dolci, Rigamonti, & Grosso, 2016)	Cereals			X	X	
(Pagani, Vittuari, & Falasconi, 2015)	Salad			X	X	
(Nessi, Rigamonti, & Gross, 2012)	Bottled water			X	X	
(Cleary, 2013)	Wine & spirits			X	X	
(Toniolo, Mazzi, Niero, Zulani, & Scipioni, 2013)	Generic			X	X	
(De Monte, Padoano, & Pozzetto, 2005)	Coffee			X	X	
(Büsser & Jungbluth, 2009)	Coffee			X		X

Table 5: A review of previous literature within packaging waste prevention

The general results from previous waste prevention studies indicate that environmental benefits can be achieved by reducing the amount of packaging used, as seen in Table 5. These studies compare a baseline scenario – often the predominant packaging solution found on the market – with various waste prevention scenarios. The studies have different methodologies and the waste prevention scenarios evaluate different parameters, such as increased packaging size or reusable packaging, but comparing a baseline with a prevention scenario is common to all studies. The studies relate to which environmental impact difference occurs when reducing packaging materials, and have been chosen since they relate to the case for zero-waste stores. As seen in the left column, most studies favour the removal of packaging in line with the zero-waste principle. For pasta, the difference is negligible. However, none of these studies account for a potential increase in food waste generation. Büsser and Jungbluth (2009) discuss this issue in their paper, but have not quantified the effects.

Nessi et al. (2016) study the case of gravity bin dispensers, where retail stores buy large containers and repack it into the dispensers. Consumers thereafter buy the product through low density polyethylene bags provided by the store. The possibility to bring their own, custom packaging was not considered in this study. As seen in Table 5, few studies account for a possible increase in food waste generation. In many cases, a better use of packaging can reduce the amount fo food waste that is generated. A few authors have found contrary results as well, including Gustavsson and Stage (2011), whose results indicate that packaging generally does not reduce food waste for vegetables in the retail store, still saying that the savings could occur at the household stage. This conclusion is investigated more closely by Wikström, Williams, Verghese & Clune (2014) and Silvenius et al. (2014), and they conclude that the effect of reduced food waste in the household stage must be considered when evaluating the entire environmental impact of a packaging choice, since different packaging choices can greatly affect the outcome of the amount of waste generated.

But for many products, a clear trade-off between increased packaging and reduced food waste exists which relates to the protective properties of packaging (Verghese, Lewis, Lockrey, & Williams, 2015; Quested, Ingle, & Parry, 2013; Halloran, Clement, Kornum, Bucatariu, & Magid, 2014). To determine the difference between a baseline and a prevention scenario for these products, it's imperative to consider how much food waste is generated. Even though several studies address food waste (Eriksson, Strid, & Hansson, 2012; Gustavsson & Stage, 2011; Quested, Ingle, & Parry, 2013), no studies have been found where different packaging solutions are evaluated against quantified food waste data.

3.3.2 Overview of waste generation within food distribution

Waste generation in general has is a prioritised issue for the European Union (Europan Union, 2008). Their solution is for companies to comply to the waste hierarchy, illustrated in Figure 9: The EU waste hierarchy Figure 9.

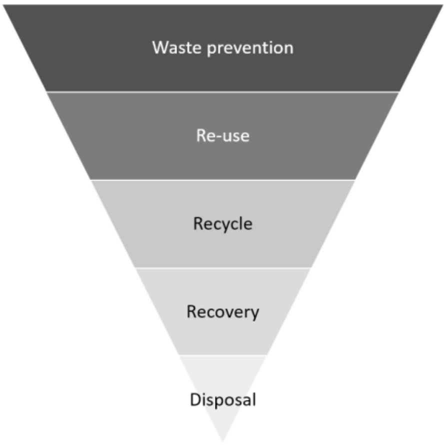


Figure 9: The EU waste hierarchy (Europan Union, 2008)

3.3.2.1 The distribution stage

Food and packaging waste occurs frequently throughout the entire distribution of a product’s life cycle. As mentioned earlier, packaging serves to protect the product, often resulting in a food waste reduction. For many products, packaging accounts for a small share of the total environmental impact which makes this increase in packaging motivated (Büsser & Jungbluth, 2009; Roy, et al., 2009; Wikström, Williams, Verghese, & Clune, 2014). But despite protective properties, the very same packaging can at the same time lead to adverse results. If several units of food – such as vegetables – are packed together, it is usually enough that a single item is spoiled for the entire packaging to be discarded (Lebersorger & Schneider, 2014). Some stores try to overcome this issue by unpacking the product and selling the remaining items loose, but many stores still discard it whole. A similar problem occurs in the distribution stage, where packaging can serve two purposes: prolonging the lifetime and protect the product from physical breakage. A good example where this is the case is for tomatoes, where both a refrigerated transport and proper packaging can ensure a prolonged lifetime and minimal spoilage (Eriksson, 2016). But for other packaged products, damage to the packaging during distribution often renders the product unsellable, even though the product itself is perfectly edible (Lebersorger & Schneider, 2014; Eriksson, Strid, & Hansson, 2012; Verghese, Lewis, Lockrey, & Williams, 2015). This is partly because customers reject the product in the store. This problem – the disconnection between the product and the packaging – increases packaging waste further as the best-before date not necessarily correspond to whether the food product is edible or not (Lebersorger & Schneider, 2014; Eriksson, Strid, & Hansson, 2012).

The impact of transport relates to which mode of transport is used, and especially which mode of transport is used during the last step between the retail store and consumer, as this transport is allocated to far fewer products than in mass distribution. While locally produced food can lead to lower emissions (Pretty, 2005), small-scale distribution systems such as where customers travel to farm shops often performs poorly compared to mass distribution models (Coley, Howard, & Winter, 2009). However, it is not determined that a local supply chain reduces impact, as this relates to the food product itself and the mode of transport (Edwards-Jones, et al., 2008).

Another issue occurs when a product is wasted to a very large extent or when the waste is rather large in combination with the product having a large, environmental footprint. Some exotic fruits sold in Sweden report retail waste levels above 50 % (Eriksson, Strid, & Hansson, 2012), and for a meat department, minced beef alone contributed to 17 % of that department's total carbon footprint (Eriksson, 2015). Relying on packaging inventions can in these cases present a false security, as more efficient waste prevention measures could be taken, such as selling minced meat frozen or exotic fruits canned (Eriksson, 2016). This would however conflict with customer demand, as it changes the inherent nature of the food product. Furthermore, for many products usually sold with packaging today, packaging does not reduce waste to a large degree (Roy, et al., 2009), and the potential to reduce waste by packaging design is argued to be more applicable to products with a high ratio between the impact of food and the impact of packaging (Williams & Wikström, 2011).

3.3.2.2 End-of-life treatment

Once waste occurs, the question arises as to which end-of-life (EOL) treatment is the preferred choice. In line with the zero-waste model, a distinction between food surplus and food waste must be made, as described in chapter 3.1.3. Avoiding downgrading of food surplus to waste is integral to reduce impacts associated with food waste (Eriksson, 2015). Selling unpackaged food would both mitigate unpackaging procedures and decrease food waste sent to incineration at retail stores. In Sweden, a master thesis by Andrée & Schütte (2010) found that approximately a third of the studied retail stores send their food directly to incineration instead of separating the packaging. But on the other hand, selling unpackaged foods makes it more difficult to handle food surplus if it is going to be upgraded into new products or donated to charity (Eriksson, 2016).

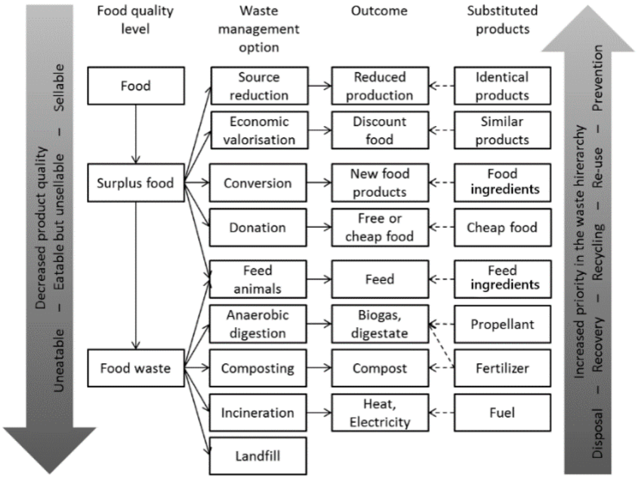


Figure 10: Waste management framework, with waste & surplus distinction (Eriksson, 2015).

If food surplus cannot be used, different EOL treatment options exist for the waste. Vandermeersch, Alvarenga, Ragaert & Dewulf (2014) evaluates the difference between anaerobic digestion and feed production as an EOL treatment. Their results indicate that moving towards using food waste as a resource for feed production is the preferred option, which is in line with the waste prevention and valorisation framework developed by Eriksson (2015), illustrated in Figure 10. Eriksson agrees that the vertical positioning of waste management options in the framework does not illustrate superiority in a descending order. For some products – such as bread – incineration is the preferred EOL treatment, outperforming both animal feed, composting and anaerobic digestion (Eriksson, 2015). As the food sector consists of such a wide variety of products, it is impossible to give a framework that captures every unique trait of all products. The waste management framework gives general guidance as to which EOL treatment options are preferred, and even though certain products are exempt from this principle, options further up along the framework generally leads to more favourable results. This means that even though the environmental impact was found to be lower for waste prevention scenarios in Table 5, it still may be a sub-optimised solution if we consider the reduced impact that comes from a better handling of surplus food. However, the waste management options presented by Eriksson (2015) are rarely employed by retail stores. In a Dutch study by van Sluisveld & Worrell (2013), the authors perform a case study, evaluating different implementation options for packaging source reduction. Out of these options, re-use was never practised in the case of food products. The second-life surplus options should therefore be considered a theoretical possibility and not as an option which needs to be accounted for in present studies.

For packaging materials, other than preventing it from occurring in the first place, the endorsed EOL treatment option is reuse, followed by recycling (Europan Commission, 2010). The problem with recycling packaging material is that downgrading occurs and the recycling process itself causes emissions (Aarnio & Hämäläinen, 2008; Hopewell, Dvorak, & Edward, 2009).

ASTM D5033 definitions	***Equivalent ISO 15270 (draft) definitions***	***Other equivalent terms***
Primary recycling	Mechanical recycling	Closed-loop recycling
Secondary recycling	Mechanical recycling	Downgrading
Tertiary recycling	Chemical recycling	Feedstock recycling
Quaternary recycling	Energy recovery	Valorisation

Table 6: Different levels of plastics recycling (Hopewell, Dvorak, & Edward, 2009)

The preferred recycling is primary or closed-loop recycling, which means that no downgrading occurs and the material can be recycled indefinite. However, as seen in Table 6, when talking about recycling in general it does not only include this perfect state of material conservation. The obstacles towards achieving a 100 % primary recycling rate of packaging materials include changing consumer behaviours to increase household recycling rate (Europan Commission, 2010), extending producer responsibility, harmonising material choices and creating practises that fit the waste producers’ needs (Aarnio & Hämäläinen, 2008).

3.3.3 Reverse logistics as a waste prevention measure

In many cases, the introduction of reusable packaging corresponds with reverse logistics (Cleary, 2013; Dias & Braga Junior, 2016). In Sweden, fruits and vegetables are often distributed in reusable plastic boxes which are then returned to the packaging plant (Svenska Retursystem, 2016). Other than this, reverse logistics within food distribution mostly consists of glass packaging for liquids such as beer, fruit juice, honey, cider or vinegar (González-Torre, Adenso-Díaz, & Artiba, 2004).

The environmental performance of these systems relies on transport distances and the trip return rate, making it more suitable for regional food supply (Cleary, 2013). This relationship is seen in Table 7 as well, where single-trip packaging outperforms reusable variants when journey distances increase. The results also strengthen previous literature findings in terms of larger containers reducing emissions compared to smaller packaging. However, consumers perceive that most food waste that occurs in their household comes from food items going bad and packaging being too large and difficult to empty (Williams, Wikström, Otterbring, Löfgren, & Gustafsson, 2012). The results show that certain product categories are wasted to a larger degree than others, in their case fruit, vegetables, dairy and prepared food.

Properly sized, easily emptiable packaging can therefore be superior to larger, reusable containers as different products have different requirements in terms of packaging qualities.

Source	Product	Return trips	Journey Distance	Packaging material			
				Returnable	*Preferable scenario*		*Single-trip*
(ERM, 2008)	Generic	Wood: 15 Plastic: 100	Not stated	Plastic pallet	X		Wooden pallet
(Franklin Associates, 2008)	Water	30 & 60	Not stated	Plastic crate	X		Corrugated box
(Sustain, 2008)	Generic	92	Not stated	Plastic crate	X		Corrugated box
(Vogtländer, 2004)	Fruit & veg.	20 & 30	0-2500 km	Plastic crate		X	Corrugated box
(Capuz Rizo, 2005)	Fruit & veg.	20	2600 km	Plastic crate		X	Corrugated box
(Jungbluth, 2005)	Drinks	50	50 & 1000 km	1 l glass bottle	<[a]		1,5 l PET bottle
				18,9 l jug	X		
(Detzel, Giegrich, Krüger, Möhler, & Ostermayer, 2004)	Drinks	0,33 l: 25 0,5 l: 21 0,7 l: -	Return: 190 & 120 km Single-trip: 250 & 320 km	0,33 0,5 & 0,7 l glass bottle	X[b]	X[b]	0,5 1,5 & 2 l PET bottle
(PTR , 2002)	Drinks	18-32	Not stated	0,3 0,33 & 0,5 l glass bottle	X[c]		0,33 & 0,5 l aluminium can
				0,5 l PET bottle	X[c]		

a) This scenario performs better than the single-trip, but worse than the jug scenario. b) The authors state no clear advantage to either system but describe several cases where the reusable glass bottle performs better. c) Both reusable scenarios perform better than the single-trip, but no comparison as to which reusable scenario is preferable is presented.

Table 7: Summary of results from reverse logistics studies (adapted from (WRAP, 2010)).

Achieving zero-waste in terms of not consuming any disposable packaging throughout the distribution is reasonably largely characterised by a reverse logistics system, and if secondary or tertiary packaging is reusable, it may result in a poorer overall environmental performance of the system compared to a single-use model.

3.4 Retail stores without primary packaging

It’s unclear when retail stores marketing themselves as package free first occurred, but some pioneers were Unpackaged, Negozio Leggero and Effecorta ((Unpackaged, 2016; Negozio Leggero, 2016; Effecorta, 2016) in (Muller & van Engeland, 2015)). The concept is still novel, but has been spreading at an increasing pace and has recently reached Sweden (Gram Malmö, 2016) and Denmark (Løs Market, 2016).

Through an interview study with eleven European store owners, Beiten-Heineke, Balta-Ozkan & Reefke (2016) have analysed the stores’ concept. They call the stores ‘zero-packaging’ and define their core concepts as a focus on environmental protection and packaging reduction. Through qualitative interviews with eleven store owners, they provide a general description of the concept. They show that even though it is a novel concept, it is growing through technological innovations and concept development. For instance, one store has developed a stainless-steel container, enabling liquid refilling without oxygen contamination. One store offers a plastic-free bulk container which is now sold to other stores.

The stores differ greatly, with product offered ranging from 300-1500. Some offer refrigerated meat and fish while some only offer non-refrigerated goods. Generally, they do not handle the inbound logistics, which means that the packaging is not always reusable from their suppliers. Generally, stores worked to minimise food waste generation, and many either prepare food from expiring products or donate surplus food to charity.

4 Life cycle inventory

In this chapter, the life cycle inventory process is described. For a more thorough description of data sources and the quality of the data, refer to Appendix C. In both system models for the conventional scenario, it was assumed that a percentage of all transports between the customer and the retail store were done by car, according to a survey from Svensk Handel about Swedish buying patterns in retail stores (Svensk Handel, 2009). This has not been assumed for the package-free scenario, as customers walk to and from the store. The car transport constitutes a major part of the total impact of the baseline scenario. Therefore, two main scenarios are presented for the conventional scenarios, both with and without the car transport.

4.1 System boundaries

An overview of the applied system boundaries is presented in Figure 11 and Figure 12. The production of the food product itself is not included, as well as the subsequent distribution and end-of-life management of it. What is included is any packaging material that flows through each system model, from every sub-supplier of packaging until it is collected and recycled or incinerated. Credits for recycling are rewarded based on whether their respective Ecoinvent dataset already includes recycled content. By doing this we effectively avoid any double-counting of inputs and outputs.

The system boundaries are applied equally to all four systems, meaning that no sub-supplier has been cut off from any system, in line with the cut-off criterion formulated in section 2.4.2.4.

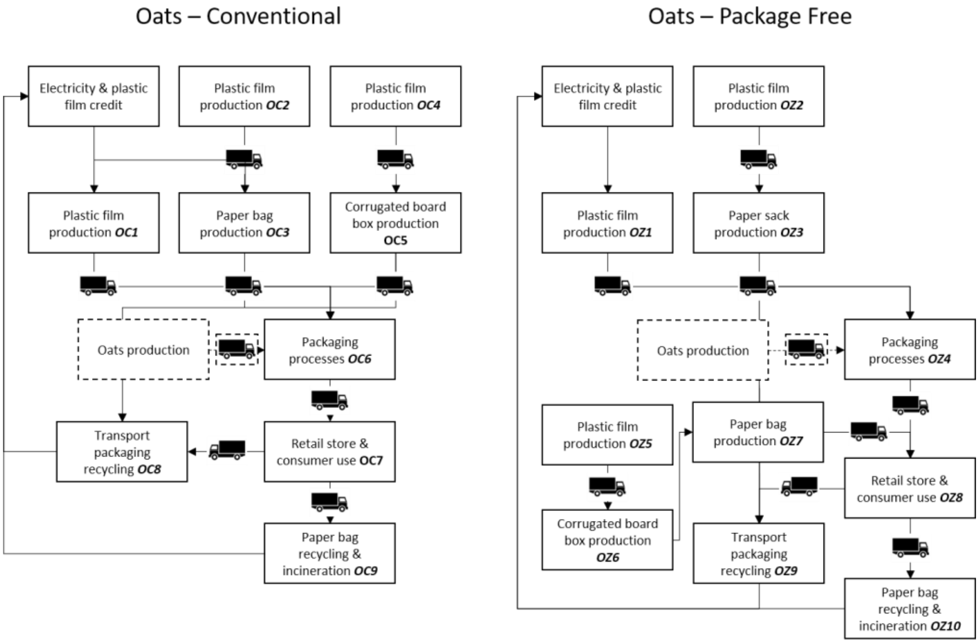


Figure 11: System boundaries for both system models of oats

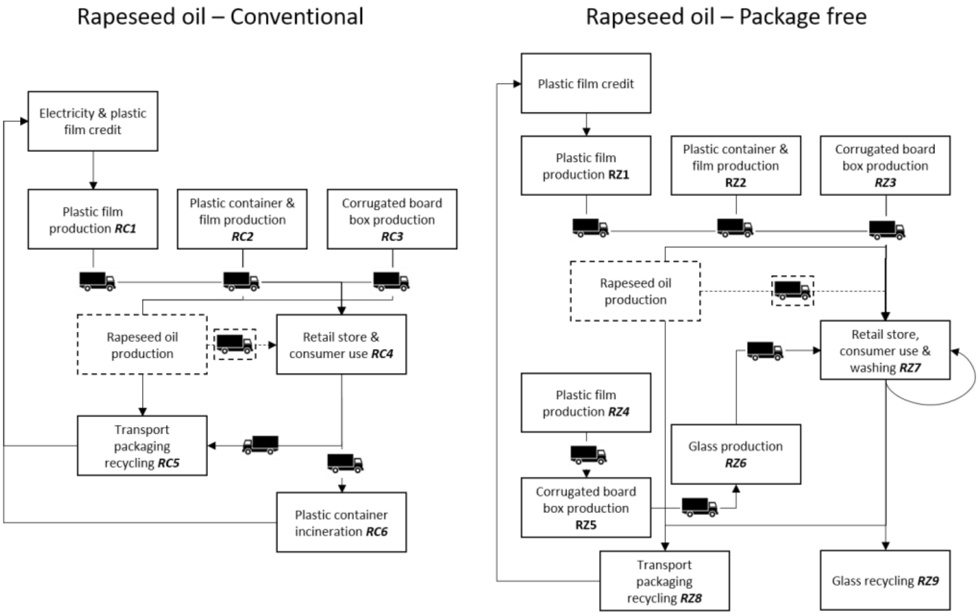


Figure 12: System boundaries for both system models of rapeseed

4.2 The rolled oats system model

4.2.1 The conventional model

The conventional system model for oats is based on a Swedish, medium-sized producer of organic oats. Data that relates to the production site and the packaging that directly relates to the product itself has been collected at the production facility by a field visit. Through this field visit, the sub-suppliers were identified and could be contacted via telephone. For most of the packaging material, primary data directly from the producers have been used. In total, every sub-supplier has been contacted, even though not all of them could provide all necessary information. The most difficult data to collect related to transports, and in several cases no reliable data could be retrieved about which environmental classification or how large the lorries used were. To overcome this, a combination of theoretical calculations, secondary data and qualified assumptions were employed.

The transport packaging is transported to the oats production facility, where the oats are packed into a 650-gram large paper bag. This is in turn packed into a corrugated box, wrapped in shrink film and loaded onto a pallet. The transport packaging is recycled, and the paper bag that reaches the consumer has been assumed to be either incinerated or recycled, per national statistics.

4.2.2 The package-free model

This package-free system model for oats is based on site specific data for the Danish package-free store. Primary data about suppliers was collected at the Danish retail store. Sub-suppliers were contacted via telephone, and as for the conventional model, all sub-suppliers were contacted. The oats are packed into 10-kilos paper sacks, loaded onto a pallet, and wrapped in shrink film. For some of the packaging material, data from the conventional model was used. Once distributed to the retail store, the oats are re-packed into gravity dispensers. The store offers paper bags, which are ordered from a French provider. For this baseline scenario, it was assumed that all purchases were performed using the paper bags provided by the store. As many customers provide their own packaging this is not entirely accurate, but due to the large variety of customer packaging, creating an accurate model was difficult which is why this case has been moved to the theoretical scenarios. The store also offers reusable cotton bags, but these could not be included in the analysis as the production takes place in India, and any information that relates to the production and subsequent transports was impossible to retrieve.

4.3 The rapeseed oil system model

4.3.1 The conventional model

The conventional model for rapeseed oil is based on a Swedish, medium-sized rapeseed producer. Data collection was performed at their production facility, where most primary data about packaging took place. Sub-suppliers were contacted via telephone. Most sub-suppliers were successfully contacted, even though not all of them could provide all information.

After the packaging materials arrive to the production site, the rapeseed oil is packed into 1-litre plastic bottles. These are packed in corrugated board boxes, loaded onto pallets, and wrapped in shrink film. The transport packaging is recycled in all stages. After being bought by the customer, the bottle is sent to incineration. For food packaging, plastics is generally not produced from recycled content due to legislation for food safety (Livsmedelsverket, 2016).

4.3.2 The package-free model

The package-free model for rapeseed oil is based on site specific data from the Danish retail store. Primary data about packaging and producers was collected at their store. Sub-suppliers were contacted via email and telephone. For this system, several sub-suppliers could not be reached. The primary producer of rapeseed oil – a Danish medium-sized producer – never responded despite several attempts of contact. As knowledge about the packaging itself could be collected at the store, the producer in the conventional model was used instead. Furthermore, the sub-supplier of glass bottles could not be contacted as the wholesale agent would not disclose their supplier. They instead provided the distance from their warehouse in Berlin to the glass producer. This distance was cross-referenced with all German glass producers, and one suited best to that distance. Further sub-suppliers were modelled in the same way, e.g. the closest providers of packaging material were used.

Figure 13: Roll container ((The Hub's Engineering Pte Ltd, 2011; Capcon Ltd, 2014) in (Elofsson, 2015))

The rapeseed oil is packed into 5-litre plastic containers, put into corrugated board boxes, loaded onto pallets, and wrapped in shrink film. The plastic containers are disposed of after use, or in other words are not part of the washing system for the glass bottles. Afterwards the oil is distributed to a wholesaler where the oil is unpacked and delivered on roll containers.

Once in the store, the rapeseed oil is tapped into glass bottles. These bottles are produced in Germany, distributed to the store, and sold to the consumer. Consumers can bring their own packaging as well, which is illustrated as a theoretical scenario in Figure 17. After being used, the bottles are brought back to the store and the customer is reimbursed for the initial glass bottle cost (a deposit system). The bottles are washed in an industrial dishwashing machine, and reused. For the main analysis, it was assumed that each bottle was reused 15 times before being sent off to recycling. This value is an assumption and cannot be seen to perfectly represent the system, which is why many different values are calculated, see Figure 17 and Figure 18.

5 Results

Initially, the results from the life cycle assessment are presented in this chapter. The tables are accompanied with shorter descriptions. A more in-depth analysis, including sensitivity analysis and the comparison to food production and waste, is found in chapter 5.6 and 5.7. Lastly, a few chosen results from the survey are presented with a short description. For the full results of the survey, see Appendix B. Throughout this chapter, the values for eutrophication (freshwater, marine, and terrestrial) are often shown as an average between the three categories. This choice was taken to make diagrams and tables easier to read. This approach has only been applied to relative values, for instance comparing the impact from freshwater eutrophication between the production of food and the packaging itself. The different units between the three categories are therefore not in conflict as the categories are evaluated against the same, and only the dimensionless relation is aggregated.

5.1 Packaging consumption per functional unit

5.1.1 **Packaging material consumption for oats**

Oats – Package free	***Weight (kg)***	***Relative amount of packaging (%)***
Paper (primary)	0,0205	101
Corrugated board box (secondary)	0,000246	1
Plastic film (secondary/tertiary)	0,000922	183
Oats – Conventional		
Paper (primary)	0,0202	100
Corrugated board box (secondary)	0,0444	100
Plastic film (tertiary)	0,000504	100

Table 8: Quick overview of the amount of packaging material used in each system for oats. The relative amount is illustrated in percent compared to the conventional model.

In Table 8, the amount of packaging material in kilograms is illustrated for both systems. For readability, the relative use is shown in percent, showing how much or less the package-free model uses compared to the conventional model. The package-free model only uses corrugated board box for transporting the small paper bags to the store, which explains the low contribution. Since they transport larger, paper sacks, more shrink film is used to stabilise the pallet. The conventional model uses corrugated board boxes, resulting in less film being required to maintain stability in the lorries.

5.1.2 Packaging material consumption for rapeseed oil

Rapeseed oil – Package free	***Weight (kg)***	***Relative amount of packaging (%)***
Glass (primary)	0,047822	-
PET (primary)	0,033199	56
Corrugated board box (secondary)	0,017774	68
Plastic film (tertiary)	0,000680	81
Rapeseed oil – Conventional		
PET (primary)	0,059356	100
Corrugated board box (secondary)	0,026000	100
Plastic film (tertiary)	0,000844	100

Table 9: Quick overview of the amount of packaging material used in each system for rapeseed oil. The relative amount is illustrated in percent compared to the conventional model.

As for the case of oats, the relative percentage of package-free distribution of rapeseed oil is shown compared to the conventional model in Table 9. As the package-free model uses a larger PET container, the weight per functional unit is lower. At the same time, a larger amount of plastic film is required to stabilize glass bottle pallets.

5.2 Life cycle impact assessment

5.2.1 **Impact results**

Impact category	*Unit (per FU)*	*Oats - Conventional*	*Oats – Conventional without car*	*Oats – Package free*	*Rapeseed – Conventional*	*Rapeseed – Conventional without car*	*Rapeseed – Package free*
Climate change	Kg CO_2-eq	1,3E-01	7,1E-02	2,2E-02	4,5E-01	4,0E-01	2,9E-01
Acidification	Mol H^+-eq	6,3E-04	3,8E-04	1,7E-04	1,7E-03	1,5E-03	1,2E-03
Freshwater eutrophication	Kg P-eq	4,9E-05	3,7E-05	1,5E-05	1,2E-04	1,1E-04	8,8E-05
Marine eutrophication	Kg N-eq	1,8E-04	1,3E-04	4,2E-05	3,2E-04	2,7E-04	2,3E-04
Terrestrial eutrophication	Mol N-eq	1,5E-03	9,7E-04	3,8E-04	3,0E-03	2,5E-03	2,2E-03
Ionizing radiation	Kg U_{235}-eq	1,7E-02	1,3E-02	7,5E-03	8,2E-03	4,1E-03	2,8E-02
Ozone depletion	Kg CFC-11	8,9E-06	9,2E-09	3,2E-09	8,9E-06	1,8E-08	2,0E-08
Photochemical ozone formation	Kg C_2H_4-eq	4,5E-04	2,6E-04	1,1E-04	1,1E-03	9,0E-04	7,4E-04
Particulate matter	Kg $PM_{2,5}$	1,1E-04	6,6E-05	4,1E-05	2,2E-04	1,8E-04	1,4E-04

Table 10: Summary of the total impact assessment for all system models

In Table 10, a summary of all life cycle assessments is presented, including both a scenario with and without car transport to the final consumer, as this stage accounts for a large share of the total impact of the system. The value for each impact category is in their respective unit of measurement, which is described in Table 2.

5.2.2 **Impacts per packaging activity**

In Figure 14 and Figure 15, the impact per activity is shown. The references, such as OC1, refer to the system boundary diagram in chapter 4.1. Eutrophication is shown as the average between the values for freshwater, marine and terrestrial, which is for readability purposes only. The values below do not include the car transport between the retail store and the consumer.

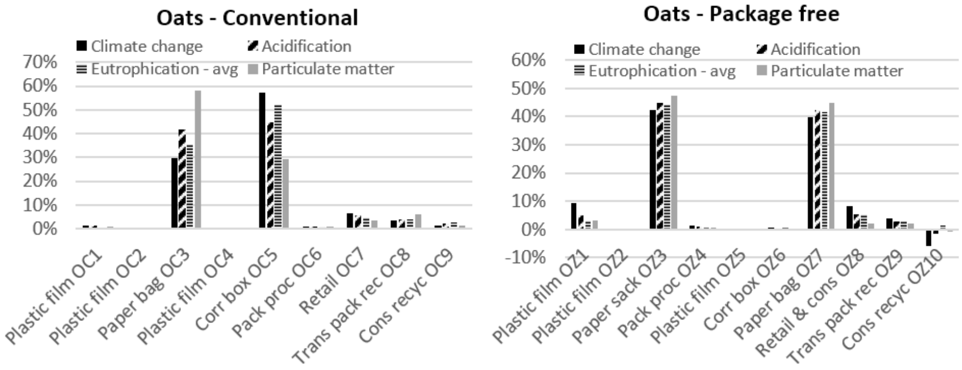


Figure 14: Impact per packaging activity for both oats system models

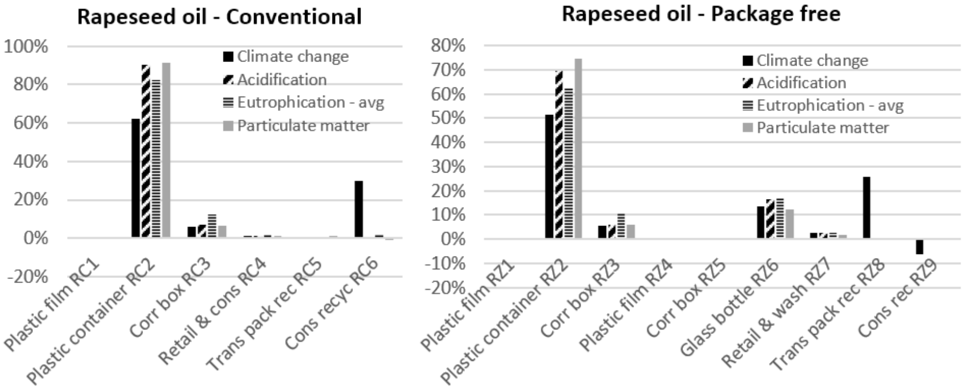


Figure 15: Impact per packaging activity for both rapeseed oil system models

5.3 Theoretical scenarios

Impact category	*Unit (per FU)*	*Oats – Theoretical, conventional*	*Rapeseed oil – Theoretical conventional*
Climate change	Kg CO_2-eq	6,7E-02	4,0E-01
Acidification	Mol H^+-eq	3,6E-04	1,5E-03
Freshwater eutrophication	Kg P-eq	3,6E-05	1,1E-04
Marine eutrophication	Kg N-eq	1,2E-04	2,7E-04
Terrestrial eutrophication	Mol N-eq	8,8E-04	2,5E-03
Ionizing radiation	Kg U_{235}-eq	1,5E-02	3,8E-02
Ozone depletion	Kg CFC-11	8,6E-09	2,2E-08
Photochemical ozone formation	Kg C_2H_4-eq	2,4E-04	9,0E-04
Particulate matter	Kg $PM_{2,5}$	6,4E-05	1,8E-04

Table 11: Values for the conventional, theoretical scenarios of oats and rapeseed oil, used as a baseline for comparison with different theoretical, package-free scenarios.

In Figure 16, the different package-free scenarios are compared to the theoretical, baseline scenario, with difference in impact shown for each category. The first category, PF baseline, refers to a scenario where previously mentioned categories have been normalised, but no other adjustments have been made. For the 50 % fill rate scenario, it is assumed that the customer only fills the paper bag half-full compared to the capacity measured at the package-free store. The last scenario considers the case where the customer brings a separate container, for which no environmental burden has been awarded. This is to consider as a best-case scenario, where a customer finds an old jar and reuses it indefinitely. This is just a theoretical case and could reasonably not be replicated in a real context, but shows the theoretical, maximum benefit of the system in its current state.

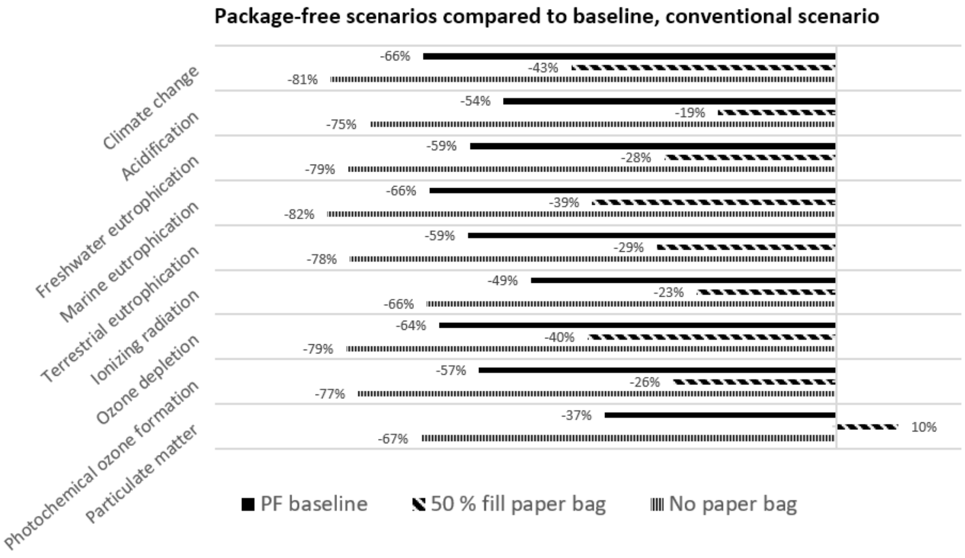
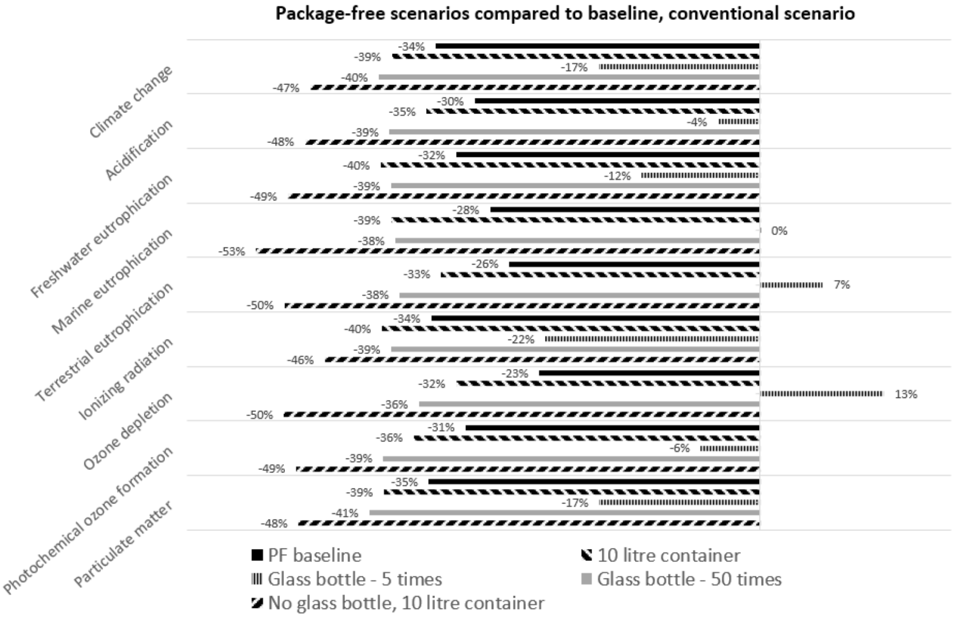


Figure 16: Theoretical scenarios compared to the theoretical, conventional scenario for oats

The rapeseed oil scenarios share several categories as both systems have the same rapeseed oil supplier. In these cases, the transport distances have not been normalized as they already were the same.

The different theoretical scenarios for rapeseed oil are displayed in Figure 17. As with the oats, the PF baseline refers to a scenario where parameters have been normalised but no further adjustments have been made. The first scenario considers replacing the 5-litre plastic container with a 10-litre. The two following scenarios consider different re-usage rates for the glass bottle in the store, where the zero-waste baseline has assumed 15 cycles before recycling. The last case is to be considered a best-case scenario, where the glass bottle is reused 50 times, and the plastic container has been replaced with a 10-litre one.



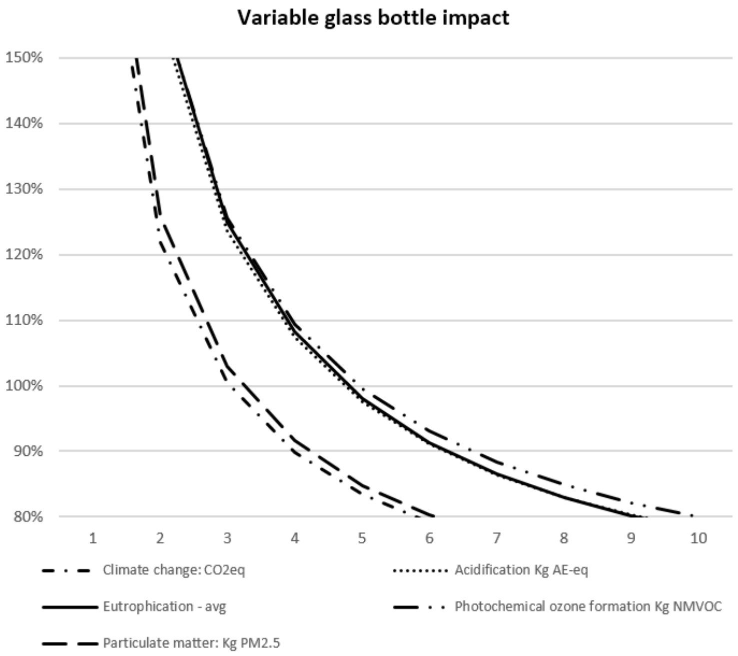
Note: The original modelling of glass bottle assumes 15 usages.

Figure 17: Theoretical scenarios compared to the theoretical, conventional scenario for rapeseed oil

In Table 12 and Figure 18, a more in-depth analysis of how the amount of usage cycles of the glass bottle affects the overall performance of the system.

Impact category	***Value***	***Relative to conventional scenario***
Climate change	0,74	185%
Acidification	3,7E-03	248%
Freshwater eutrophication	2,3E-04	204%
Marine eutrophication	7,2E-04	270%
Terrestrial eutrophication	7,8E-03	303%
Ionizing radiation	5,7E-02	149%
Ozone depletion	7,1E-08	329%
Photochemical ozone formation	2,2E-03	242%
Particulate matter	3,5E-04	190%

Table 12: Theoretical worst-case scenario for the package-free model of rapeseed oil, assuming a single usage cycle of the glass bottle before disposal.



Note: The horizontal axis shows how many times the bottle is assumed to be reused.
Figure 18: Theoretical package-free impact compared to conventional, setting glass bottle reuse as a variable.

In Table 12, we see that the worst-case scenario when the bottle is not reused at all but only bought once and then disposed of results in about two to three times increase in overall impact. As the glass bottle is reused, the impact per functional unit decreases, as shown in Figure 18. For the impact categories climate change and particulate matter, we see that the package-free model outperforms the conventional model after three or four use cycles, whereas for acidification, photochemical ozone formation and eutrophication, we find a threshold to be at five use cycles.

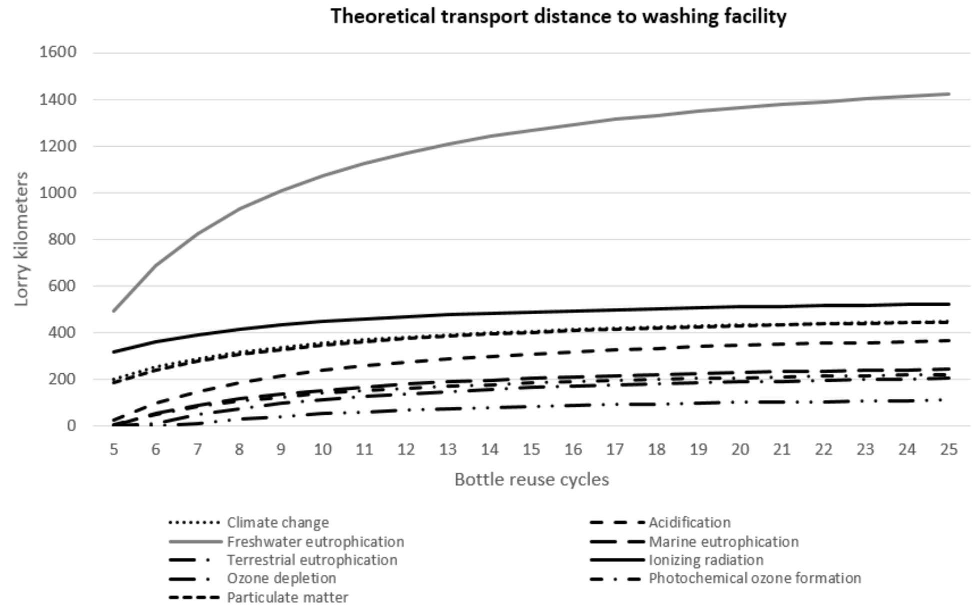


Figure 19: Theoretical point of break-even between conventional and package-free assuming a centralised washing facility, equalising the models' impact with transport distance as variable.

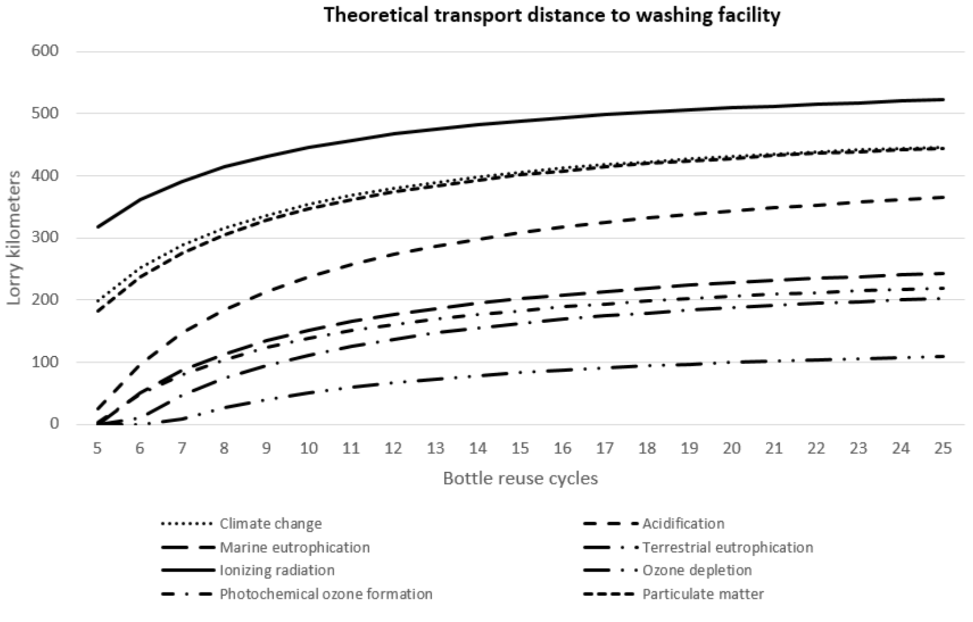


Figure 20: Same figure as Figure 19 but with freshwater eutrophication omitted for clearer scaling.

Finally, Figure 19 and Figure 20 illustrates what would happen if we assume a centralised washing facility in place of the in-store solution found here, and when the emissions from transporting the glass bottle back and forth to this washing station are equal to the emission reduction achieved by adopting the package-free model. In our baseline scenario, we assumed 15 use cycles. This means that depending on which impact factor we look at, the conventional model will outperform the package-free model if the washing facility is placed further away than between 100-500 kilometres or 1200 kilometres for freshwater eutrophication.

5.4 Completeness check

All packaging materials have been modelled from cradle to grave, and no material flows have been missed.

For both oats systems, no reliable data could be obtained for the paper bag production process, and it has therefore not been included in the analysis. The impact from the paper bag is therefore slightly higher in reality than what is presented in this study, both due to the omitted production processes and that the amount of paper material required to create one bag most likely is higher as not all packaging paper material is utilised during the paper bag production process.

As the process is excluded for both systems, the possible difference from different paper utilisation between the paper bag (conventional) and the paper sack (package-free) is assumed to be negligible.

For the package-free rapeseed oil system, primary data is missing for several different packaging processes. Firstly, the entire production and packaging process have been modelled based on a different rapeseed oil provider. This could affect the outcome of the impact results for the system itself, but for the comparison between the systems it rather enhances the results as the comparability between the systems increases. Secondly, all upstream processes from the Berlin packaging glass wholesaler have been approximated. It is not known if any relevant material flows have been missed. These processes have been modelled based on the primary data obtained from other companies throughout this study, and the comparability is assumed to be good. Typical values estimated or calculated are the amount of shrink film needed to wrap a pallet or how many corrugated board boxes fit on a pallet.

5.5 Toxicity analysis

For most processes, the conventional and package-free models use identic, generic data from Ecoinvent in different amounts. Within these processes, a qualitative analysis of toxicity would be too complex to perform for this study.

The main difference between the systems is the washing procedure at the package-free retail store. The store uses a dishwasher detergent marked with Ecolabel (European Commission, 2014). If a detergent complies with these criteria, it restricts both chemical usage in the product itself as well as in the production phase. Furthermore, an upper limit exists for how much chemicals can be used per wash cycle. Because of this, it is unlikely that the package-free model includes toxins that would make it less desirable than the conventional model.

5.6 Sensitivity analysis

5.6.1 Conventional oat system

As shown in Figure 14, the secondary packaging is a larger contributor in several impact categories compared to the primary packaging. This raises the question if the results are bound to an unnecessary inefficiency at the studied company and whether it is applicable for oats distribution in general. But when the amount of packaging is minimised for primary packaging, producers may have to increase the secondary packaging to ensure stability during transport.

The contribution relates to the production of the paper bag and the corrugated board box, with plastic film contributing to a far smaller share. A main contributing factor is the car transport, and it is dependent on the assumed size of the consumer grocery bag, as this affects the allocated impact to the functional unit. The extreme case where a consumer only buys one package of oats, the car transport itself accounts for between 75%- 99% of the total impact across all categories. Due to the lack of quality in the underlying inventory, this constitutes key data, as shown in Figure 5. But since the scope of this project is to assess the difference between two supply chain models, this value is of less interest as it is not an inherent attribute in either system. This line of reasoning also apples for the conventional scenario of rapeseed oil.

5.6.2 Package-free oat system

The three main contributors are the plastic film that is wrapped around the oat sack pallets, the paper sack itself, the distribution to the retail store and the paper bag from the French provider. These represent up to 95% of the total impact of this system. The values are not sensitive to change. A 30% increase for each of these three parameters results in an overall increase of 26% for the parameter climate change, and similar values for the rest of the impact categories.

5.6.3 Conventional rapeseed oil system

As for the case of oats, the results heavily depend on the car transport to the consumer. However, the packaging in the rapeseed oil system is larger than the impact of oats, which means that the relative impact of the car transport is lower for rapeseed oil than for oats. This is because the same assumptions have been made regarding car transport for both systems, and as the impact is higher for rapeseed oil, the relative impact of the car transport becomes lower.

Across most impact categories, the most important factor is the plastic bottle, with production and incineration making up between 50%-90% of the total impact across all impact categories except ozone depletion. Both the inventoried information about the bottle itself and the underlying datasets are of good quality, both in representativeness and timeliness.

5.6.4 Package-free rapeseed oil system

As seen in Figure 15, the impact is slightly more evenly distributed between different processes for the package-free rapeseed oil system. The production of the plastic container sticks out, but both the corrugated board box for the plastic container as well as for the glass bottle contributes about 5 % each, and the glass bottle slightly over 10 %. For these values, the information is directly measured at the retail store and the rapeseed oil provider, and the generic data is of good quality.

The performance of the system largely depends on how many times the glass bottle is reused. This is illustrated in Figure 18, showing where the package-free system reaches break-even, and in Figure 17, where both a scenario without the glass bottle and one with 50 usage cycles is assumed. No quantitative data could be obtained about how many times customers reuse the glass bottle, but the sensitivity analysis has considered many possible scenarios.

5.7 Impact compared to the food production

5.7.1 **The percental impact of packaging**

In Table 13, a summary of previous life cycle assessments of oats and rapeseed oil is presented. As the studies partly use different impact assessment methodologies, it is not possible to directly translate the results from this study to the results presented in the table since one would be required to perform unit conversion first. See notations provided in the table.

Sources	***Climate change***	***Acidification***	***Eutrophication - average***	***Ionizing radiation***	***Ozone deletion***	***Photochemical ozone form.***	***Particulate matter***
Impact of 1 kg oats							
(Nielsen, et al., 2007)[c]	0,57	0,006[b]	0,033[b]			2,2E-04	
(Nielsen, et al., 2007)[ac]	0,39	0,0064[b]	0,046[b]			2,5E-04	
(Nielsen, et al., 2007)	0,66	0,007[b]	0,017[b]			3,0E-04	
(Ecoinvent; Mouron, P, 2016)[c]	0,714	0,093	0,144	0,03	3,4E-08	0,003	0,002
(Tynelius, 2008)	0,74						
(Hille, Solli, Refsgaard, Krokann, & Berglann, 2012)	0,522						
Proposed value	***0,5***	***0,093***	***0,144***	***0,03***	***3,4E-08***	***0,003***	***0,002***
Impact of 1 kg rapeseed oil							
(Angervall & Sonesson, 2011)	1,4						
(Ecoinvent; Dauriat, A, 2016)	2,194	0,047	0,074	0,105	1,6E-07	0,01	0,002
(Schmidt, 2007)	2,39	0,026[b]	0,211[b]		1,5E-07	8,7E-04	
(Schmidt, 2007)[d]	2,17	0,024[b]	0,166[b]		1,4E-07	8,2E-04	
(Schmidt, 2007)[d]	2,79	0,029[b]	0,294[b]		1,6E-07	9,5E-04	
(Nielsen, et al., 2007)[c]	1,51	0,012[b]	0,149[b]			3,7E-04	
(Nielsen, et al., 2007)[ac]	0,95	0,011[b]	0,181[b]			4,5E-04	
Proposed value	***1,3***	***0,047***	***0,074***	***0,105***	***1,5E-07***	***0,01***	***0,002***

a) This refers to organic farming. b) These values are computed with a different LCIA methodology than used in this report. c) These scenarios do not include the refinery process, e.g. turning oats into flakes or rape seed into oil. d) These cases present results from the sensitivity analysis.

Table 13: Overview of previous life cycle assessments of oats and rapeseed oil

Both the oats and the rapeseed oil in this study are produced from organic farming, and therefore this will be assumed here as well. The results for the organic farming are not as comprehensive as those for conventional models, so an average must be assumed. For photochemical ozone formation, different sources all employ a similar LCIA model. However, as seen in Table 13, the difference between the value computed by Ecoinvent greatly differs from the other values, which must be due to an underlying methodological inconsistency. Attempts were made to correct for this but without success, which is why the value from Ecoinvent was chosen.

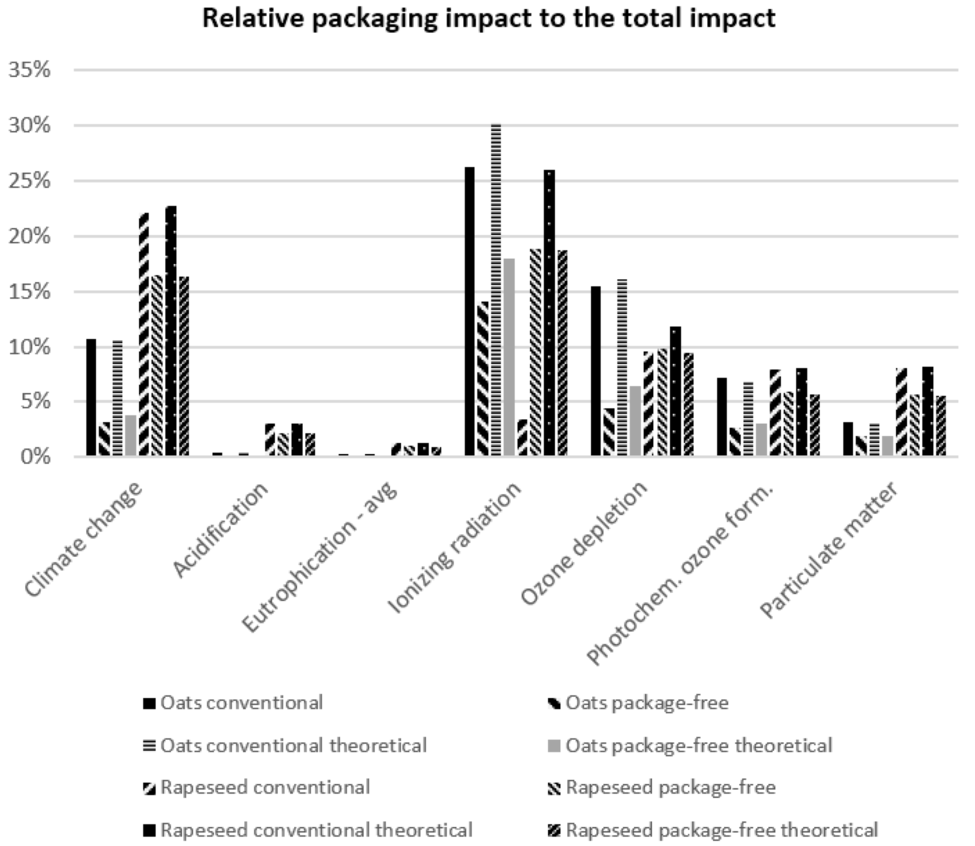


Figure 21: Comparison between packaging and food impact

In Figure 21, the impact of packaging is compared to the impact of the food product itself. The proposed values from Table 13 have been corrected with all transports that affects the food product in all different system models, e.g. modelling the transport of one kilo food product from gate to recycling.

Each bar represents a different scenario, including all baselines scenarios and all theoretical scenarios. The conventional scenarios used here are modelled without the final car transport to the consumer. For the impact category climate change, we see for instance that the production and distribution of the packaging material itself constitutes 10 % of the total impact of the food distribution for conventionally distributed oats, e.g. the production and distribution of the food product itself accounts for the remaining 90 %. Each impact category has 8 bars, each representing the different scenarios denoted below. The first four bars correspond to the oat scenarios, and the final four to the rapeseed oil scenarios.

5.7.2 Food waste generation

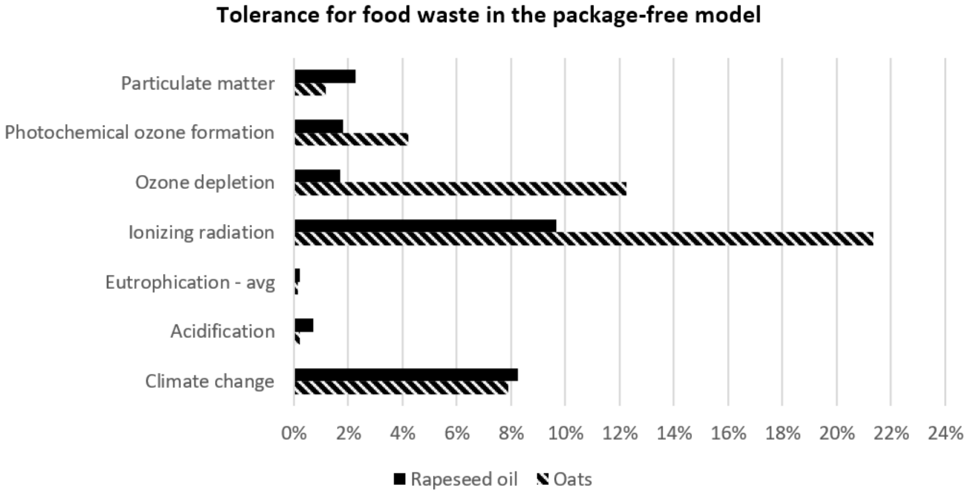


Figure 22: Overview of point of break-even between conventional and zero-waste setting zero-waste food generation as a variable

In Figure 22, a theoretical calculation is presented, where food waste was set as a variable, satisfying the equation where the conventional and package-free scenario reach break-even. As discussed earlier, it is very difficult to translate these results directly to which system is favourable. The tolerance for some categories are far higher than for others, and no methodology exists to compare them. For several categories, including acidification and eutrophication, the tolerance is almost negligible. This means that whichever system best aids in minimising food waste will be preferable to the other.

5.7.3 Possible areas for differences in food waste generation

Towards the end of the packaging process for oats, the paper bag goes through a metal detector to avoid any harmful items from reaching the end consumer. If metal is detected, the oats are disposed of. Due to the larger packaging used in the package-free system, food waste most likely increases as more oats are disposed of when metal is detected. At the same time, the smaller paper bags used in the conventional model may increase food waste in the distribution as the larger packaging uses more robust packaging paper, according to the employees working with warehousing and distribution.

At the studied package-free retail store, oats are first refilled from the paper bag into the gravity dispensers, which could amount in smaller losses. Then, the oats are again refilled into the final consumer packaging. If the consumer fills carefully, no waste should occur at this stage, but it is a sensitive system as some product easily ends up on the floor. If we disregard product damage during distribution, food waste for dry products is most likely slightly higher when using gravity bin dispensers than conventional, disposable packaging. This issue could be alleviated through packaging innovation, designing larger packaging tailor-made to fit into gravity dispensers, thereby eliminating the need for repackaging.

For the oil, no difference during production was observed between larger or smaller plastic containers. In the store, the oil is stored at ground level and pumped up through a dispenser. It is unclear which level of utilisation is obtained with this model, e.g. how empty the plastic container is once emptied. This problem might multiply as the oil is repackaged several times. As some oil remains in the packaging even after emptying, repackaging it several times may increase this amount, as some oil remains in every container.

5.8 Selected survey results

A few chosen results from the survey are displayed here. For a full summary, refer to Appendix B.

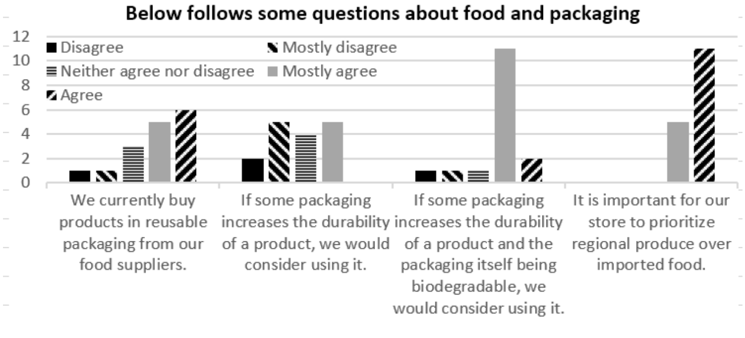


Figure 23: Overview of Likert questions used.

Figure 24: Overview of product categories offered by the retail stores

5.9 Analysis of survey results

Despite efforts to zero in on package free stores, five out of sixteen stores did not identify themselves with a concept where packaging is entirely excluded, but rather that they mostly offer package free foods with few items packaged.

In general, the results show that the package-free concept is not unified, and stores differ both in terms of ideology and how their respective store operates.

5.9.1 **Store operation procedure**

The concept found at the Danish zero-waste store is not applicable for the package-free/zero-waste concept at large. Different answers are given to almost every question.

The deposit system analysed in this study only applies to eight stores, even though fifteen stores offer oils and vinegars. This is not the case for oats, where all respondents answered that they use gravity dispensers.

The supply chain model differs between different stores. In this study, it has been assumed that the store buys food from a wholesale agent. This model cannot be generalised as seven stores state that they buy food directly from the farm, and six stores employ a combination between wholesalers and farmers. In terms of transport packaging, the majority state that they buy most or all food in reusable packaging from their suppliers, unlike the disposable packaging solution found in this model. The food product itself also differs, as some stores only sell organic produce, whereas others also sell conventionally grown produce.

Regarding the conflict between food and packaging waste, stores have different opinions whether to use packaging to increase shelf life. Stating that the packaging is made from bio-degradable material makes the stores more positive towards it. This raises the question if the store concept is based on avoiding inorganic materials such as plastics, but are not ideologically opposed to bio-based packaging if it promotes environmental benefits.

Finally, to solve the issue with food waste of animal products, one store states that they only sell dried or salted products of fish and meat.

5.9.2 Values and ideology

The most preferred label for the store concept was ‘unpackaged store’, but different stores preferred different labels and it does not seem as if they are unified under a common label. In general, no strong correlations or clear patterns could be identified when studying the individual responses.

For some stores, it is important to remain vegetarian, whereas others offer animal products. Not all stores strive towards only offering organic produce and some aim at offering most products offered by conventional stores whereas others do not. It seems as if most stores prioritise locally produced food, as all mostly agreed or agreed that this is important.

6 Discussion

6.1 Previous work

Nessi, Dolci, Rigamonti & Grosso (2016) looked at other dry products than oats. They found that for pasta, the waste prevention scenario did not result in any major savings. For breakfast cereals and rice on the other hand, larger savings were found. In this study, savings were found for the theoretical package-free baseline in the order of 40-60 %. This can be compared to the savings found by previously mentioned authors, where waste prevention scenarios for breakfast cereals lead to net savings of 60-80 %. This difference likely exists because the breakfast cereals are packed in a plastic bag inside a carton box, meaning that more, and more resource demanding packaging is required compared to a single paper bag analysed in this study.

For rapeseed oil, the results from this study are not as strong as those found by Cleary (2013), where refillable glass bottles are evaluated in Toronto. Cleary assumed 15 usage cycles of the refillable glass bottles, making the results from this study comparable. Here, we found potential savings for most impact categories around 20-30 %, whereas Cleary calculated net savings of about 80 %. This can be explained as Cleary compared a refillable glass bottle to a conventional single use glass container, instead of a single use plastic container evaluated here.

As we saw in Table 7, as journey distances increase, single use containers tend to be preferable to reusable alternatives (Capuz Rizo, 2005; Vogtländer, 2004). Previous studies showed that return systems perform well when journey distances do not exceed around 200 kilometres. In this study, we found that for most impact categories, journey distances that exceed 400 kilometres renders a single-use system preferable compared to reusable solutions for almost every impact category, and for some categories even at distances of 100 kilometres. This relates directly to the weight of the container used for the reusable distribution. If the glass bottle in this study would be replaced with a reusable, plastic solution, one could expect a higher tolerance for farther journeys between the store and the washing facility, but this has not been analysed.

Pagani, Vittuari & Falasconi (2015) also concluded that reducing packaging for pre-packed salad would lead to large environmental benefits. However, as mentioned earlier, none of these studies account for the conflict between packaging and food waste. In this study, the relative impact between packaging and food production is illustrated and the emission savings are put in context. The results show that even for rolled oats having a relatively small impact across many categories, the relative impact of packaging is small. If we were to extrapolate these results to other dry products having higher emissions, the tolerance for food waste would be far smaller. If the results from this study are applicable to rice, studied by Nessi, Dolci, Rigamonti & Grosso (2016), even one or two percent increase in food waste would make the conventional model preferable (Kasmaprapruet, Paengjuntuek, Saikhwan, & Phungrassami, 2009).

6.2 A zero-waste retail store framework

The survey, despite receiving few responses, shows that the package-free concept is used in different ways by different stores. This is in line with the results found by Beitzen-Heineke, Balta-Ozkan & Reefke (2016), where seven interviews with store owners were conducted.

In chapter 3, the existing base of knowledge was presented. We could see that no framework or conclusion could be valid for all different products, and many results depend on the system boundaries, geographical location, how the authors award credit of substitution and which heterogeneity exists for similar product categories. This limitation also applies to this study, and a framework setting out to provide an answer to which distribution model minimises waste generation for all products is not feasible. However, throughout the literature, a few overarching results have been identified and have been translated into a framework, hoping to give general guidance to practitioners in mitigating waste and minimising climate impact.

6.2.1 **The framework**

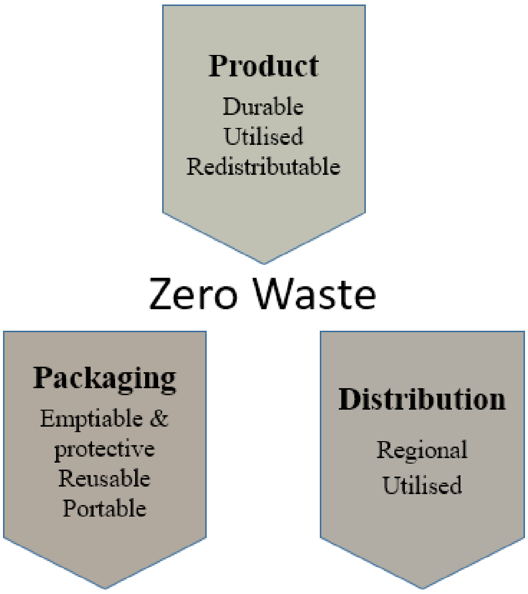


Figure 25: Proposed framework for zero-waste in the food industry context. No strict hierarchy exists, neither between the three areas or the properties within.

By combining the results from the literature review and a few results from the survey, the framework presented in Figure 25 is recommended as a standard for the zero-waste retail stores.

The framework consists of three categories: product, distribution, and packaging, and relates to how both avoid waste and minimise emissions for each of these three areas. Within each of these categories, different properties have been identified. For each category, no strict hierarchy exists between the different properties, yet an attempt has been made to order them in terms of importance. If we look at packaging, being emptiable and protective, which mitigates food waste, is arguably more important than the packaging being portable and optimised for a return-based distribution model. The same line of reasoning applies to the product, that a durable product that does not generate food waste is more important than an efficient handling of food surplus that should not have existed to begin with. However, this order does not always make sense. If we look at rapeseed oil, there is a large potential for the remaining oil cake to be used for human consumption instead of going to animal feed. As oil has a long durability, increasing the level of utilization may be of higher importance for this product.

This framework does not account for customer preferences in any extent, and is only intended to use as an instrument to achieve zero-waste. By applying this framework, several products usually found in retail stores would most likely be deemed inappropriate for a zero-waste distribution model. Some examples would be sensitive, fresh produce such as fresh berries or leafy greens, fresh fish, and many types of meat with short durability such as chicken or minced meat. It also does not account for customer convenience in terms of packaging when phasing out disposable packaging solutions. The results should therefore not be seen as an attempt to propose an optimal framework for the industry at large, as it excludes previously mentioned aspects. Again, the purpose of the framework is to be used by a practitioner of zero-waste, and the framework therefore promotes zero waste, regardless of convenience sacrifices.

A more in-depth description of each property of the framework and which parts of the theory section is used as a foundation follows below.

6.2.2 The product

6.2.2.1 Durable products

In line with the definition for zero waste in Table 3, creating a zero-waste framework for the food sector means that waste is avoided, not minimised. Based on the discussion in chapter 3.3.2, many products generate excessive waste despite efforts to enhance packaging design. Instead of these sub-optimised solutions, the zero-waste should in principle avoid waste by redirecting food production towards more durable processing. Some examples could be to prioritise salted or dried meat, fermented milk products or durable vegetables such as starchy roots. A liberal interpretation, in case changing the inherent property is not an option, is to properly evaluate the different distribution options for the food product itself. An example is minced meat which would benefit from being sold frozen instead of fresh. Instead of selling a waste-generating product, the industry should design products to last and minimise waste through their inert properties instead of mitigating damage with packaging innovation.

6.2.2.2 Utilization of food production

In chapter 3.1.2, eco-effectiveness and the importance of upscaling products was discussed. For food products, this means both avoiding unnecessary waste and to capture as much (environmental) value of each product as possible. Some examples include waste from the disposal of unaesthetically looking produce, or by upcycling bi-products. An example of upcycling is for rapeseed oil production. The rapeseed cake that remains is high in nutrients and viable for human consumption, but is today mostly used as animal fodder. The grade of utilization is far greater if the rapeseed cake goes directly to human consumption than passing through animals, and this should be considered for the zero-waste practitioner. To achieve this, the suppliers to zero-waste stores must reverse their value proposition thinking. Instead of farming to create a certain product - such as an orange, straight carrot – the farmer should consider what he or she grows and which portfolio of products would optimise the utilization level of the entire yield. An example could be by offering fresh, fermented and pureed carrots as the value proposition.

6.2.2.3 Redistributable food

As we saw in the framework developed by Eriksson (2015), it is important to create food which is redistributable in case it cannot be sold. It is difficult to imagine a cradle-to-cradle mindset for food products as they are consumed and naturally downgraded, but the core value of cradle-to-cradle is to minimise downcycling of products. Therefore, utilisation principles based on biogas recycling should as far as possible be avoided in favour of economic valorisation, conversion, or donation, as argued in chapter 3.3.2.2. This means that a trade-off between packaging and redistributable design must be performed. If donation is used as a food surplus handling method, using packaging may reduce food waste generation during this stage.

6.2.3 **The distribution**

6.2.3.1 Regionalize food and packaging sourcing

Every store responded that prioritising regional food is important to their business concept. This is also in line with the zero-waste theory, as discussed in chapter 3.1. By regionalizing the supply, municipalities can better control which waste enters their waste streams and work towards directing these practises in a more sustainable direction. As discussed in chapter 3.3.3, transport distance is the critical success factor for any reverse logistics implementation. By regionalizing the supply, we can avoid a solution where reversed logistics would result in greater emission than a single-use model. This assumes a theoretical case where even transport packaging is reusable, making it sensitive to transport distance. For the retail store studied here, this parameter is of less importance as they use disposable transport packaging.

6.2.3.2 Utilize optimised load capacity

As discussed in chapter 3.3.2.1, driving back and forth to farms to buy small quantities is sub-optimised compared to a larger, mass distribution of food. If retail stores source food locally and solve the logistical challenges by several, small-scale transports to and from farms, this will result in higher emissions and invalidate the usefulness of the zero-waste concept. Therefore, the logistics should be characterised by large vehicles with maximised load factors. This is directly applicable at larger stores, whereas smaller stores will be bound to resolving this issue with synergistic solutions to combine their demand into larger logistical systems.

6.2.4 **The packaging**

6.2.4.1 Emptiable and protective

The core purpose of packaging is to protect the product, and the agreement for this is strong in all literature, including the zero-waste theories. Packaging should protect the product and minimise any spoilage during storage and transport.

Another key aspect is to design emptiable packages. Because the zero-waste model includes more packaging stages between producers and consumers, it is vital that no additional waste occurs in these transition stages. The packaging should therefore be designed to make it entirely emptiable. An example is the refill solution employed at the Danish store studied here. As customers refill their own packaging from a larger, plastic container, it's vital that all rapeseed oil is emptied. As discussed in chapter 5.7.2, a theoretical break-even point can be calculated between the conventional and zero-waste case where the conventional is preferable due to the increase in food waste for the zero-waste model. By designing packaging that is entirely emptiable, this problem can be mitigated.

6.2.4.2 Reusable with material harmonisation

Eleven stores identified themselves with the ambition to entirely free their store from disposable packaging, while 5 claimed they also offer a few items in disposable packaging. As discussed in section 3.1, material should be downcycled as little as possible, which is not the case of disposable packaging. The containers should be designed to last for as long as possible. But inevitably, these containers will eventually end up in material recycling. As shown in chapter 3.3.2.2, mixing packaging material decreases the grade of recyclability. To overcome this issue, packaging should be homogenous in terms of material choice, so that once it is sent to recycling, it can be recovered through closed-loop recycling, per Table 6.

6.2.4.3 Portable

Lastly, the packaging should be portable. This means that it is weight efficient and minimises emissions from transport. As discussed in chapter 3.3.3, a zero-waste concept will be characterised by reverse logistics. This means that packaging should not only be light, but also portable in terms of the opposite transport route. Some examples of this could be to design foldable packaging, which once used can be transported back to the supplier at a low cost.

6.2.5 **Package free or zero-waste**

It is unclear how to interpret the term ‘package free’, as no previous literature addresses this. If a store reduces packaging without considering all aspects covered in the zero-waste framework in Figure 25, emissions will likely be higher than with a single-use packaging model. However, it is not known how closely related stores identifying themselves as package free are to the zero-waste framework presented here. The zero-waste framework presented above is based on many previous articles and provides a model that standardises the store concept and ensures reduced emissions. If the stores identify themselves with this framework, it would reduce ambiguity and make it easier for customers to know what they are buying into if it was adopted.

6.3 Combining models

Answering how package-free stores operate around the world is not possible due to the few responses from the survey. Little can be said about which positive and negative aspects exist when stores adopt this model, as only a few earlier studies have been found, and that the results from this study are not translatable to other store concepts. The discussion that follows will therefore relate to how retail stores can benefit from combining the zero-waste approach with a conventional model.

6.3.1 **Impact results**

Under the condition that food waste is not increased, the potential savings for oats exist. The packaging constitutes roughly 5-10% of the total impact of the product, and few indicators of an increase in food waste have been identified. If we account for a change in user behaviour towards employing reusable packaging, the net savings for the product itself is close to 9%. Based on the review of previous studies in Table 5, the results are consistent with several different dried products, and probably consistent for most dry food offered in conventional stores. The savings on a store level are therefore significant. However, the tolerance for food waste is most likely much lower for products with a higher impact profile, which makes this model more suitable for products with a low environmental burden.

It is not known if a package-free or a conventional distribution model leads to less food waste. If no indicators exist that the food waste would increase by adopting a system with gravity dispensers, it would be sensible for the industry to adopt it and redesign their current packaging model as it at least can be concluded that emissions are reduced from packaging. This conclusion is restricted to the environmental perspective and fails to regard the economic incentive. As single-use packaging is the dominant solution found on the market, a ‘bias-of-the-present’ exists, transitioning the burden of proof to the zero-waste model. This is because the economic cost of a transition must be motivated by an actual increase in environmental performance to be motivated. In other words, had no existing system been in place, food waste generation for both systems been unknown and no indicators that a conventional model would generate less waste than a package-free model existed, the package-free model would be preferable.

For liquids, the results are more inconclusive. Firstly, the model is sensitive to glass bottle reuse, and if customers do not properly return glass bottles to be washed, the system results in large net losses in environmental performance. Secondly, if larger retail stores adopt the cleaning model, they will likely implement a centralised solution. This is then sensitive to the distance to the washing facility. If the one-way transport distance from store to washing facility exceeds 300-400 kilometres, it is better to keep the existing packaging solution. Lastly, due to the viscosity of oil, several other product categories are more suitable for a refill solution as the packaging will be easier to clean and better emptied. If a store were to adopt this, it is recommended to start with thin liquids such as vinegar and evaluate the performance before trying to implement it for thicker fluids as oil.

The survey illustrated that several stores offer milk products, fish, and meat, which is consistent with earlier findings discussed in chapter 3.4. Also, discussed in the theory chapter is how packaging can mitigate food waste for high-impact products such as meat. Many previous studies show that through improved packaging technology, the amount of food waste for meat can be reduced, and the emission savings from this are far greater than what can be achieved by reducing packaging, as it constitutes a very minor share of the total impact. By restricting the transitioning towards package-free products to densely packed, dry products with low environmental impacts and keeping packaging for other product categories, this conflict can be overcome.

6.3.2 Pragmatic evaluation of relative packaging impact

A common misconception of an optimised distribution of food is to confuse relative impact to the total impact of the distribution model instead of comparing different improvements’ relative weight to each other. It is therefore misleading to state that because packaging constitutes a small share of the total impact of the system, we can disregard potential savings from reducing the packaging amount. This is because we are comparing what can be improved with what cannot, creating a biased foundation for decision-making. Instead, we can find out the relative impact of packaging by summarising all potential savings in the entire life cycle of the food product, excluding all impacts that cannot be reduced, or only to a small degree to a very large cost.

What does this mean in practise? If we consider the results from Figure 21, the relative impact for oats in the conventional scenario is somewhere between 0.5%-25%, depending on impact category. These numbers do not give us the actual room of improvement for this system. Reasonably, we cannot eliminate impact from packaging and distribution entirely, as the oats need to be produced, packaged in something, and then reach the final consumer. We should instead – as we've done in this study – investigate which options exist and how much they reduce the impact. If we look at our best-case theoretical scenario we saw that we could reduce many impact categories by about 80%. This number must then be put in relation to which improvements exist in terms of production and food waste mitigation. Just as with packaging, we cannot reasonably eliminate the impact from the production of the food product itself, as it, to some extent, will require fertilisers, tractors, and post-harvest treatment. We must then look at which options exist to minimise these. This could be for example switching to biodiesel in the tractors. If this would, as an example, reduce the impact of climate change by 5%, we need to evaluate the relative packaging impact as an 80% reduction of packaging compared to a 5% reduction in production. Going back to our case with conventional distribution of oats, looking at relative impact between the entire impact of food production and the entire impact of packaging, the contribution of packaging is 8% for climate change. If we instead compare the two improvements discussed above, the relative impact of packaging would be 43%.

The example above is trivial, but is only intended to illustrate the purpose of justly calculating relative impact. In a real-world scenario, we would compare a packaging reduction to several other reduction measures, both in terms of production, distribution, minimising food waste and better utilising food surplus.

7 Conclusions

7.1 Research question 1

> *RQ1: Which definitions of 'zero waste' currently exist within food distribution; are they contradicting each other, and can a general definition be found which can be used as a framework for the practitioners?*

Through the literature review, the different definitions of zero waste have been presented and their contradictability is discussed. Initially, based on the theory in section 3.1, a way of interpreting zero waste is proposed and is differentiated from zero landfill and zero incineration. This core concept is the underlying philosophy of the framework presented in section 6.2. But as discussed, both in the theory section 3 and about food waste in 5.7, the minimisation of waste within food distribution is not one-dimensional and limited to packaging, but rather must encompass the entire production of food, the distribution and potential end-of-life treatment. To enhance the framework, a review of findings in previous literature in regards to waste minimisation is presented throughout the theory section. It is shown that just removing packaging material will not mitigate waste as it instead risks increasing food waste. Also, if any waste would occur, it is important to upcycle it and choose end-of-life treatments that best utilise it, such as redistributing food surplus to charity instead of sending it to biogas plants. The theory section also covers several other aspects, such as how systems of reusable packaging systems rely on short distribution distances to be preferable. The framework does not claim to provide an answer to which model of distribution is optimal for every food product. It rather provides general advice to the practitioner based on general situations. It is entirely possible that for a certain product, the critical distance of the returnable packaging system is much higher than discussed here. But for the general case, minimising the distance of the return-trip will often help ensuring that the returnable system does not become suboptimal to a disposable alternative.

In short, the framework guides practitioners in designing a retail-store concept that minimises waste as much as possible while still admitting that it cannot provide a perfect answer for every food product and must be accompanied with more in-depth studies of specific products to give guarantees.

7.2 Research question 2

> *RQ2: For rolled oats and cold pressed rapeseed oil, what is the difference in environmental impact between the ‘package-free’ distribution model and the conventional, packaged distribution?*

If we disregard the difference in food waste, the zero-waste distribution model show significant savings potentials for oats, but more inconclusive results for rapeseed oil.

The savings for oats are not bound to customers bringing their own packaging. Still, by bringing their own container, the savings are increased further. For oats, the impact from packaging can potentially be reduced by 60%-80% across all impact categories. For rapeseed oil, the potential savings are a bit lower, about 40%-50%. The results show us that for oats, even when customers do not bring their own packaging and use disposable packaging provided by the store, the potential savings are still around 50% for most impact categories. A case is also investigated if the customer only fills half the bag with oats, leading to a lower material utilisation and is backed up by observed user behaviour. Despite this, the package-free model is preferable to the conventional one, except for the impact category particulate matter where a 10% increase was shown.

For rapeseed oil, several weaknesses have been found, making the package-free model more questionable. It is highly dependent on customers reusing the glass bottles. If the glass bottle is not reused, e.g. it is disposed of after one use, the package-free model results in higher emissions across all impact categories. The relative impact is the lowest for ionising radiation at 150%, and highest for ozone depletion at 329%. But more importantly, the tolerance for food waste is very low for several impact categories, which combined with an uncertainty about how much oil can be utilised in repackaging stages and how much more is lost due to several containers being used, makes the conventional model the preferred choice until a more in-depth analysis of how much food waste is generated by each system is done. This does not mean that the package-free model is less preferable than the conventional one, but based on the high uncertainty of the model, conventional stores are not recommended to replace their current packaging solution as that may lead to higher emissions. Novel stores with no existing packaging solution of choice may choose between them and should prioritise the package-free model if they can monitor how many times the glass bottle is reused and which emptiness can be achieved in the repackaging stages, and compare their results to the thresholds presented in this report. If they cannot, the conventional model is likely a better option.

7.3 Research question 3

> *RQ3: In terms of environmental performance, which positive and negative aspects exist when grocery stores adopt a package-free model and in which ways could a store benefit by combining the different models?*

As no reliable data could be obtained about how the zero-waste stores operate at large, no conclusions could be drawn about which positive and negative effects exist when grocery stores adopt the concept as it is not known how the stores operate in general. Based on the few responses received, stores operated in many different ways and how the Danish store operates is not representable. The stores differ both in terms of their line of products, as other stores also offer meat, fish, frozen products, and ready-made meals, which was not the case for this Danish store. Furthermore, some stores only sourced their products directly from farms and not via a wholesaler as in this context.

Based on the results of oats and previous studies, retail stores should consider redesigning their packaging distribution of certain dry products. The focus should be on densely packed products with a low environmental impact, and especially those using excessive packaging solutions at present. This means that products such as rice should be excluded, as even the slightest increase in food waste would make the savings from reduced packaging redundant. For this transition to be successful, retail stores should keep a close dialogue with producers and enable a system where larger packaging are designed to fit into gravity containers in the store, thereby eliminating the stage of repackaging and by that minimising the risk that food waste is increased. The possibility to use reusable packaging even at the supplier stage has not been addressed in this study, but based on the results of rapeseed oil, it is most likely bound to short return distances and is therefore not suitable for exotic products.

For rapeseed oil, the results are not strong enough to support a shift to a package-free model. More longitudinal studies need to be done, both evaluating how many times customers reuse the glass bottles, and how the shift to a zero-waste model affects food waste generation.

If zero waste becomes an emerging concept, retail stores may have to position themselves towards it as customers may demand it. The zero-waste framework presented in section 6.2 serves as a good start for understanding what zero waste means in a food context. The framework can be used as a foundation for communicating the zero-waste values to the consumers, and make them aware of the trade-offs that exists between achieving zero-waste and sacrificing their convenience. As we discussed in section 3.3.2, products such as certain exotic fruits and minced meat leads to large wastage, and by communicating this to consumer, stores could shift their offers to more sustainable alternatives. In regards to the current debate about package-free distribution of food, the framework can also help communicate the complex relationship between different areas, and that each product may benefit most by improvements in other areas than weight reduction of packaging.

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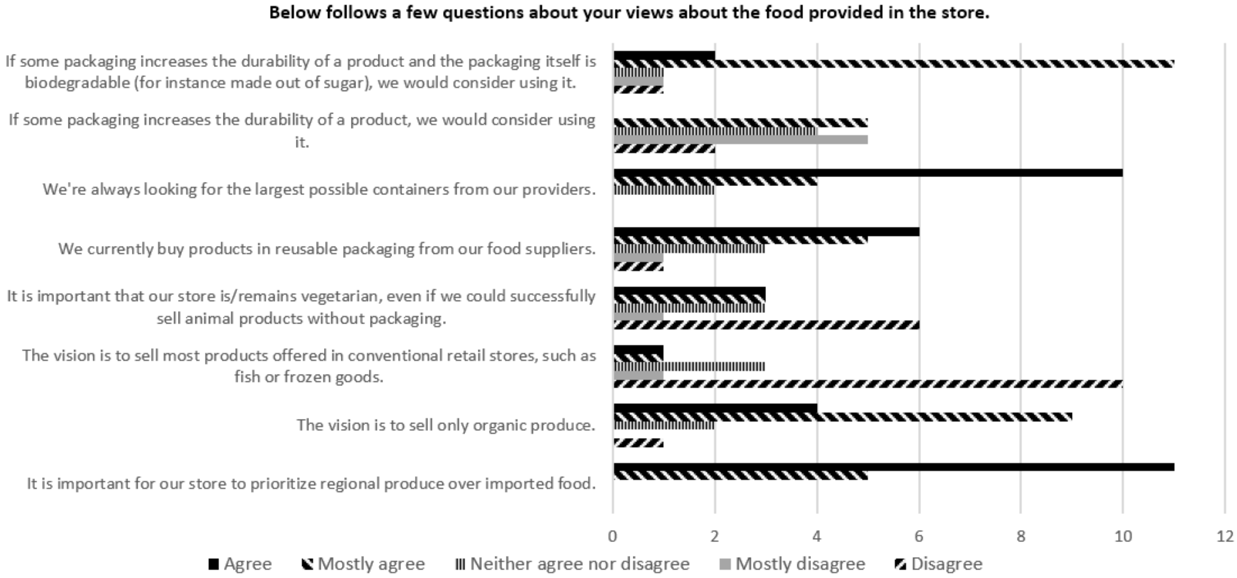
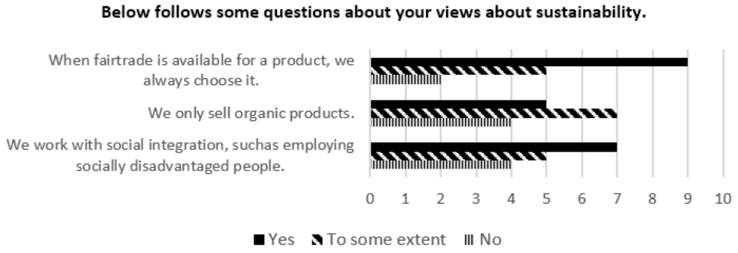
Appendix A

Question	***Possible answers***
My store aims to remove disposable packaging as far as possible, offering customers bulk food and the possibility to bring their own, reusable packaging.	Yes / No / We offer mostly unpackaged food but also sell certain food items packaged.
It is important for our store to prioritize regional produce over imported food.	Disagree / Mostly disagree / Neither agree nor disagree / Mostly agree / Agree
The vision is to sell only organic produce.	
The vision is to sell most products offered in conventional retail stores, such as fish or frozen goods.	
It is important that our store is/remains vegetarian, even if we could successfully sell animal products without packaging.	
We currently buy products in reusable packaging from our food suppliers.	
We're always looking for the largest possible containers from our providers.	
If some packaging increases the durability of a product, we would consider using it.	
If some packaging increases the durability of a product and the packaging itself is biodegradable (for instance made out of sugar), we would consider using it.	
We work with social integration, such as employing socially disadvantaged people.	Yes / No / To some extent
We only sell organic products.	
When Fairtrade is available for a product, we always choose it.	
Where do you usually buy your food from?	Wholesaler / Directly from the farm / Other
We offer a deposit system for glass bottles, where customers can bring back empty glass bottles to be cleaned by us.	Yes / No
We use gravity dispensers for selling dry goods.	
We sell dry foods in another way than gravity dispensers, such as large cloth sacks.	
Below follow some questions about waste. Fill in which waste procedures take place for each of the following waste types. • Transport package from food suppliers. • Food waste • Disposable items, such as hygienic latex gloves for food handling or similar appliances	Normal waste disposal / Donation to charity / No regular waste exists / Recycling / Biogas recycling
Which product categories does your store offer? (Multiple)	Dry foods / Oils, vinegar and other liquids / Soaps and hygienic products / Cheese or other milk products / Meat and/or fish / Fresh vegetables / Frozen products / Ready-made meals / Other
Below is a list of labels for the package free concept. Which one do you prefer to use for your store's concept?	Bio-based store / Zero packaging store / Zero waste store / Package free store / Unpackaged store
In your own words, how would you define the store's concept? Which are the most central aspects that makes it different from conventional stores?	Free text answer
Where is your store located?	Europe / North America / South America / Asia / Australia and the Pacific

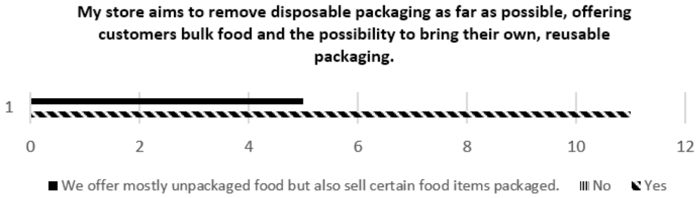
Appendix B


Below follows a few questions about your views about the food provided in the store.


Below follows some questions about your views about sustainability.


Below is a list of labels for the package free concept. Which one do you prefer to use for your store's concept? You may choose several options.


Below follows some practical questions about how your store operates.


My store aims to remove disposable packaging as far as possible, offering customers bulk food and the possibility to bring their own, reusable packaging.


Below follows some questions about waste. Fill in which waste procedures take place for each of the following waste types.


Which product categories does your store offer? (Select all that you offer)


Where do you usually buy your food from?


Where is your store located?

Appendix C

Group	***Ecoinvent name***	***Data source***	***Data quality***	***External references***
General inventory				
Pallet lifetime and storage times	EUR-flat pallet production	Gunnarshögs Gård. Literature	Primary, Theoretical	(Paletten Boerse, 2015)
Distribution to customer	Transport, passenger car, EURO4	Theoretical	Theoretical	(Svensk Handel, 2009; Sveriges Bussföretag, 2016)
Oats - conventional				
1.1 Plastic film - From Trioplast to Stenqvist				
1.1.1 Plastic film – primary	Polyethylene production, linear low density + extrusion plastic film	Stenqvist	Secondary: Saltå Kvarn	
1.1.2 Plastic film – tertiary	Polyethylene production, linear low density + extrusion plastic film	Stenqvist	Secondary: Gunnarshögs Gård	
1.1.3 Lorry distribution	Transport, freight, lorry 16-32 metric ton, EURO4	Stenqvist	Primary	
1.2 Paper bag – From Stenqvist to Saltå				
1.2.1 Kraft paper	Kraft paper production, unbleached	Saltå Kvarn	Primary	
1.2.2 Paper bag production process	Missing	Missing	Missing	
1.2.3 Corrugated board box	Corrugated board box production	Saltå Kvarn, Stenqvist	Primary	
1.2.4 Lorry distribution	Transport, freight, lorry 16-32 metric ton, EURO4	Saltå Kvarn	Primary	
1.3 Plastic film – From Trioplast to Stora Enso				
1.3.1 Plastic film – primary	Polyethylene production, linear low density + extrusion plastic film	Stora Enso	Secondary: Saltå Kvarn	
1.3.2 Plastic film – tertiary	Polyethylene production, linear low density + extrusion plastic film	Stora Enso	Secondary: Gunnarshögs Gård	
1.3.3 Lorry distribution	Transport, freight, lorry >32 metric ton, EURO4	Stora Enso	Primary	
1.4 Corrugated board box – From Stora Enso to Saltå Kvarn				
1.4.1 Corrugated board box production	Corrugated board box production	Saltå Kvarn	Primary	
1.4.2Lorry distribution	Transport, freight, lorry, 16-32 metric ton, EURO4	Saltå Kvarn	Primary	
1.5 Plastic film – From Cyklop Plast to Saltå				
1.5.1 Plastic film production	Polyethylene production, linear low density + extrusion plastic film	Saltå Kvarn	Secondary: Saltå Kvarn	
1.5.2Plastic film production – tertiary	Polyethylene production, linear low density + extrusion plastic film	Cyklop Plast	Primary	
1.6 Packaging processes – Saltå Kvarn				
1.6.1 Machine electricity consumption	Electric voltage transformation, from high to medium voltage, SE	Saltå Kvarn	Primary, Theoretical	(Beumer, 2016; Fawema; Österbergs; RobotWorx)
1.7 Distribution – From Saltå to retailer				
1.7.1 Lorry transportation, to Saltå Warehouse	Transport, freight, lorry 3.5-7.5 metric ton, EURO4	Saltå Kvarn	Primary	

Group	*Ecoinvent name*	*Data source*	*Data quality*	*External references*
1.7.2 Lorry transportation, wholesaler	Transport, freight, 16-32 metric ton, EURO4	Saltå Kvarn	Primary, Assumption	
1.7.3 Lorry transportation, retail	Transport, freight, lorry, 7.5-16 metric ton, EURO4	Saltå Kvarn	Primary, Assumption	
1.8 Transport packaging recycling				
1.8.1 Distribution to Fiskeby recycling	Transport, freight, lorry, 7.5-16 metric ton, EURO4	Saltå Kvarn	Primary	
1.8.2 Distribution from Saltå to Högdalens incineration	Transport, freight, lorry, 7.5-16 metric ton, EURO4	Saltå Kvarn	Primary	
1.8.3 Distribution from retail store to recycling plant	Transport, freight, lorry, 7.5-16 metric ton, EURO4	Saltå Kvarn	Primary, Theoretical	(Transportstyrelsen)
1.9 Recycling				
1.9.1 Lorry transport, to recycling sorting	Transport, freight, lorry, 7.5-16 metric ton, EURO5	Denmark	Secondary: Lös Market	
1.9.2 Lorry transport, to recycling & incineration	Transport, freight, lorry >32 metric ton	Assumption	Assumption	
Oats – Zero Waste				
2.1 Plastic film – From Signode to Lantmännen				
2.1.1 Plastic film – primary	Polyethylene production, linear low density + extrusion plastic film	Lantmännen	Secondary: Saltå Kvarn	
2.1.2 Plastic film – tertiary	Polyethylene production, linear low density + extrusion plastic film	Lantmännen	Secondary: Gunnarshögs Gård	
2.1.3 Lorry distribution	Transport, freight, lorry, >32 metric ton, EURO4	Signode	Primary	
2.2 Plastic film – From Trioplast to Stenqvist				
2.2.1 Plastic film – primary	Polyethylene production, linear low density + extrusion plastic film	Stenqvist	Secondary: Saltå Kvarn	
2.2.2 Plastic film – tertiary	Polyethylene production, linear low density + extrusion plastic film	Stenqvist	Secondary: Gunnarshögs Gård	
2.2.3 Lorry distribution	Transport, freight, lorry, 16-32 metric ton, EURO4	Stenqvist	Primary	
2.3 Paper sack – From Stenqvist to Lantmännen				
2.3.1 Kraft paper	Kraft paper production, unbleached	Lös Market	Primary	
2.3.2 Paper bag production	Missing	Missing	Missing	
2.3.3 Corrugated board box	Corrugated board box production	Stenqvist	Primary	
2.3.4 Lorry distribution	Transport, freight, lorry, 16-32 metric ton, EURO4	Lantmännen	Primary	
2.4 Packaging process – Lantmännen				
2.4.1 Machine electricity consumption	Electric voltage transformation, from high to medium voltage, SE	Saltå Kvarn	Secondary: Saltå Kvarn, Theoretical	(Beumer, 2016; Fawema; Österbergs; RobotWorx)
2.5 Distribution – From Lantmännen ro retailer				
2.5.1 Lorry distribution, wholesaler	Transport, freight, lorry, 16-32 metric ton, EURO4	GrönFokus	Primary	
2.5.2 Lorry distribution, retail	Transport, freight, lorry 3.5-7.5 metric ton, EURO4	Lös Market	Primary	
2.6 Plastic film – From unknown to Smurfit Kappa				
Modelled according to similar processes, ref 1.1, 1.3, 1.5, 2.1, 2,2				
2.7 Corrugated board box – From Smurfit Kappa to Tapiero				
2.7.1 Kraft paper	Kraft paper, unbleached	Lös Market	Primary	

Group	*Ecoinvent name*	*Data source*	*Data quality*	*External references*
2.7.2 Lorry distribution	Transport, freight, lorry 16-32 metric ton, EURO4	Tapiero	Primary	
2.7.3 Lorry distribution, on RoRo-ship	NTM: Transport, freight, lorry, on RoRo-ship	Tapiero	Primary	
2.8 Transport packaging recycling				
2.8.1 Distribution from Lantmännen to Fiskeby	Transport, freight, lorry, 7.5-16 metric ton, EURO4	Assumption	Secondary: Saltå Kvarn	
2.8.2 Distribution from Lantmännen to Högdalen incineration	Transport, freight, lorry, 7.5-16 metric ton, EURO4	Assumption	Secondary: Saltå Kvarn	
2.9 Recycling				
2.9.1 Distribution to recycling sorting	Transport, freight, lorry, 7.5-16 metric ton, EURO5	Marius Pederson	Primary	
2.9.2 Distribution to recycling	Transport, freight, lorry, >32 metric ton, EURO4	Marius Pederson	Primary	
2.9.3 Distribution to incineration	Transport, freight, lorry, >32 metric ton, EURO4	Marius Pederson	Primary	
Rapeseed oil – Conventional				
3.1 Plastic container – From Terekas to Gunnarshög				
3.1.1 Plastic bottle	Polyethylene terephthalate production, granulate, bottle grade + injection moulding	Gunnarshögs Gård	Primary	
3.1.2 Plastic film – primary	Polyethylene production, high density, granulate + extrusion plastic film	Gunnarshögs Gård	Primary	
3.1.3 Plastic film – tertiary	Polyethylene production, linear low density + extrusion plastic film	Gunnarshögs Gård	Primary	
3.1.4 Lorry distribution	Transport, freight, lorry, >32 metric ton	Gunnarshögs Gård, Terekas	Primary	
3.1.5 Lorry distribution, on RoRo-ship	NTM: transport, freight, lorry, by RoRo-ship	Terekas	Primary	
3.1.6 Lorry distribution	Transport, freight, lorry, 3.5-7.5 metric ton	Terekas	Primary	
3.2 Corrugated board box – From Smurfit Kappa to Gunnarshög				
3.2.1 Corrugated board box	Corrugated board box production	Gunnarshögs Gård	Primary	
3.2.2 Fibreboard	Fibreboard production, hard	Gunnarshögs Gård	Primary	
3.2.3 Lorry distribution	Transport, freight, lorry, 7.5-16 metric ton, EURO4	Smurfit Kappa	Primary	
3.3 Plastic film – From Bologna to Packteam				
3.3.1 Plastic film – primary	Polyethylene production, linear low density + extrusion plastic film	Gunnarshögs Gård	Primary	
3.3.2 Plastic film – tertiary	Polyethylene production, linear low density + extrusion plastic film	Gunnarshögs gård	Primary	
3.3.3 Lorry distribution	Transport, freight, lorry, 3.5-7.5 metric ton, EURO4	Packteam	Primary	
3.4 Distribution – From Gunnarshögs Gård to retailer				
3.4.1 Lorry transportation, to wholesaler	Transport, freight, lorry, >32 metric ton, EURO4	Gunnarshögs Gård	Primary	
3.4.2 Lorry transportation, to retail	Transport, freight, lorry, 7.5-16 metric ton, EURO4	Assumption	Assumption	
3.5 Transport packaging recycling				
3.5.1 Distribution from Gunnarshögs Gård to Sysav	Transport, freight, lorry, 7.5-16 metric ton, EURO4	Gunnarshögs Gård	Primary	

Group	*Ecoinvent name*	*Data source*	*Data quality*	*External references*
3.5.2 Distribution from retail store to recycling	Transport, freight, 7.5-16 metric ton, EURO5	Assumption	Assumption	
3.6 Recycling				
Modelled according to the Danish situation for oats, ref 2.9				
Rapeseed oil – Zero Waste				
4.1 Plastic container – From Terekas to Gunnarshög				
Identical to the conventional scenario, ref 3.1-3.2				
4.2 Plastic film – From Bologna to Packteam				
Identical to the conventional scenario, ref 3.3				
4.3 Distribution – From Gunnarshög to Lös Market				
4.3.1 Steel cage production	Reinforced steel production	Lös Market	Primary	
4.3.2 Lorry distribution to GrönFokus	Transport, freight, lorry, >32 metric ton, EURO4	Gunnarshögs Gård	Primary	
4.3.3 Lorry distribution, to Lös Market	Transport, freight, lorry, 7.5-16 metric ton, EURO5	Lös Market	Primary	
4.4 Glass bottle washing				
4.4.1 Electricity consumption	Electricity voltage transformation from high to medium voltage, DK	Lös Market	Primary	(Hobart)
4.4.2 Sodium hydroxie	Chlor-alkali electrolysis, mercury/membrane cell	Lös Market	Primary	(JVM A/S, 2015; Lahega, 2013; Ikaros AB, 2006; Althaus, Hischier, & Osses, 2007; European Commission, 2000)
4.4.3 Potassium hydroxide	Potassium hydroxide production	Lös Market	Primary	(JVM A/S, 2015; Lahega, 2013; Ikaros AB, 2006)
4.5 Plastic film – from DE producer to DE corrugated board box producer				
4.5.1 Plastic film – primary & tertiary	Polyethylene production, linear low density + extrusion plastic film	Assumption	Secondary: Gunnarshögs Gård	
4.5.2 Lorry distribution	Transport, freight, lorry >32 metric ton, EURO4	Assumption	Assumption	
4.6 Corrugated board box – From DE producer to DE glass producer				
4.6.1 Corrugated board box	Corrugated board box production	Lös Market	Primary	
4.6.2 Lorry distribution	Transport, freight, lorry, >32 metric ton, EURO4	Assumption	Assumption	
4.7 Glass bottle – From DE producer to Glaeserundflaschen				
4.7.1 Glass production	Packaging glass production, white	Lös Market	Primary	
4.7.2 Lorry distribution	Transport, freight, lorry >32 metric ton, EURO4	Glaeserundflaschen	Primary	
4.8 Glass bottle – from Glaeserundflaschen to Lös Market				
4.8.1 Lorry distribution	Transport, freight, lorry 7.5-16 metric ton EURO4	Glaeserundflaschen	Primary	
4.8.2 Lorry distribution, on RoRo-ship	NTM: Transport, freight, lorry, by RoRo-ship	Glaeserundflaschen	Primary	
4.9 Transport packaging recycling & recycling				
Modelled according to the conventional rapeseed scenario, ref 3.5-3.6, and the zero-waste scenario for oats, ref 2.9				