Nordic Council
of Ministers

LCA on reuse of packaging in the Nordics

A case of comparing reusable alternatives to current disposable packaging

Contents

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Acronyms

LCA	Life Cycle Assessment
PEF	Product Environmental Footprint
EU	European Union
NCE	Nordic Working Group for Circular Economy
EPR	Extended Producer Responsibility
PEF	Product Environmental Footprint
EF	Environmental Footprint
PEFCR	The Product Environmental Footprint Category Rules
CFF	Circular Footprint Formula
LCI	Life Cycle Inventory
EoL	End Of Life
LCIA	Life Cycle Impact Assessment
TA	Takeaway
CS	Case study, i.e., one analysed product system
SUPA	Single-use paper
SUPL	Single-use plastic
TPE	Thermoplastic Elastomer

Executive Summary

In an effort to facilitate a shift towards greater sustainability in the Nordics, this study provides an in-depth analysis of the environmental impacts associated with different types of packaging. Emphasis is placed on reusable packaging, investigating its lifecycle impacts from production to disposal and contrasting it with conventional, single-use packaging.

The packaging solutions under investigation cover takeaway containers and e-commerce packaging. In the takeaway sector, these are one reusable and one single-use. In the e-commerce sector, these are one reusable and returnable packaging, as well as two single-use variants made from LDPE film and paper, respectively.

As policymaking and corporate strategy increasingly lean towards sustainability, this comprehensive review and comparative lifecycle assessment serves as an informative guidepost. It offers robust, evidence-based insights to public authorities and private corporations alike, aiding decision-making processes in their pursuit of implementing and promoting environmentally friendly packaging solutions.

The following types of packaging are studied:

Table 1 Studied product systems

	Takeaway containers		E-commerce packaging		
	Reusable container 	Single-use, disposable container 	Reusable packaging 	Single-use, plastic 	Single-use, paper 
Material	Plastic	Plastic	Plastic	Plastic	Fibre/paper
Capacity	1,25 litre		21 litre		
Reference flow per unit	226g Polypropylene	59g Polypropylene	118g, woven Polypropylene	12g LDPE	65g corrugated cardboard
Number of uses	10	1	4	1	1
Reference flow per functional unit	26g virgin Polypropylene	59g virgin Polypropylene	29,5g virgin, woven Polypropylene	12g Virgin LDPE	65g corrugated cardboard

Commissioned by the Nordic Working Group for Circular Economy (NCE) under the Nordic Council of Ministers, this study sheds light on the environmental consequences and advantages of reusable packaging in the Nordics.

An additional goal of the study is to indicate a recommended number of reuses for which the reusable solution shows benefits. The hope is that these findings, while not definitive, will guide public authorities and private businesses in pursuing improved practices with lower environmental impact. This study could serve as a steppingstone towards understanding and promoting more environmentally friendly packaging solutions in the Nordics.

Literature review

A policy review was performed to ensure a relevant study. The aim was to consider factors such as changing circumstances, new information or evidence, and stakeholder feedback. The outcome of the policy review has produced a knowledge base and guide recommendations for which cases to include in the study. The review concluded that the European Commission envisages ambitious goals to cut packaging waste, thereby driving the increasing adoption of reusable alternatives across diverse industries.

In addition to the policy review, a comprehensive review of previous relevant comparative LCA studies was conducted. This review utilised past insights from comparing single-use vs. reusable transportation packaging and takeaway and beverage packaging within the Nordics. The results from these studies showed that three out of four reports deemed the reusable option more environmentally friendly than the single-use counterpart. In the selected literature, the success factors for reusable packaging systems were many use cycles, low transport distances, packaging weight, material choice, and recycled content. Overall, the literature review showed the lack of life cycle assessment studies of reusable vs. single-use packaging in the Nordics.

The selection of the investigated packaging field in this comparative LCA study was based on findings from the literature review and discussions with the steering committee. A desk-based-research was carried out to identify relevant reusable packaging systems from companies operating in the Nordics. Each identified reusable alternative was evaluated to be able to choose the most relevant packaging field for this study. Based on the evaluation of the reusable alternatives, e-commerce and takeaway containers were selected as the field to be assessed.

The research showed that numerous solutions were available for reusable containers suitable for takeaway food or beverages. For this case study, it was decided to investigate solutions for food containers made from plastic based on the results of a rating matrix, which evaluated criteria such as the potential to gain new knowledge, being in line with existing and upcoming regulations, the potential of waste reduction and technical feasibility for implementation. As the single use counterpart, a conventional plastic container was chosen.

When researching reusable packaging solutions fit for e-commerce, a few solutions were found, stretching from packaging solutions made of plastic and fibre. Plastic bags are expected to be more durable than fibre-based alternatives; therefore, plastic shipper bags can potentially be looped more times in a circular system. The one selected for this case study was a reusable bag made of woven polypropylene. As the single use counterpart, a conventional single use plastic bag (SUPL) and a conventional single use paper bag (SUPA) was chosen.

Methodological framework

The environmental assessment of the takeaway and e-commerce packaging was carried out through a Life Cycle Assessment (LCA). LCA has a standardised structure and standardised review and reporting requirements to account for the potential environmental impact of the resources necessary to produce, use, and dispose a product.

In order to compare the single-use and reusable takeaway containers, the **functional unit** is formulated. The functional unit enables the comparison of different products or systems. The comparison between reusable and single-use packaging solutions must consider "what?", "how many times?", "where?", and "how well?". A volumetric function is used, accounting for the fact that the packaging solutions might weigh differently based on their materials.

The functional unit for **takeaway containers** is defined as the following:

"To contain and protect one 1.25 litre restaurant meal for 1 use in one of the Nordic countries".

For the **e-commerce packaging**, the functional unit is defined as:

"To contain and protect one shipment of clothes with a maximum capacity of 21 litres for 1 time in the Nordics".

The assumed reuse rates for the takeaway containers and e-commerce packaging are 90% and 75%, respectively. The assumptions are tested with a break-even analysis.

The studied system comprises all life cycle stages from cradle to grave, including the return logistics and cleaning for the reusable systems. For both reusable systems, it was assumed that the distance from the customer to the return point was the same as to the picked-up point. For the reusable takeaway container, the packaging was assumed to be cleaned by the user before returning, as well as at the service point (restaurant) with a professional dishwasher.

The life cycle impact assessment (LCIA) method used was the Environmental Footprint 3.1, from which 13 impact categories are reported. The results were not normalised or weighted due to the comparative nature of the assessment (ISO, 2006b). Therefore, it is not possible to compare the results across impact categories.

Results comparative LCA – takeaway containers

This study presents a comprehensive comparative Life Cycle Assessment (LCA) of takeaway packaging options. The results of the study established that in terms of environmental impacts, reusable containers are generally less impactful than single-use containers across 11 out of 13 impact categories.

Raw materials and manufacturing stages were key contributors to the environmental impacts of single-use packaging. For reusable containers, the impacts were more evenly distributed across life cycle stages, from raw material acquisition to the manufacture and use phase.

Results from sensitivity analysis tests also supported the base case - reusable containers consistently showed a lower environmental impact than single-use options in most tested categories. Factors like container weight, consumer behaviour (such as avoiding pre-washing during the use phase or avoiding energy-intensive transportation methods), and various end-of-life modelling parameters all demonstrated the relative environmental advantage of reusable containers.

Tests of different parameters influenced by consumer behaviour revealed that reuse rates are crucial for reusable containers; reaching the environmentally preferred break-even point requires a minimum of 6 uses. However, for the environmental benefits of the reusable containers in all impact categories, 14 repeated uses are necessary. Furthermore, environmental impact can be minimized by choosing low/no emission transportation methods and avoiding unnecessary cleaning.

The study highlights the significance of the number of reuses in a reusable container system to reach the potential environmental benefits. Thus, for successful implementation, strategic design and planning of the reusable container system are vital. Guidelines and incentives should be established to influence consumer behaviour positively. Encouragement to adopt behaviours like swift container return and avoiding redundant washing can improve the relative benefit of reusable systems. This approach could ultimately lead to the optimal use of the system and bring about its environmental benefits.

In conclusion, this study affirms the environmental preference for reusable takeaway containers in Nordic countries – demonstrating high robustness in 10 out of the 13 impact categories studied.

Results comparative LCA – e-commerce packaging

This study provides a thorough comparative Life Cycle Assessment (LCA) of e-commerce packaging options encompassing single-use plastic (SUPL), single-use paper (SUPA), and reusable systems. The core findings reveal that for most environmental impact categories, the single-use plastic system yields lower impacts compared to the reusable system, and the single-use paper system predominantly yields higher impacts than the reusable system.

The upstream life cycle stages, including raw material extraction and manufacturing, are key contributors to the environmental impacts of single-use and reusable systems. In the single-use system, raw material extraction followed by distribution were the main driving impacts. For the reusable system, the manufacturing stage played a relatively more dominant role, with the usage phase also creating a higher impact due to incorporated reverse logistics.

Of the 13 investigated impact categories, single-use plastic packaging offers environmental benefits in all categories, 12 of which showcase high robustness and one displaying medium robustness. Meanwhile, single-use paper packaging offers environmental benefits in 5 categories: one with high robustness and four with medium robustness. On the other hand, the reusable system presents less environmentally impactful results than the single-use paper packaging in 8 out of 13 categories; six of the eight demonstrate high robustness, while two categories show medium robustness.

A sensitivity analysis lends credibility to the findings as the results mostly conform with the core comparison, maintaining medium to high robustness. Even though certain individual assumptions modify the relationship between the compared systems, no single assumption or variation remarkably influences the results across a majority of impact categories. Transporting the package to the final client also had a minimal impact on the results.

Notably, the number of reuses has a significant impact on reducing the environmental burden of the reusable system. The higher the reuse rate, the lower the impact per use, suggesting the importance of designing a system that encourages high reuse rates. Four uses (75% reuse rate) were set as a baseline in the study, but a higher number of reuses (around 18 uses), or even lower upstream impacts, could shift the results to the benefit of the reusable system for most of the impact categories.

In summary, the study underlines that single-use plastic packaging is the more environmentally friendly solution compared to its reusable counterpart. Meanwhile, the reusable system shows potential benefits compared to single-use paper packaging, particularly under conditions of high reuse rates.

Overall results

In general, outcomes of the study were largely robust, though there are influencing factors that could potentially affect the comparison between single-use and reusable packaging.

Primarily, the key stakeholders affecting these potential factors include the companies offering packaging solutions, packaging manufacturers, as well as users of the packaging. All these elements contribute to the complex task of determining the packaging option with the lowest environmental profile. Nevertheless, it was noted that with correct implementation, reusable packaging has substantial potential for lower environmental impacts compared to single-use alternatives. The determination to improve such solutions will be vital to enhancing the overall environmental performance of packaging on the market. This could also go beyond the solutions within the scope of the study, such as eradicating packaging altogether rather than substituting single-use packaging with a reusable solution.

Still, it is crucial to keep in mind that many variables influence the results of this study, which depend heavily on the specific circumstances and contexts. Hence, the figures presented should be used cautiously, considering the possible variability of each unique situation. The LCA should thus be viewed as a comprehensive examination of product systems that can give valuable insights and lead to fruitful discussion rather than offering definitive answers.

From this study, a number of conclusions and recommendations have emerged supporting transitioning from single-use to reusable packaging. In designing reusable packaging, factors such as durability, low weight, recyclability, and use of recycled materials are essential to consider. Also, establishing efficient reuse systems and incentivizing consumers to choose reusable packaging and return the packaging, is crucial.

Looking towards a European setting for the upstream stages, it became clear that local supply chains and less energy-intensive transportation can also play a role in reducing environmental impacts. Lastly, the study highlighted the importance of proper waste segregation and treatment at the end of a product's life, supporting a more circular economy.

In conclusion, it's evident that these factors make it a complex equation to achieve the lowest environmental impact. Yet, this study affirms the potential and value of embracing reusable packaging in Nordic countries with the correct set-up and incentives, leading to a more sustainable future.

Sammanfattning

För att underlätta övergången mot mer hållbarhet i Norden tillhandahåller denna studie en djupgående analys av miljöpåverkan av olika typer av förpackningar. Fokus läggs på en återanvändbar förpackning, där studien undersöker dess hela livscykel-påverkan från produktion till bortskaffande, samt jämför det mot konventionella engångsförpackningar.

Förpackningslösningarna som undersöks är takeaway (så kallad hämtmat) förpackningar och transportförpackningar för e-handel. Takeaway-sektorn representeras av: en återanvändbar och en engångsförpackning. E-handels-sektorn representeras av: en återanvändbar och returnerbar förpackning, samt två engångsvarianter gjorda av LDPE-film och papper.

Eftersom beslutsfattande och företagsstrategier alltmer lutar mot hållbarhet, fungerar denna omfattande genomgång och jämförande livscykelbedömning som en informativ vägledning. Den erbjuder robusta, evidensbaserade insikter riktade till både offentliga myndigheter och privata företag, vilket stödjer beslutsprocesser i deras strävan att implementera och främja miljövänligare förpackningslösningar.

Följande typer av förpackningar studeras:

Tabell 1 Studerade produktsystem

	Takeaway containers		E-commerce packaging		
	Reusable container	Single-use, disposable container	Reusable packaging	Single-use, plastic	Single-use, paper
					
Material	Plastic	Plastic	Plastic	Plastic	Fibre/paper
Capacity	1,25 litre		21 litre		
Reference flow per unit	226g Polypropylene	59g Polypropylene	118g, woven Polypropylene	12g LDPE	65g corrugated cardboard
Number of uses	10	1	4	1	1
Reference flow per functional unit	26g virgin Polypropylene	59g virgin Polypropylene	29,5g virgin, woven Polypropylene	12g Virgin LDPE	65g corrugated cardboard

Denna studie, som initierats av den Nordiska Arbetsgruppen för Cirkulär Ekonomi under Nordiska Ministerrådet, avser belysa de miljökonsekvenser och fördelar som återanvändbara förpackningar medför i de nordiska länderna.

Ett ytterligare mål med studien är att peka på ett rekommenderat antal återanvändningar för vilka den återanvändbara lösningen visar fördelar. Förhoppningen är att dessa resultat, även om de inte är definitiva, kommer att vägleda offentliga myndigheter och privata företag i att sträva efter förbättrad och miljövänligare praxis. Denna studie skulle kunna fungera som en språngbräda mot att öka förståelsen och främja mer miljövänliga förpackningslösningar i Norden.

Litteraturstudie

För att säkerställa att studien analyserar relevanta områden utfördes en policygranskning. Syftet var att överväga och inkludera faktorer så som förändrade omständigheter, ny information samt återkoppling från intressenter. Resultatet av policyöversynen har gett en kunskapsbas och vägledande rekommendationer för vilka analyser som ska ingå i studien. Granskningen drog slutsatsen att Europeiska kommissionen planerar ambitiösa mål för att minska förpackningsavfallet, vilket driver ett ökat införande av återanvändbara alternativ inom olika branscher.

Utöver policygranskningen genomfördes en omfattande granskning av tidigare relevanta jämförande LCA-studier. Denna granskning syftade till att dra nytta av tidigare insikter från jämförande studier som jämför engångsförpackningar mot återanvändbara transportemballage och takeaway- och dryckes-förpackningar inom Norden. I den valda litteraturen var framgångsfaktorerna, för återanvändbara förpackningssystem, ett högt antal användningscykler, låga transportavstånd och förpackningsvikt, materialval och återvunnet innehåll. Sammantaget visade litteraturöversikten bristen på livscykelstudier av återanvändbara förpackningar jämfört med engångsbruk i Norden.

Valet av fallstudier för denna jämförande LCA-studie grundades på resultaten från litteraturgenomgången och diskussioner med styrgruppen. För att identifiera relevanta återanvändbara förpackningssystem genomfördes en undersökning för att hitta förpackningssystem från företag verksamma i Norden. De identifierade återanvändbara alternativen utvärderades för att kunna välja det mest relevanta förpackningsfältet för denna studie. Baserad på utvärderingen av de återanvändbara alternativen valdes e-handel och takeaway-behållare som objektet för studien.

Förstudien visade att många lösningar fanns tillgängliga för återanvändbara behållare lämpliga för hämtmat eller dryck. För denna fallstudie beslutades att undersöka lösningar för matbehållare tillverkade av plast baserat på resultaten av en betygsmatris, som utvärderade kriterier som möjligheten att få ny kunskap, vara i linje med befintliga och kommande regelverk, potentialen för minskningen av stora avfallsvolymer och teknisk genomförbarhet för implementering. Som den motstycke valdes en konventionell engångs plastbehållare.

När det gäller återanvändbara förpackningar som passar för e-handel hittades många lösningar, så som förpackningar av plast och/eller fiber. Plastpåsarna förväntas vara mer hållbara än fiber-alternativen och kan därför potentiellt återanvändas fler gånger i ett cirkulärt system. Lösningen som valdes för denna fallstudie var därför en återanvändbar påse av vävd polypropen. Som engångs-motstyck valdes en konventionell engångsplastpåse (SUPL) och en konventionell engångspapperspåse (SUPA).

Metodologiskt ramverk

Miljöbedömningen av takeaway- och e-handelsförpackningar utfördes med hjälp av livscykelanalys (LCA). LCA har en standardiserad struktur och gransknings- och rapporteringskrav för att analysera den potentiella miljöpåverkan som är kopplad till de resurser som krävs för att producera, använda och avyttra en produkt.

För att jämföra engångs- och återanvändbara takeaway-behållare definieras den funktionella enheten. Den funktionella enheten möjliggör jämförelse av olika produkter eller system. Jämförelsen mellan återanvändbara och engångs-förpackningslösningar måste överväga "vad?", "hur många gånger?", "var?" och "hur bra?". Ett volymförhållande används för att ta hänsyn till att förpacknings-lösningarna kan väga olika mycket på grund av olika material.

Den **funktionella enheten för takeaway-behållaren** definieras som följer:

"Att innehålla och skydda en 1,25 liters restaurangmåltid för 1 användning i ett av de nordiska länderna".

För **e-handelsförpackningen definieras den funktionella enheten** som:

"Att innehålla och skydda en frakt av kläder och med en maximal volymkapacitet på 21 liter för 1 gång i Norden".

De antagna återanvändningsfrekvenserna (reuse rate) för takeaway-behållare och e-handelsförpackningar är 90% och 75%. Dessa antaganden har testats genom en break-even analys.

Det studerade systemet omfattar alla livscykelstadier från vaggan till graven, inklusive returlogistik och rengöring för de återanvändbara systemen. För båda återanvändbara systemen antogs att avståndet från kund till återlämningsställe var detsamma som till avhämtningsställe. För den återanvändbara takeaway-behållaren antogs det att förpackningen potentiellt diskades av användaren innan den returnerades och dessutom på servicestationen (restaurangen) med en professionell diskmaskin.

Miljöpåverkansbedömningsmetoden (LCIA) som användes var Environmental Footprint 3.1, från vilken 13 påverkanskategorier rapporteras. Resultaten normaliserades eller viktades inte på grund av bedömningens jämförande natur (ISO, 2006b), därför är det inte möjligt att jämföra resultaten över påverkanskategorierna.

Resultat från jämförande LCA - takeaway-behållare

Denna studie presenterar en omfattande jämförande livscykelanalys (LCA) av takeaway-förpackningsalternativ. Resultatet av studien fastställer att återanvändbara behållare generellt sett visa betydligt lägre miljöpåverkan än engångsförpackningar i 11 av 13 miljöpåverkanskategorier.

De största bidragande processerna till miljöpåverkan för engångsförpackningar var råmaterial och tillverkningsprocessen. För de återanvändbara behållarna fördelades miljöpåverkan mer jämnt över livscykelstadierna råmaterialutvinning, tillverkning och användningsfas.

Resultat från känslighetsanalysen bekräftade också det ursprungliga resultatet - återanvändbara behållare visade konsekvent lägre miljöpåverkan jämfört med engångsalternativ i de flesta undersökta kategorier. Faktorer som behållarens vikt, konsumentbeteende (till exempel att undvika tvätt innan återanvändning eller undvikande av energikrävande transportmetoder), och olika parametrar för avfallshantering, visade alla den relativa miljöfördelen med återanvändbara behållare.

Tester av olika parametrar som påverkas av konsumenternas beteende, visade att återanvändningsfrekvensen är avgörande för återanvändbara behållare. För att nå den miljömässigt föredragna jämvikten krävs det minst 6 användningar. Dock krävs det 14 återanvändningar för fullständig miljöfördel för de återanvändbara behållarna i alla påverkanskategorier. Dessutom kan miljöpåverkan minskas genom att välja transportmetoder med låg eller inget utsläpp samt att undvika onödiga rengöringssteg.

Studien lyfter upp betydelsen av antalet återanvändningar i ett system för återanvändbara behållare för att nå potentiella miljöfördelar. Därför är strategisk design och planering vitala för en framgångsrik implementering av ett system för återanvändbara behållare. Riktlinjer och incitament bör etableras för att positivt påverka konsumentbeteenden. Uppmuntran till att snabbt returnera behållaren och undvika onödig disk kan förbättra den relativa fördelen med återanvändbara system. Denna strategi kan i slutändan leda till optimal användning av systemet och framhäva dess miljöfördelar.

Sammanfattningsvis bekräftar denna studie en miljömässig preferens för återanvändbara takeaway-behållare i de nordiska länderna – samt uppvisar en hög robusthet i 10 av de 13 studerade påverkanskategorierna.

Resultat från jämförande LCA - e-handelsförpackningar

Denna studie presenterar en omfattande jämförande LCA av förpackningsalternativ för e-handel, som innefattar engångsplast (SUPL), engångspapper (SUPA), och återanvändbara systemen. Huvudresultaten visar att för de flesta miljöpåverkanskategorierna har engångsplasten en lägre miljöpåverkan än det återanvändbara systemet, medan har engångspapper en högre miljöpåverkan än det återanvändbara systemet.

De största bidragande faktorerna till miljöpåverkan för engångs- och återanvändbara system är uppströms livscykelstadier, inklusive råmaterialutvinning och tillverkning. I engångssystemet dominerar råmaterialutvinning följt av transporter. Tillverkningsfasen spelade en relativt stor roll för det återanvändbara systemet samt att resultaten peka på att användningsfasen ha en högre påverkan orsakad av ytterligare logistik för återanvändning.

Av de 13 undersökta påverkanskategorierna visa engångsplastförpackning (SUPL) miljöfördelar i alla kategorier, 12 av dessa visar hög robusthet och en visar medel robusthet. Samtidig visa engångspappersförpackning (SUPA) miljöfördelar i 5 kategorier, med hög robusthet i en kategori och fyra med medel robusthet. Däremot visar det återanvändbara systemet miljömässigt lägre påverkan i 8 av 13 kategorier, sex av dessa med en hög robusthetsnivå och två med medelnivå.

En känslighetsanalys ger ytterligare tillförlitlighet åt resultaten eftersom resultatet mestadels överensstämmer med huvudjämförelsen, med en bibehållen medel- till hög robusthet. Även om vissa individuella antaganden ändrar förhållandet mellan de jämförda systemen, så påverkar inget enskilt antagande eller variation resultatet påtagligt över en majoritet av påverkanskategorierna. Transporten av paketet till slutkunden hade också minimal inverkan på resultaten.

Särskilt är att antalet återanvändningar har en betydande inverkan på att minska den återanvändbara systemets miljöbelastning. Ju högre återanvändningsgrad, desto lägre påverkan per användning, vilket tyder på vikten av att utforma ett system som uppmuntrar till höga återanvändningsgrader. För studien sattes fyra användningar (75% återanvändningsgrad) som utgångspunkt, men ett högre antal återanvändningar, eller till och med lägre uppströmspåverkan, skulle kunna förskjuta resultaten mot återanvändbara systemets fördel.

Sammanfattningsvis framhäver studien engångsplastförpackningen (SUPL) som det mer miljövänliga alternativet när det jämförs mot sitt återanvändbara motstycke. Samtidig visar det återanvändbara systemet potentiella fördelar jämfört med engångspappersförpackningen (SUPA), särskilt vid höga återanvändningsgrader.

Sammanfattande resultat

Generellt sett var resultaten från studien robusta, även om det finns faktorer som potentiellt kan påverka jämförelsen mellan engångs- och återanvändbara förpackningar.

De viktigaste aktörerna som påverkar dessa faktorer och jämförelsen av engångs och återanvändbara förpackningar är företag som erbjuder förpackningslösningar, förpackningstillverkare samt användare av förpackningarna. Alla dessa bidrar till den komplexa uppgiften att fastställa det förpackningsalternativ som har den lägsta miljöpåverkan. Trots detta noterades det att med korrekt genomförande har återanvändbara förpackningar en betydande potential för lägre miljöpåverkan jämfört med engångsalternativ. Avsikten och engagemanget att minska miljö-påverkan av förpackningar kommer att vara avgörande för att förbättra övergripande miljöprestanda. Detta kan också gå utöver lösningarna inom ramen som undersöktes i studien, till exempel att man avskaffar förpackningar helt och hållet snarare än att ersätta engångsförpackningar med en återanvändbar lösning.

Det är dock viktigt att komma ihåg att resultaten av denna studie påverkas av många variabler som är starkt beroende av de specifika omständigheterna och sammanhangen. Därför bör siffrorna som presenteras användas med försiktighet och man bör överväga den inneboende variabiliteten i varje unikt fall. Denna LCA studie bör därför ses som en omfattande undersökning av produktsystem som kan ge värdefulla insikter och leda till produktiva diskussioner snarare än att erbjuda definitiva svar.

Denna studie presenterar ett antal slutsatser och rekommendationer som stödjer övergången från engångsförpackningar till återanvändbara förpackningar. Vid produktutveckling av återanvändbara förpackningar är faktorer som produkt-hållbarhet, låg vikt, återvinningsbarhet och användning av återvunnet material viktiga att beakta. Dessutom är det avgörande att inrätta effektiva åter-användnings system och att ge incitament till konsumenter att välja åter-användbara förpackningar.

Från ett europeiskt perspektiv gällande uppströmspåverkan, blev det dessutom tydligt att lokala leveranskedjor och mindre energikrävande transporter också kan spela en viktig roll i att minska miljöpåverkan. Slutligen framhöll studien vikten av korrekt avfallssortering och behandling vid slutet av produktens livslängd, vilket stöder en mer cirkulär ekonomi.

Sammanfattningsvis är det uppenbart att dessa faktorer bidrar till en komplex ekvation att uppnå den minsta miljöpåverkan. Ändå bekräftar denna studie potentialen och värdet av att gå över till återanvändbara förpackningar i nordiska länder med rätt uppsättning och incitament på plats, vilket leder till en mer hållbar framtid.

1. Introduction

The aim of this project is to obtain more knowledge about the environmental impacts and benefits of reuse of packaging in the Nordics, compared to current single use of packaging and subsequent waste treatment. Packaging waste volumes are increasing and are amplified by increased on-the-go consumption and e-commerce, and this waste is mainly recycled or incinerated today and only a minor part is directly reused.

This study was commissioned by the Nordic Working Group for Circular Economy (NCE) under the Nordic Council of Ministers which aims at assessing the environmental impacts of reusable packaging in the Nordics, specifically for transport packaging and primary packaging in the takeaway and beverages sector compared to current single use alternatives. To attain that, two comparative life cycle assessments were carried out, based on case studies of two reusable packaging solutions currently in the Nordic market. The results are intended to be used as decision support for public authorities and private companies to push towards the use of more sustainable solutions.

2. Methodology

The study comprises two main phases, (1) a literature review, and (2) the Life Cycle Assessment (LCA).

Literature review

A literature review was performed to understand the state-of-art, the statistics for each of the studied countries, an overview of the most relevant and upcoming policies and legislation on both European and national level and existing life cycle assessments done for reusable packaging in the Nordics within transport packaging and takeaway with the purpose of establishing some relevant case studies to be assessed with the LCA.

LCA Methodological approach

Currently, Life Cycle Assessment (LCA) provides the best and most mature framework for assessing the potential environmental impacts of products and services according to the European Commission (European Commission, 2019). One of the most frequent applications of LCA studies is the comparison of specific goods or services (European Commission - JRC - Institute for Environment and Sustainability, 2010). Several results of life cycle based assessments are already being used in relation to certain EU policies (e.g. Ecolabel Regulation, Green Product Procurement, Eco-design Directive). Given the method's standardised framework, maturity and methodological adaptation to policy needs, the consideration of LCA studies in policymaking is expected to increase (European Commission, 2017). A very prominent example of the use of LCA in EU policies and impact assessment is the justification of possible changes in the waste hierarchy due to environmental concerns (European Commission, 2017). Given the previously outlined context and rationale for this study, it is important to acknowledge LCA as an iterative and continuous learning process rather than a mere calculation tool. As such, the modelling choices should be tailor-made to facilitate an efficient learning process and generate as much knowledge as possible about the specific case (Ekvall, 2020).

For the quantitative assessment of relevant systems from an ecological point of view, the methodology of LCA is suitable (in accordance with relevant ISO standards 14040 and 14044). The general methodology for LCA aims to assess identified and generated Life Cycle Inventories (LCIs), consisting of quantified elementary flows referring to the functional unit, in relation to their potential impact on the natural environment, human health, and issues related to natural resource use (European Commission - JRC - Institute for Environment and Sustainability, 2010).

LCA is a well-established four-step methodology. These steps are iterative and involve the following tasks (Guinée, et al., 2001):

1. Goal and scope definition: object and aim of the study are described, as well as system boundaries, functional unit and data sources; impact categories, indicators and characterisation models are selected.
2. Inventory analysis: this phase collects and quantifies data-based processes of inputs (e.g. fuel demand, energy demand, raw materials weights, air emissions, waste weights) in the whole life cycle of a system or product – as defined in step 1.
3. Impact assessment: inventory analysis results are assigned to the selected impact categories by means of established, scientific impact assessment methods; category indicator results are then calculated; the results can be evaluated by varying relevant parameter within a sensitivity analysis.
4. Interpretation: this phase analyses and interprets the results of the impact assessment, tries to highlight uncertainties and paths for improvement of the system.

A Life Cycle Assessment (LCA) study according to the ISO 14040/44 standards is carried out. Key parameters and environmentally important life-cycle stages of the systems are identified and analysed. Further, the influence of certain key variables for the results is evaluated.

The assessed systems are modelled in Umberto 11, using ecoinvent 3.9 as the background database, and the Environmental Footprint (EF) method as the impact assessment method.

This study follows the principles of an attributional analysis, meaning that a specified and static state of a system or product is examined (Guinée, et al., 2001). Therefore, average data (representing average environmental burden from a specific activity or production volume) is incorporated in this assessment and results refer to an unambiguously defined current system. However, the allocation procedure of the Circular Footprint Formula (CFF) also comprises consequential perspectives and approaches. This means that both recycling and energy recovery are modelled with assumed substitution (i.e., avoided energy or material provision). This approach is widely established practice and particularly used in consequential LCAs in order to estimate how the global environmental impacts are affected by a decision. In this regard it is important to acknowledge the comparative nature of this assessment in which different options fulfilling the same function are considered. These options are made of different processes along the life cycle (e.g., raw materials extraction, manufacturing, transport, end-of-life stage).

3. Literature Review

3.1 Packaging statistics and reduction targets

The Nordic countries have set packaging waste reduction targets as part of their efforts to promote sustainable production and consumption. In 2018, the Nordic Council of Ministers set a joint target to reduce the consumption of plastic carrier bags by 50% by 2025. This target was set in recognition of the environmental impact of single-use plastics and the need to reduce their use.

In addition, the Nordic countries have established extended producer responsibility schemes to promote the recycling and reuse of packaging waste. These schemes place the responsibility for the collection and recycling of packaging waste on the producers, who are incentivised to reduce the amount of packaging they use and increase the use of recycled materials.

Each Nordic country has also set its own packaging waste reduction targets. For example, Finland has set a target to reduce the amount of packaging waste generated by 15% by 2025, while Norway aims to increase the recycling rate of plastic packaging to 50% by 2025.

3.1.1 Denmark

Denmark has set waste reduction targets for both household and industrial waste. For household waste, the government has set a target to reduce the amount of household waste sent to incineration or landfill by 50% by 2030 compared to 2010 levels. To achieve this goal, the government has implemented a range of measures, such as increasing recycling, reducing food waste, and promoting the circular economy.

The overall packaging waste generated in Denmark by packaging material and its sources is presented in Figure 1. It must be noted that the cardboard and paper packaging were not reported individually but they include other cardboard and paper waste. However, based on a recent report from the Danish Environmental Protection Agency, there is an estimation of e-commerce packaging to be around 29,000 tons of cardboard, 2,000 tons of paper and 3,000 tons of plastic.

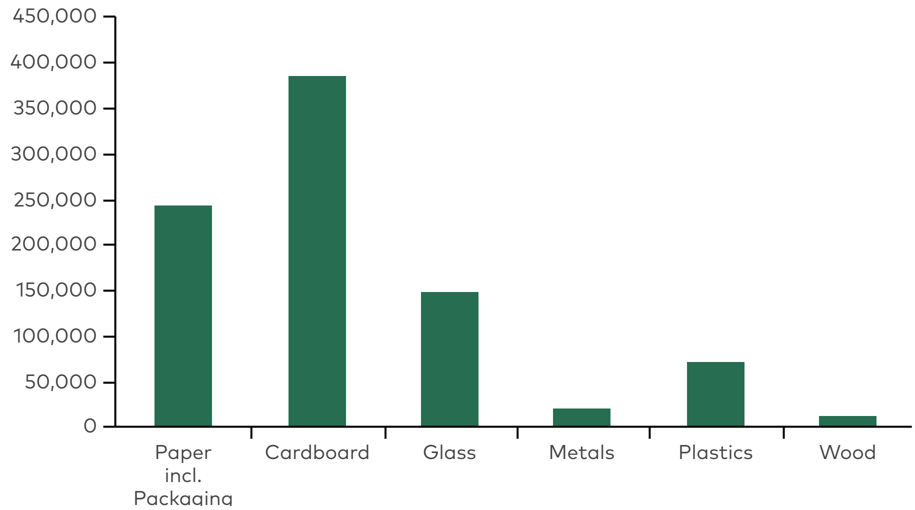

Figure 1 Packaging waste generated by material in Denmark 2020 (Miljøstyrelsen, 2022).

3.1.2 Sweden

Data for Sweden was obtained from the Sweden Environment Agency (Naturvardsverket) and summarizes the output of packaging in Sweden from both the household and Industrial levels for various material types; as seen in Figure 2 – Packaging waste generated by material in Sweden for 2020, below. Paper and cardboard generate the most overall amount of waste compared to other materials.

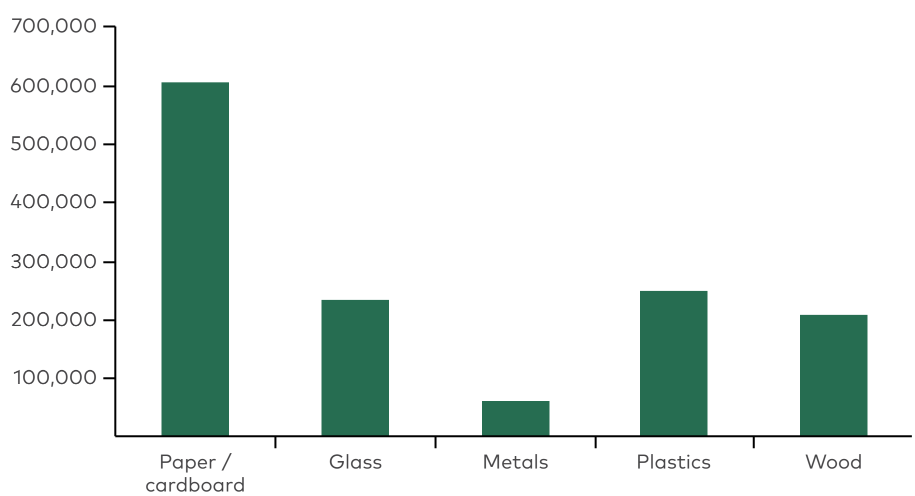

Figure 2 Packaging waste generated by material in Sweden for 2020, (Naturvårdsverket, 2022).

3.1.3 Finland

Centre for Economic Development, Transport and Environment (ELY) compiles and delivers packaging and packaging waste statistics in Finland to the European Commission annually. Statistics have been provided since 1997.

The statistics are based on information reported annually by producers and producer associations. The statistics do not include all packaging used in Finland, as the figures are missing, for example, companies with a turnover of less than one million euros, imports by private parties, online shopping, and so-called free passengers. The figures for Åland are also not included in the statistics. In the years 2012-2019, the recycling rates of fiber (cardboard and paper), glass, metal, plastic, and wood have developed in a positive direction.

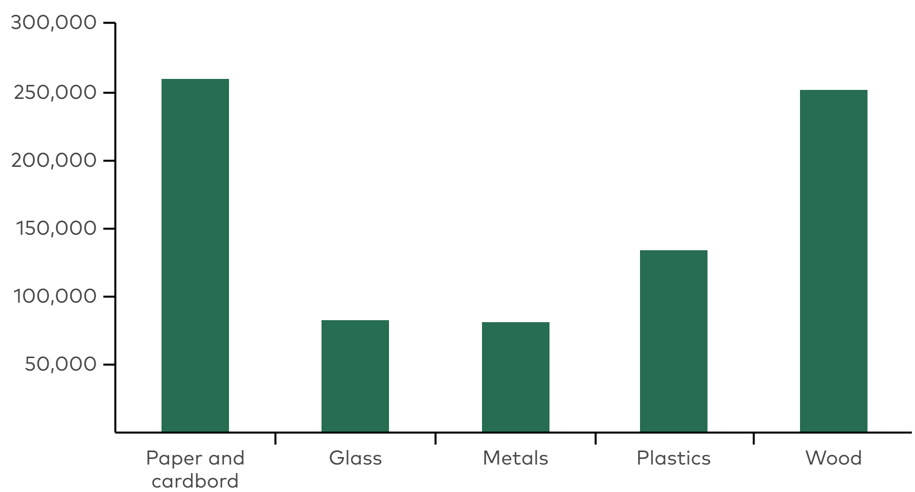

Figure 3 Packaging waste generated by material for Finland in 2019.

3.1.4 Norway

Figure 4 summarises packaging waste generated in Norway by material in 2020, packaging and printed materials account for most of the paper waste in Norway. Around 78% of the paper and cardboard packaging that is collected goes to material recycling, while the rest mainly goes to incineration with energy utilisation. In 2020, approx. 27,000 tonnes of metal packaging were collected (via take-back schemes). In 2020, around 28% of the plastic packaging from Norwegian households and businesses was recycled (Miljødirektoratet, 2022).

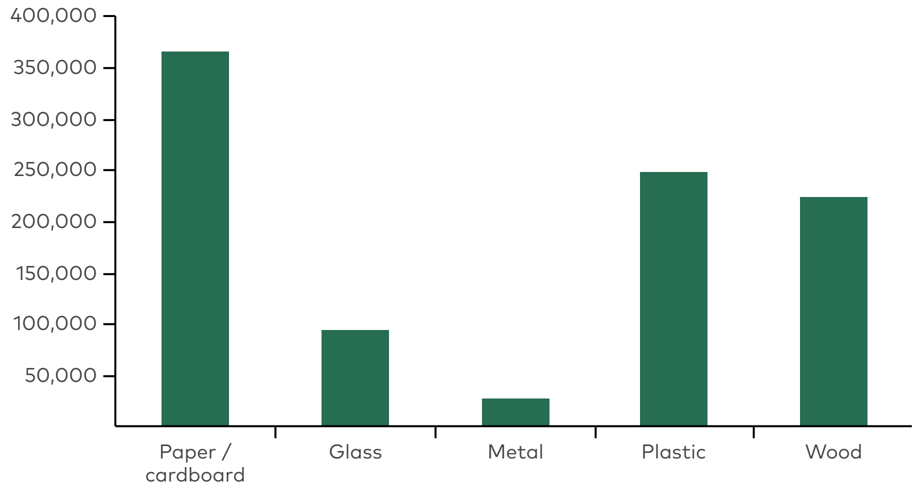

Figure 4 Packaging waste generated by material in Norway for 2020 (Miljødirektoratet, 2022).

3.2 Policy review

To ensure a relevant LCA-study a policy screening was performed at the beginning of 2023. The aim is to consider factors such as changing circumstances, new information or evidence, and stakeholder feedback. The outcome of a policy review aims to produce a knowledge base and serve at a framework and guidance to the selection of case products which to include in the LCA-study.

3.2.1 The Packaging and Packaging Waste Directive

A cornerstone in European waste legislation is the directive on packaging waste which is aimed at reducing the environmental impact of packaging waste. It establishes rules for the recovery and recycling of packaging waste and sets targets for member states to achieve in this area. The directive also establishes a producer responsibility principle, which requires producers to contribute to the costs of waste management and to take measures to reduce the environmental impact of packaging waste. The directive was first introduced in 1994 and has been updated several times, most recently in 2018. The overall goal of the directive is to promote a circular economy and reduce the amount of packaging waste generated, while ensuring that packaging is managed in an environmentally sound manner.

2022 Proposal for a Packaging and Packaging Waste Regulation

In November 2022 a proposal for a revised packaging and packaging waste regulation was released by the European Commission. The aim of this proposal is mainly to include measures to reduce the generation and therefore the environmental impacts of packaging and packaging waste by increasing recycled content in packaging, tackle excessive packaging, reducing packaging waste and promoting reuse and recycling in the packaging design (European Commission. 2022).

The proposal sets ambitious and specific targets for reuse/refill for 2030 and 2040. Table 2 lists the targets for the relevant product categories in this study. Targets for takeaway packaging (containers) are 80% and 40% reusable containers for beverages and food respectively in 2040 (European Commission. 2022). At the conclusion of this report, the proposal remained in hands of the co-legislators.

Table 2 Re-use and refill targets set up in the proposed regulation (European Parliament, 2023)

	From 1 January 2030	From 1 January 2040
Cold or hot beverages (filled into a container at the point of sale for take-away)	Share of beverages made available in reusable packaging or by enabling refill **20%**	Share of beverages made available in reusable packaging or by enabling refill **80%**
Take-away ready-prepared food (intended for immediate consumption with no need of any further preparation, and typically consumed from the receptacle)	Share of products made available in reusable packaging or by enabling refill **10%**	Share of products made available in reusable packaging or by enabling refill **40%**
Transport packaging (pallets, plastic crates, foldable plastic boxes, pails and drums for conveyance or packaging)	Share of packaging used that is reusable **30%**	Share of packaging used that is reusable **90%**
Transport packaging (e-commerce) Operators using transport packaging for the transport and delivery of non-food items sold via e-commerce	Share of such packaging used is reusable packaging **10%**	Share of such packaging used is reusable packaging **50%**
Transport packaging (pallet wrappings and straps)	Share of such packaging used is reusable packaging **10%**	Share of such packaging used is reusable packaging **30%**

The goal for reusable packaging in 2040 is 90% for transport packaging (pallets, crates etc.) and 30% for wrapping and straps. Furthermore, there is an ambitious goal of 90% reusable packaging in 2040 when it comes to e-commerce (boxes, bags etc.).

The full list of use and refill targets is placed in Appendix A.

3.2.2 Waste Framework Directive - Extended producer responsibility

Extended Producer Responsibility (EPR) is part of the Waste Framework Directive (2008/98/EC) and requires that businesses – including brands, importers, and manufacturers – share the cost of packaging waste disposal. In practice, this involves that the producers or importers needs to pay a fee to a national EPR organisation that manages and finance the waste collection and treatment of the products at end-of-life.

Initially introduced as a concept by Thomas Lindhqvist from Sweden in 1990, EPR is typically understood to involve a shift in responsibility (administratively, financially, or physically) from governments or municipalities to producers as well as an encouragement of producers to take environmental considerations into account during the design and manufacture phases of product development. Ideally, this leads to financial benefits for producers who reduce e.g. packaging or make their packaging more recyclable. And even better – consumers who choose products or packaging with less environmental impact than others should ideally have cost savings as well.

The directive is perceived to help reduce the amounts of packaging placed on the market and if fee is increased in the future it could result in a shift towards more reusable packaging solutions.

3.2.3 The EU-commission’s Circular Economy Action Plan

The EU Commission's Circular Economy Action Plan is a set of initiatives and proposals put forward by the European Commission with the aim of transforming the EU into a more circular economy. The plan is intended to promote sustainable consumption and production, and to reduce waste and pollution. It includes a range of measures such as setting targets for recycling and reducing landfill, supporting the development of new business models and technologies, and creating a level playing field for sustainable products. The plan also includes measures to improve the environmental performance of products, such as setting eco-design requirements and creating a labelling scheme for circular products.

For packaging the action plan includes the following actions (European Commission, 2020):

- reducing (over)packaging and packaging waste, including by setting targets and other waste prevention measures;
- driving design for re-use and recyclability of packaging, including considering restrictions on the use of some packaging materials for certain applications, in particular where alternative reusable products or systems are possible or consumer goods can be handled safely without packaging;

- considering reducing the complexity of packaging materials, including the number of materials and polymers used.

The plan was first announced in 2015, and updated in 2020, with the aim of achieving a more circular economy by 2030.

3.2.4 The Single Use Plastics Directive (EC 2019/904)

The Single Use Plastics Directive is a European Union directive that aims to reduce the environmental impact of certain single-use plastic products. The directive came into force in 2019, and Member States had until July 2021 to transpose the directive into national law.

The directive bans certain single-use plastic products, such as cutlery, plates, straws, and balloon sticks, places a 90% collection target for plastic drinks bottles, and states that Member States must impose consumption reduction measures for single use-products such as cups for beverages and food containers. It also requires manufacturers to contribute to the costs of waste management and clean-up of litter.

At the moment the directive does not include single use packaging within transport, but the directive ultimately aims to phase out unnecessary single-use plastics. In the future our definition of "unnecessary single-use plastics" could change and the directive could be updated to include additional products. Such an update could increase the need for reusable alternatives and therefore the directive is important to follow.

3.2.5 Conclusions from the policy review

The policy review finds it clear that the European commission have an ambitious goal to reduce packaging waste and one way is to foster reusable alternatives. The proposed update of the Packaging and Packaging Waste Directive ambitiously includes targets for reusable packaging within transport and takeaway with up to 90% reuse in 2040. Even though this is a proposal, it shows the level of ambition and direction from the commission. It demonstrates that the landscape for packaging enviably will change radially in the future.

Directives such as the Extended Producer Responsibility and the Single Use Plastics further supports the direction to reduce packaging and packaging waste by increasing packaging cost and banning certain unnecessary plastic products.

The overall direction is set to move towards a more circular economy by collecting and recycling more waste, while at the same time reducing consumption. The path forward is likewise to avoid fossil-based materials and single-use whenever possible, which results in a need for more reuse systems.

3.3 Life Cycle Assessments literature

Previous LCA studies comparing single-use vs reusable in transportation packaging and takeaway and beverage packaging within the Nordics were reviewed to gain knowledge on previous work done in the field. Some of the key words used to find the studies include "LCA", "reusable". "packaging", "transport", "refill", "takeaway", "Nordics".

A list of 70 different articles was initially found and the research was additionally narrowed down with the following criteria:

- Packaging type: the studies should focus on transport packaging (e.g. crates, drums, pallets, e-commerce, among others) and for the takeaway and beverage packaging (hot and cold cups, containers, cutlery, among others)
- Geographical representativeness: The studies should have been done in any of the Nordic countries (Denmark, Finland, Sweden, Norway)
- Time representativeness: Only publication from 2010 onwards were considered
- Comparative LCA: life cycle assessments comparing single use packaging versus reusable options were

Several LCA studies comparing single-use vs. reusable options from other geographical locations within Europe were also reviewed, as well as LCAs for single use packaging. However, after the exhaustive review, only a total of four reusable packaging LCAs within the Nordics were found to be compliant with the criteria and additional two studies outside the Nordics. These studies can be found in Table 3. Three of them were for transport packaging (two for crates, and one for e-commerce), and one in the takeaway and beverage category (beer cups in festivals).

Table 3 Literature found for LCAs done on reusable packaging in the Nordics.

Packaging type	Category	Company	Geography	Findings	Reference
SRS reusable box vs Corrugated cardboard	Commercial and Industrial/Goods sold/ crates	Svenska Heterosystems	Sweden	In all calculated scenarios, the result has indicated that the SRS fully boxed system contributes to a reduced environmental impact compared to similar distribution systems with corrugated cardboard.	(Svenska Retursystem; Linköpings Universitet, 2016)
Reusable plastic crate vs recyclable cardboard box	Commercial and Industrial/Goods sold/ crates	Stora Enso Oyj and the Finnish Environment Institute (SYKE)	Finland	They concluded that the recyclable CCB box system was a more environmentally friendly option than the reusable HPDE plastic crate system in all the studied impact categories based on the defined boundaries and assumptions.	(Koskela, Dahlbo, Judl, Korhonen, & Niininen, 2014)
E-commerce reusable packaging vs mailing bag and boxes	E-commerce	Re-zip	Denmark	The result indicates that for the full life cycle, a RE-ZIP bag used 10 times saves 313 grams CO2eq (42%) in comparison with 10 single-use mailing bags. But it also leads to slightly higher water consumption	(Deloitte, 2021)
Reuse vs. single use beercup	Food and beverage	Øyafestivalen	Norway	Festivals that currently have a disposable system can achieve a significant climate benefit by introducing a collection system and sending the glasses for material recycling, for example through a deposit scheme.	(Lyng & Sadeleer, 2021)
Different reusable vs single use packaging type (bottle, bucket, crates, cups, etc.)	Commercial/Industrial/ Food and beverage	Zero Waste Europe	Europe	Success of a reusable packaging is dependent on different factors, such as number of cycles, transport distances, packaging weight, choice of material, and recycled content.	(Zero Waste Europe, Reloop, 2020)
E-commerce reusable vs single use packaging	E-commerce	Fashion for good	Worldwide	This research demonstrated the clear impact case for reusable packaging, in some instances presenting more than an 80% reduction in CO2eq emissions compared with a single-use alternative	(Fashion for good, 2021)

According to the findings of the retrieved studies, three out of the four reports for the Nordic countries found the reusable option to be more environmentally friendly that the single-use option. The recyclable cardboard box resulted in lower environmental impacts than the reusable crate, indicating that the material selection and origin is also of importance. Overall, the literature review revealed the lack of life cycle assessment of reusable packaging vs single-use in the Nordics.

3.4 Selection of case studies

Based on findings from the literature review, where it was highlighted that the success factors for reusable packaging systems are a high number of use cycles (and return-rate), low transport distances and packaging weight, material choice and recycled content.

A desktop-research was carried out to find possible reusable packaging product systems from companies operating in the Nordics. A detailed overview of the findings can be found in Appendix A. Each of the reusable alternatives found were evaluated to identify the most relevant.

A scoring matrix is developed for each selected relevant parameter, to subsequently evaluate each of the identified packaging categories. The evaluation is a qualitative assessment based on opinion and relative to the scope and goal of the project.

The parameters being evaluated are the following and are based on the requirements mentioned in the original project description from Nordic Council of ministers:

- Potential to gain new knowledge.
- Based on existing and upcoming regulations
- Potential for large waste volumes
- Replacing single use plastic packaging
- Technical feasibility for implementation

A scoring system was given for each parameter according to the following matrix, where:

\- = not meeting expectations

0 = meets some expectations

\+ = Fully meets expectations

The case categories were evaluated based on the knowledge gained during the literature review and in close collaboration with the steering committee appointed by the Nordic Council of ministers. The results can be observed in Table 4.

Table 4 Matrix rating of packaging types

Case category	New knowledge	Regulation targets	Potential Volume	Replace plastic	Technical Feasibility	Comment
			Reusable transport packaging			
E-commerce	+	+	+	0	+	less widespread, high potential
Crates	-	+	+	0	+	Already well established
Pallets	-	+	+	0	+	Already well established
Drums	-	+	0	0	+	Already well established
Looping Module cover	+	-	-	+	0	Low potential
ClipLock	+	+	0	0	-	cumbersome return flow
			Reusable takeaway packaging			
Coffee cups	+	+	+	0	+	
Food Containers	+	+	+	+	+	
Beer/drink cups	0	+	0	+	+	Well established with events and festivals
Food packaging (from the supermarket)	+	-	+	0	-	Out of scope (not transport nor takeaway)

The best scores for the transport and takeaway are **E-commerce** and **takeaway containers** respectively, based on the criteria and the qualitative scoring system, and therefore, are selected as the objects of assessment of the study.

As researching **reusable containers suitable for takeaway food or beverages** numerous solutions were available, however often limited to smaller geographies such as larger cities. In the Nordics only a few market players were identified.

The takeaway category includes, slightly simplified, food and beverages. The volumes for food are expected to be greater than for beverages, furthermore it is not common to use reusable packaging for food. It is the authors opinion that the potential for improvements is larger for packaging of food than for beverages.

Soft drinks (such as soda, beer, juice etc.) are already covered by the public deposit systems in the majority of the Nordic countries ensuring recycling. Takeaway coffee is a challenge as the cups cardboard (and plastic liner) and not part of the deposit system. The cups are disposable and often does not get recycled, but there has been a strong focus on this case in recent time, resulting in a lot of reusable alternatives present on the market already.

Ultimately, it has been decided to investigate solutions for food as this seems to have the highest potential compared to beverages - Figure 5 illustrates a few examples of reusable packaging systems for foods.

Figure 5 Examples of reusable containers suitable for takeaway food.

The majority of the research reusable systems were made from plastic, only a minority were made from metal. Compared to metal, plastic is lightweight and therefore seems to be the most promising material. Therefore, a plastic container will be included as a case study.

When researching **reusable packaging solutions fit for e-commerce**, a few emerges although they do not seem common worldwide. A few companies operating in the Nordics were identified providing both shipper bags and boxes made from plastic or fibre – see Figure 6.

Figure 6 Examples of reusable packaging suitable for e-commerce.

The plastic shipper bags are versatile, does not require void filler material e.g., air pillows, packaging peanuts, or kraft paper (which boxes do), and is expected to be more durable than the fibre-based alternatives. Due to the many reuses, the plastic bags can potentially be looped many times in a circular system and are therefore chosen as a case study.

4. Goal and Scope of the LCA

In this chapter, the first phase of the LCA will be presented, where the five selected case studies are described, along with the followed methodology, system definitions, and assumptions, in order to fulfil the defined goal.

4.1 Goal of the study

This section aims to determine the goal of the study, intended use of the assessment and its potential users.

4.1.1 Reasons for carrying out the study

Packaging waste volumes are increasing and are amplified by trends in increased convenience, on-the-go consumption, and e-commerce. The EU wants to reduce the consumption of single-use plastics and foster recycling to incrementally ensure plastic packaging circularity (European Commission, 2022). Currently, some packaging waste is recycled but the majority is still incinerated in the Nordic countries. The potential environmental benefits of focusing on circular economy and on reusable packaging alternatives will be analysed in this study.

The reason for carrying out this study is to increase the knowledge base on climate and other environmental effects of reuse of packaging, to support more sustainable choices. The study shall thus evaluate the potential environmental impacts of reusable packaging solutions, specifically transport packaging and primary packaging in takeaway sector, compared to the present single-use, disposable solutions from a cradle-to-grave perspective. Hence, a comparison of the environmental impacts of generic reusable packaging systems against generic single-use packaging will be conducted. **The goal is to gain knowledge and identify aspects that makes each solution a better or worst option according to its environmental impacts**.

4.1.2 Intended audience and application

The study is commissioned by the Nordic Council of Ministers and steered by representatives from the national environmental protection agencies of respectively Denmark, Sweden, Norway, and Finland. The study is to be disclosed to the public as the commissioner will publish the study online.

The intended audience are the public, private companies, and authorities. The results are to be used by public authorities and companies within the geographical scope of the Nordic countries. The results can also be useful for private companies to create better solutions regarding packaging and support identifying important aspects that must be fulfilled to ensure a less environmentally damaging solution. An executive summary is included addressing high-level decision makers within the specified groups.

The study includes comparative assertions between reusable and disposable packaging solutions. The study is conducted according to the principles and framework of ISO 14040 (ISO, 2006a) and the requirements of ISO 14044 (ISO, 2006b).

4.2 Scope

This section scopes the LCA in accordance with the goal and intended application as formulated in the previous section. Together with the goal definition it determines how the other LCA steps should be performed. Scoping ensures the consistency of the applied methods, assumptions, and data and to strengthen the reproducibility of the study. Therefore, case studies are described, as well as time coverage, technology coverage, end-of-life allocation approach, cut-off criteria, LCIA methodology, data quality requirements, Circular Footprint Formula description, assumptions and limitations on a system level, normalisation and weighting, and critical review process.

Two different reusable systems will be assessed and compared to its single-use packaging alternative as part of this study:

- Reusable container for takeaway vs single-use container
- Reusable e-commerce packaging vs single-use cardboard vs single-use plastic

4.2.1 Case studies description

The comparison of the different systems is based on representative case studies, i.e., studied product systems in their **base cases**. Each base case assessment is used as a general, hypothetical generic setup to illustrate the potential environmental impact of the respective packaging solutions. Thereby, potentially decisive parameters, assumptions, data, etc. around the respective systems are identified. The base case comparison should thus be understood as an evidence-based reference for deriving potential boundary conditions under which one or the other system may be preferable in terms of certain environmental impacts.

The reuse rate for reusable packaging refers to the number of times a particular packaging material or container is used before it is either recycled or disposed of. The number of uses (for multiple use) relates to the reuse rate as defined in Equation (1).

$$\text{Number of uses} = \frac{1}{100\% - \%\ \text{reuse rate}} \qquad (1)$$

Takeaway containers

Takeaway containers are packaging containers that store and contain meals. The specific function can be different depending on the type of food being stored, however, it is relevant the container is made of a food grade material that can resist heat.

Functional unit

The following functional unit was chosen for the **takeaway food containers**,

"To contain and protect one 1.25 litres restaurant meal for 1 use in one of the Nordic countries".

With this functional unit, the single-use and reusable containers can be compared, as they are expected to achieve the same function. A volumetric function is used, as it accounts for the fact that the packaging solutions might weight different based on their materials. Also allowing suitability for different types of food, such as salads, Chinese, Indian, Thai, etc. It is assumed that the materials used in the takeaway market at the moment are made from food grade materials and are heat resistant.

Additional functions (also referred to as secondary use or service) could be relevant to include in the study as single-use products can be reused, either for the same or a different purpose by the user. For example, many takeaway containers can be washed and reused for storing food and leftovers. Yet this assessment is studying the environmental impacts of packaging as a system, for which secondary use will be out of scope, and therefore excluded as part of this study. Additional uses may be avoided if there are sufficient incentives to return the reusable packaging systems which is a presumption for this study.

Single-use takeaway container

Single-use takeaway containers come in many different designs and shapes. They differ based on the type of food being stored on, e.g., on size, material, see Figure 7.

In general, many takeaway food containers on the Nordic markets are expected to be made from fibres (lined with plastic) or plastic or a composite. For example, it is common for salads to see a design consisting of a fibre bowl with a plastic lid. The most common plastic material for hard containers are polypropylene and extruded polystyrene (Gallego-Schmid, Mendoza, & Azapagic, 2019). Aluminium containers with a cardboard lid are also present but is considered rare.

Figure 7 Examples of single-use takeaway containers.

To specify which container type to be assessed as the reference product, the current, most widely use containers in the Nordics were assessed. Given that part of the reason of the study is to evaluate reusable packaging against plastic single-use packaging, a plastic takeaway container will be evaluated. The single-use container was defined as a polypropylene plastic tray, which is one of the more common plastic containers on the market (Gallego-Schmid, Mendoza, & Azapagic, 2019).

Multiple-use takeaway container

Reusable packaging for takeaway food refers to containers, boxes, or bags designed to be used multiple times for the purpose of transporting and storing meals. These packaging solutions come in various volumes, materials, and sizes tailored to the diverse needs of consumers and businesses. Volume-wise, they can range from small individual portions (500 ml) to larger sized containers (1250 ml), or with compartments to accommodate different quantities of food. In terms of materials, reusable packaging can be made from durable options such as stainless steel, glass, or high-quality food-grade plastic. The choice of materials depends on factors like cost, weight, durability, and sustainability. This versatility in volume, materials, and size allows for the effective transportation of takeaway food while minimising single-use waste. The reusable container was defined as a plastic container, based on data reported by reusable container operators (see Appendix E)

Reference Flow

Considering the different lifetimes for the two types of packaging the reference flow will describe the quantified number of product(s), including product parts, necessary for a specific product system to deliver the performance described by the functional unit.

The reference flow for each of the product systems are listed in Table 5.

Table 5 Takeaway – Description of the product systems and key parameters for the base case comparison.

Aspect	Single-use	Multiple use
Picture	[1] 	[2] 
Raw material and subsequent processing/ manufacturing	Virgin PP	Virgin PP
Type of use	Single-use	Multiple use
Number of uses	Out of scope	10
Reuse rate (%)	0%	90%
Max. load capacity (liter)	1.25	
Net container weight (kg)	0.059	0.226
Transport Factory to retail	3,500 km by truck (>32 t, EURO 4)	
Transport Retail to final client	62%: 5 km, by passenger car (average) 5%: 5 km round trip, by van (lorry <7.5t, EURO 3 with utilisation ratio of 20%) 33%: no impact modelled	
End-of-life treatment	Average treatment within the Nordic Countries	
Reference Flow		
Reference Flow (kg)	0.059	0.022

1. (TIYA Takeout Food Containers, 2023)
2. (Mepal, u.d.)

The following further assumptions are made in the table:

- Reuse rate (for multiple use): Due to lack of information, a 90% reuse rate is assumed.

E-commerce

The e-commerce packaging (secondary transport packaging) has the main purpose of covering and protecting goods, while being transported from the manufacturing to the use phase. Packaging usually differs greatly in size and material depending on the contained products. For the sake of this study, the type of goods being contained in the e-commerce packaging is defined as clothing, as it is the most common type of goods sold in the Nordic countries under study (Tilastokeskus, 2022; Statistics Denmark, 2022; Statistics Sweden, 2022; Statistics Norway, 2022). Therefore, a standard cloth packaging is chosen, i.e., assuming that no special care is required such as protection of fragile, heat-sensitive, and hazardous goods.

The clothing itself may be packed in a primary packaging for the handling in the warehouse in, e.g., a plastic bag. This primary packaging is not included in the scope as it is understood to be the same regardless of secondary packaging.

Functional Unit

The following functional unit was chosen for the **e-commerce packaging**:

"To contain and protect one shipment of clothes (1 time) with a maximum capacity of 21 litres in the Nordics"

Like the takeaway containers, a functional unit was defined based on the service provided by the packaging, which is to facilitate distribution and storage of a certain volume from the retailers to the users. Likewise, the positioning properties, e.g., labelling, perceived eco-friendliness, were not included as part of the functional unit as it might make the packaging not comparable.

Single-use E-commerce packaging

There are multiple transport packaging solutions on the Nordic market currently ranging from cardboard boxed with all kinds of fillers to simple shipping bags (see Figure 8). Their design and material composition differentiate greatly depending on volume, cost, and retailer preference. Boxes provide structural protection of the goods inside whereas bags (also referred to as soft packaging) are generally used for items that do not break e.g., clothing.

Figure 8 Examples of disposable e-commerce packaging.

The most bought items online in Europe (including Nordic countries Denmark, Norway, and Finland) are *clothing and footwear* according to a PostNord market survey (Postnord, 2021). In Sweden *clothing and footwear* were the second most bought only exceeded by *pharmaceuticals*.

In order to investigate which type of packaging is most common for clothing and footwear, the two biggest fashion retailers were identified, and their packaging solutions investigated. In 2022, the retailers with the highest net sales were Zalando in Norway, Denmark, and Finland, and H&M in Sweden (Yltaevae, 2022). Both retailers inform that they are in process of switching away from plastic to paper-based packaging solutions (Zalando, 2022, H&M, 2023) which seems to be the general trend in the market. As seen in Figure 8 Zalando and H&M packaging differentiates between paper bags (softbags) or cardboard boxes. It was understood the paper bags are used for smaller orders of clothing. Boxes are used for fragile items and larger orders.

The reference product for this study is defined as soft packaging suitable for containing clothing. The study covers both a comparison of the with a Single Use Plastic bag (SUPL) solution and a comparison with a Single Use Paper bag solution (SUPA). For SUPL a reference product of LDPE film is chosen, for SUPA a reference product like the Zalando and H&M packaging is chosen.

Both materials are assumed recyclable in the waste management system.

Reusable e-commerce

The e-commerce packaging is suitable for clothes as previously mentioned but can be used for any smaller items that are not fragile.

Reusable e-commerce bags on the market come in different sizes, from small to large. A solution that can hold up to 21 litres was chosen as reference (RePack, 2023).

Reference Flow

Considering the different lifetimes for the three packaging types, the reference flow will describe the quantified number of product(s), including product parts, necessary for a specific product system to deliver the performance described by the functional unit.

The reference flow for each of the product systems are listed in Table 6.

Table 6 E-commerce packaging – Description of the product systems and key parameters for the base case comparison.

Aspect	Single-use		Reusable
Picture			
Name of product system	SUPL	SUPA	Reusable
Raw material and subsequent processing/ manufacturing	Low density Polyethylene (LDPE) Extrusion	Paper Paper sack production	Polypropylene (PP) Extrusion and weaving
Type of use	Single-use		Multiple-use
Number of uses	1	1	4
Return rate (%)	Not applicable	Not applicable	75%
Breakage rate (%)	0	0[3]	
Dimensions (cm)	34x25x10		
Max. load capacity (litre)	21 l		
Net container weight (kg)	0.012[4]	0.065	0.118[5]
Transport factory to distribution centre	Assumed to be 3,500 km by truck (>32 t, EURO 4) (LCA method)		
Transport distribution centre to final client	100% Local: 250 km round trip by van (lorry <7.5t, EURO 3, utilisation ratio of 20%). (LCA method)		
End-of-life treatment	Average treatment within the Nordic Countries		
Reference Flow			
Reference Flow (kg)	0.012	0.065	0.0295

3. It is assumed that even if a single use container breaks after one trip, it has already fulfilled its purpose (functionality) unless the product gets damaged.
4. (Miljøstyrelsen, 2023)
5. https://www.originalrepack.com/files/RePack-Carbon-and-Waste-Footprint-english.pdf

4.2.2 System Boundaries

The study includes all life cycle stages from cradle-to-grave for the five studied systems, an initial diagram of both systems is presented in Figure 9.

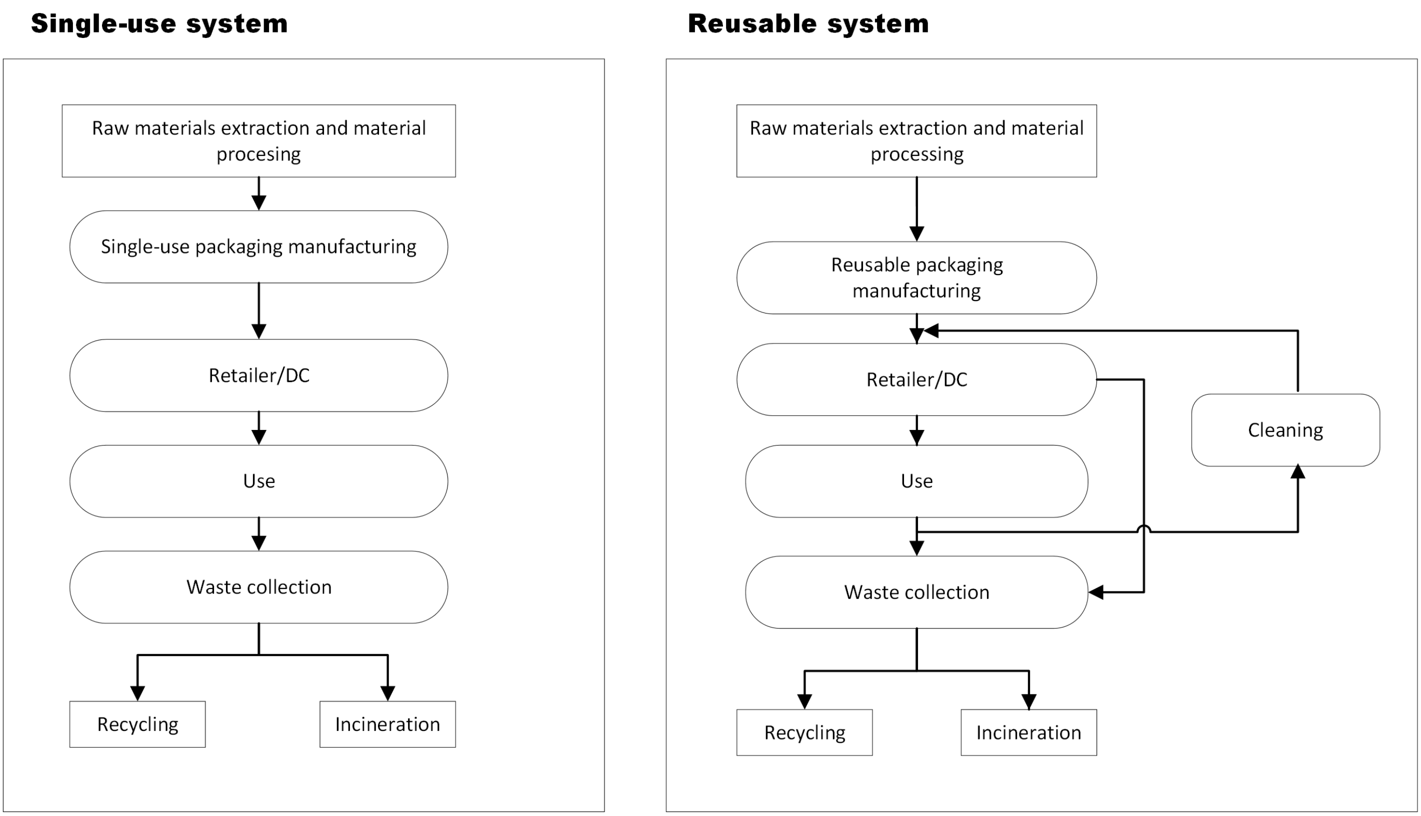

Figure 9 System boundaries for the single-use and reusable systems for both takeaway container and e-commerce. Transportation and utilities are included inside the system boundaries, but not shown in the diagram for simplicity.

Environmental impacts are presented in this study grouped by life cycle stages – this is aimed at facilitating disclosure of results. Table 7 lists the life cycle stages included for each system.

Table 7 Overview of life cycle stages and processes of the two single-use and reusable systems included in the analysis.

Life cycle stage	Single-use	Reusable
Raw material extraction	• Cradle-to-gate production of the main materials	• Cradle-to-gate production of the main materials
Manufacturing	• gate-to-gate production of the single-use packaging • cradle-to-gate production of auxiliary materials and products • gate-to-gate recycling to recycled plastic granulate (input) • waste treatment of pre-consumer production waste • intermediate transports	• gate-to-gate production of the reusable packaging • cradle-to-gate production of auxiliary materials and products • gate-to-gate recycling to recycled plastic granulate (input) • waste treatment of pre-consumer production waste • intermediate transports
Distribution	• transport of the packaging from manufacturing plants to retailer/restaurants	• transport of the packaging from manufacturing plants to retailer/restaurants
Use	• transport of the packaging to the final user	• transport of the packaging to the final user • Pre-cleaning by user either by hand or dishwasher (Only for takeaway container system) • Reverse logistics for transporting packaging to service/ distribution centre. • Washing of the packaging (Only for the takeaway)
End-of-life treatment: recycling	• transport from customer to recycling plant • post-consumer collection and sorting • recycling process • intermediary transports	• transport from customer to recycling plant • post-consumer collection and sorting • recycling process • intermediary transports
End-of-life treatment: incineration	• transport from customer to incineration plant • incineration with energy recovery of sorted post-consumer waste • intermediary transports	• transport from customer to incineration plant • incineration with energy recovery of sorted post-consumer waste • intermediary transports
Credits for material	• Post-consumer credits, as cradle-to-gate plastic granulate production or paper fibre	• Post-consumer credits from the converting, as cradle-to-gate granulate production
Credits for energy	• Post-consumer credits, as cradle-to-consumer Nordic electricity grid mix • Post-consumer credits, as cradle-to-consumer thermal energy according to the Nordic mix	• Post-consumer credits, as cradle-to-consumer Nordic electricity grid mix • Post-consumer credits, as cradle-to-consumer thermal energy according to the Nordic mix

Exclusion

The content inside the packaging, including the main goods and extra additaments (e.g. cutlery in the case of the takeaway or plastic bag in the case of clothing) and possible secondary use of the packaging box or possible return of clothes is expected to be the same between the compared systems.

Clothing return (e-commerce case) is excluded for this study, as the process is assumed to be identical for both systems (single-use and reusable)

4.2.3 System boundaries towards nature and geographical Scope

All known use of resources and emissions to air, water, and soil are included. The environmental impacts of the various activities in the life cycle are included regardless of geographic location. The sensitivity of the recipient environment in question has not been considered. The geographical location for the use of the packaging solutions is the Nordics.

This geographical boundary mostly is reflected in the assumptions around the foreground systems (e.g., manufacturing processes, transport distance and recycling rates) and the implemented background datasets (e.g., electricity from grid). The geographical scope of all background processes is documented transparently.

4.2.4 Life Cycle Impact Assessment (LCIA) methodology

The impact assessment method used is the EU Environmental Footprint method 3.1,[6] which is an internationally recognized method, using the ecoinvent 3.9.1 database. This impact method was selected as it is on scope for the Nordic countries, and it covers a broad range of relevant environmental impacts.
The default impact categories are listed in Table 8, including the impact category indicator and its robustness according to the Plastic LCA method (Nessi, et al., 2021). This study includes the impact categories that have a robustness of I or II. For indicators with robustness III a case specific reasoning was developed. For all of these the following disclaimer should be considered:

Disclaimer for results of indicators with Robustness level III (default EN 15804+A2 disclaimer)

The results of this environmental impact indicator shall be used carefully as the uncertainties on these results are high or as there is limited experienced with the indicator.

6. The EF Flows, Methods, Characterisation Factors, Unit Groups and Flow Properties can be accessed through the website of the *European Platform on LCA* (EPLCA) https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml

Included in the study are the listed indicators with robustness class III due to the following reasoning:

- Land Use
  - To reveal the effect between biobased and fossil systems, i.e., paper and fossil
  - The LANCA method could be included to the extend implemented in the database, as generic products are modelled.
- Water Use
  - To reveal the effect of washing in reusable systems
  - The AWARE method could be included to the extend implemented in the database, and as implemented in the software.
- Resource Use – minerals and metals;
  - To reveal the effect of resource use in reusable systems
  - It is understood that the characterisation method with ultimate stock reserves might be outdated, but the study is consistent across the assessed systems, such that an indication for the resource depletion can still be derived
- Resource use – fossils
  - To reveal the effect of resource use in reusable systems
  - It is understood that the characterisation method with ultimate stock reserves might be outdated, but the study is consistent across the assessed systems, such that an indication for the resource depletion can still be derived

From the study excluded impact categories are "Human toxicity – non-cancer effect", "Human toxicity – cancer effects" and "Ecotoxicity, fresh water". (Nessi, et al., 2021) specify that the uncertainties of these indicators can be up to 1-2 orders of magnitude. To avoid misleading comparative assertions due to mistakes in the background data or LCIA method no results are presented for these indicators.

Table 8 Impact categories from EF method 3.1, their robustness and inclusion in the study.

EF Impact category	Impact category indicator	Robustness	Included
Climate change	kg CO2eq	I	X
Ozone Depletion	kg CFC-11 equivalent	I	X
Human toxicity – non-cancer effect	CTUh (Comparative Toxic Unit for humans)	III	
Human toxicity – cancer effects	CTUh (Comparative Toxic Unit for humans)	III	
Particulate Matter/Respiratory Inorganics	Disease incidences	I	X
Ionising Radiation – human health effects	kBq U-235 eq	II	X
Photochemical Ozone Formation	kg NMVOC eq	II	X
Acidification	mol H+ eq	II	X
Eutrophication, terrestrial	mol N eq	II	X
Eutrophication, fresh water	kg P eq	II	X
Eutrophication, marine	kg N eq	II	X
Land Use	pt (Regionalised CFs)	III	X
Ecotoxicity, fresh water	CTUe (Comparative Toxic Unit for ecosystems)	III	
Water Use	m3 water eq of deprived water (Regionalised CFs)	III	X
Resource Use – minerals and metals	kg antimony (Sb) equivalent	III	X
Resource use – fossils	MJ	III	X

4.2.5 Data quality requirements

According to ISO 14044 data quality requirements must be included for the following aspects:

Technological representativeness

The technological representativeness for both singe use and reusable packaging systems relate to modern, current state level in means of production, transport, and EoL processing. Secondary data represents average technologies used in the respective geographies of the life cycle stage, as described in respective background datasets.

Geographical representativeness

In general, all data and assumptions refer to or are applicable to the respective geographical scopes, as long as data availability allows. Geographical coverage is, however, dependent on the available data. Geographical coverage of primary and secondary data is disclosed in the respective inventories in the Life Cycle Inventory section of this study.

Time-related representativeness

The reference time of the primary data is no older than 2020. Secondary data is retrieved, when possible, from the past 5 years. If no data can be retrieved in the past 5 years, the research is extended to the past 10 years, especially for the secondary data which is mainly based on desk-research findings. However, for some secondary datasets, the research is extended to more than 10 years.[7] Crucial life cycle stages and processes refer to the most recent literature and guidance documents or otherwise publicly available information. At the time of modelling latest available secondary data is implemented for background processes (see section 5.4).

Precision

The accuracy of the data is achieved by using primary data to the extent possible. Key parameters with a high level of uncertainty will be tested on the sensitivity analysis to assess their variability.

Completeness

Data exclusions are reported transparently under the system boundaries and limitation section. Cut-offs have been applied consistently across the life cycle for each of the products being compared.

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7. Secondary data is retrieved from ecoinvent 3.9.1, and it could be possible that some of the datasets are older than 10 years. In some cases, datasets (more than 10 years old) have been "extrapolated to the year of calculation [year 2022]". The latter means that, to some extent, information used for providing the dataset has not been updated, but rather calculations have been performed to extrapolate this information to the year of the publishing of the database.

Consistency

Consistency in the assumptions, modelling choices, and the selection of data sources is of utmost importance for this comparative assessment. In the absence of unambiguous data or references for critical assumptions equal assumptions or references are applied to all product systems. The LCA methodology is uniformly applied to all product systems, and it is ensured that modelling and methodological choices do not affect the results and conclusions. If so, respective modelling and methodological choices are reflected in the sensitivity analysis. The CFF formula is used in this study to increase consistency of the results. Moreover, to increase consistency of the results, one single database for background data (secondary data) is used in the model.

Reproducibility

Primary data, context information, and reference flows are disclosed to the extent possible. All other assumptions as well as implementation of secondary data is documented in a way that allows for reproduction of the underlying models.

Uncertainty of information

Major uncertainties are addressed by means of a sensitivity analysis as well as qualitative discussions. Remaining uncertainties are taken into consideration when interpreting results.

4.2.6 Allocation

Allocation refers to the partitioning of the inputs and outputs of a process or product system between the product system under study and one or more other product systems. Allocation methods reflect value choices; thus it was chosen to follow the recommendations of the Plastic LCA method in this study. This leads to different allocation methods across the study aiming to reflect the relationship of the product systems to the connected environmental impact of different processes. These are for example for washing (number of dishes), transport by van (weight), transport by car (volume), and waste management (the CFF).

Further the secondary data induce their inbuilt allocation procedures. These were adopted unchanged.

4.2.7 Circular Footprint Formula implementation

This study implements the Circular Footprint Formula (CFF), which is based on the latest available guidance.[8] The most recent applicable default application-specific and material-specific values are considered in the CFF, as available in the PEFCR and Annex C (transition phase).[9] The provided default parameters can be adjusted context-specifically, following the PEF method (European Commission, 2021) and the European Plastics LCA method in particular (Nessi, et al., 2021).

8. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021H2279#page=7 Annex 1
9. https://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml

The formula is detailed on equation 2, with its respective parameters explains in Table 9.

$$(1-R)\,E_v + R_1 \times \left(AE_{recycled} + (1-A)\,E_v \times \frac{Q_{\text{sin}}}{Q_p}\right) + (1-A)\,R_2 \times \left(E_{recycl \in gEoL} - E_v \times \frac{Q_{Sout}}{Q_P}\right)$$
$$+ (1-B)\,R_3 \times (E'_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec'} \times E_{SE,elec})$$
$$+ (1-R_2-R_3) \times E_D$$

(2)

$$(1-R)\,E_v + R_1 \times \left(AE_{recycled} + (1-A)\,E_v \times \frac{Q_{\text{sin}}}{Q_p}\right) + (1-A)\,R_2 \times \left(E_{recycl \in gEoL} - E_v \times \frac{Q_{Sout}}{Q_P}\right)$$
$$+ (1-B)\,R_3 \times (E'_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec'} \times E_{SE,elec})$$
$$+ (1-R_2-R_3) \times E_D$$

(2)

Table 9 Parameters for the CFF, copied directly from EU,2021.

A	Allocation factor of burdens and benefits (jointly: "credits") between supplier and user of recycled materials.
B	Allocation factor of energy recovery processes. It applies both to burdens and benefits.
Q_{sin}	Quality of the ingoing secondary material, i.e., the quality of the recycled material at the point of substitution.
Q_{sout}	Quality of the outgoing secondary material, i.e., the quality of the recycled material at the point of substitution.
Q_p	Quality of the primary material, i.e., quality of the virgin material.
R_1	Proportion of material in the input to the production that has been recycled from a previous system.
R_2	Proportion of the material in the product that will be recycled (or reused) in a subsequent system. R2 shall therefore take into account the inefficiencies in the collection and recycling (or reuse) processes. R2 shall be measured at the output of the recycling plant

R_3	Proportion of the material in the product that is used for energy recovery at EoL.
$E_{recycled}$	Specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process
$E_{recyclingEoL}$	Specific emissions and resources consumed (per functional unit) arising from the recycling process at EoL, including collection, sorting and transportation process
Ev	Specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material
E*v	Specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials
E_{ER}	Specific emissions and resources consumed (per functional unit) arising from the energy recovery process (e.g. incineration with energy recovery, landfill with energy recovery, etc.).
$E_{SE,heat}$	Specific emissions and resources consumed (per functional unit) that would have arisen from the specific substituted energy source, heat and electricity respectively.
E_D	Specific emissions and resources consumed (per functional unit) arising from disposal of waste material at the EoL of the analysed product, without energy recovery or other usable product output.
$X_{ER, heat}$	The efficiency of the energy recovery process for both heat and electricity
LHV	Lower heating value of the material in the product that is used for energy recovery.

Table 10 summarises the CFF parameters for the base case analysis, used in this study. The values R1, A, B as well as Qsin/Qp and Qsout/Qp follow the default value. R2 and R3 were calculated based on the latest statistics, see section 5.3. Refer to Appendix F for a full list of factors.

Table 10 CFF parameters for different materials used in the model (base case).

Parameter*	R1	A	B	R2	R3	Qsin/Qp and Qsout/Qp
Paper packaging	0	0.2	0	80.78% (Nordic average)	19.23% (Nordic average)	1 (recycling process considers fibre loss)
Plastic packaging	0	0.5	0	30.93% (Nordic average)	69.08% (Nordic average)	0.9 (PP) 0.75 (LDPE film)

*Legend: R1= recycled content manufacturing; A= burdens and credits between supplier and user of the recycled material; R2 = recycling output rate; R3 = incineration rate; Qsin = quality of the ingoing secondary material; Qp = quality of the primary material (virgin ones); Qsout = quality of the outgoing secondary material.

4.2.8 Assumptions and limitations on a systems level

This study is based on hypothetical generic products. Thus, the life cycle inventory is based on default assumptions and available secondary production processes. Nevertheless, surveys were made to companies operating reusable packaging, to define the hypothetical generic products.

4.2.9 Normalisation and weighting

According to ISO 14040, normalisation and weighting of midpoint impact categories are optional parts of the life cycle impact assessment procedure. According to ISO 14040, weighting shall not be used in LCA studies with comparative assertions intended to be disclosed to the public. In this comparative LCA study, both normalisation and weighing are not taken into account.

4.2.10 Requirements for Comparative Studies

The assessment presented in this report will support comparative assertions intended to be disclosed to the public, therefore the following additional reporting requirements will be stated on the report, as specified in ISO 14044 (2006b):

- analysis of material and energy flows to justify inclusions or exclusion;
- assessment of the precision, completeness and representativeness of data used;
- description of the equivalence of the systems being compared;
- description of the critical review process;
- an evaluation of the completeness of the LCIA;
- a statement as to whether or not international acceptance exists for the selected category indicators and a justification for their use;
- an explanation for the scientific and technical validity and environmental relevance of the category indicators used in the study;
- the results of the uncertainty and sensitivity analyses;
- evaluation of the significance of the differences found.

4.2.11 Critical review needs

A critical review is recommended to increase the quality and credibility of the LCA study, and according to ISO requirements, a critical review is required in case of publishing comparative assertions disclosed to the public.

Following the ISO 14044 guidelines (2006b), a critical review is conducted by LCA-expert Tomas Ekvall, Adjunct Professor in Environmental Systems Analysis at Department of Technology Management and Economics at Chalmers University, Sweden. The review is performed continuously throughout the study to ensure an iterative process. The review is not a panel review and does hereby not adhere to the standard. The final review report is included as Annex N in this the report.

5. Life Cycle Inventory Analysis

In this section, the data used as an input for performing the LCA is described, including relevant processes, assumptions and identified gaps.

5.1 Data Collection

The required data was collected from different sources. Primary data was gathered, whenever possible directly from companies, or from collected samples, to attempt to approximate reality on parameters such as raw materials, energy, waste, return rates, means of transport and distances, among others.

In case primary data was not available, secondary data was retrieved from literature, statistics and LCI databases.

5.1.1 Data from companies

Primary data was collected from companies operating in the Nordic countries offering reusable packaging systems within e-commerce and takeaway containers, with the support from the New European Reuse Alliance. Companies included are: kleenhub, reCIRCLE, Re-zip, Repack, Kamupak, among others (see Appendix E). The data collection was carried out via a questionnaire to assess the different types of systems in the market at the moment the study was performed. The data gathered was then reviewed to assess completeness and cohesion. It was found that the reviewed systems are very different from each other, therefore showing there is not a standard way a reusable system operates within this region. However, the collected data was used to find similarities and create a hypothetical setup, i.e., no specific product is modelled, but the information is used to inform the generic model. The data was then connected with its appropriate LCI datasets on the LCA model.

5.1.2 Secondary data collection

Whenever there were data gaps, secondary data was retrieved from statistics, literature, and LCI datasets, specifically for the end-of-life processes.

5.1.3 Cut-off criteria

The cut-off criteria applied in this Life Cycle Assessment (LCA) for generic product systems take into consideration the limited availability and intended generic representability of foreground data.

Given the constraints, we employed the following cut-off rules:

1. Equipment and infrastructure employed during use phase, such as washing machines, and end of life, such as waste collection containers.

Despite these limitations, it should be explicitly noted that no flows were intentionally excluded from the analysis for reasons beyond these cut-off rules.

These cut-off criteria, although necessary due to data constraints, may affect the precision of the analysis and this limitation should be acknowledged when interpreting the results of this study. Notably, the cut-off criteria in the background data represent a significant impact on the excluded flows.

5.2 System Modelling Per Life Cycle Stage

In this section, the inventory data for each life cycle stage is described for both of the takeaway containers and e-commerce bags.

5.2.1 Takeaway containers

The life cycle stages of the systems are described below. For more details on the LCI, such as specific values and dataset collection please refer to Appendix G.

Raw material extraction and manufacturing

- The production is assumed to take place in Europe.
- The manufacturing stage was modelled similarly for both takeaway systems (single-use and reuse). As previously mentioned, both containers are assumed to be made from polypropylene. The lid of the multiuse container is made from polypropylene and thermoplastic elastomer (TPE).
- Different manufacturing processes are employed depending on the material, shape and size of the container. According to Gallego et al. (2019), the method used for manufacturing a single-use polypropylene container, consists of extrusion and thermoforming. The multiuse polypropylene container was assumed to be produced by injection molding, according to questionnaire from the reusable takeaway containers operators (see Appendix E).

Distribution

- For both systems, the product is transported from the production plant to the location of use, which in this case is assumed to be in the Nordics. A distance of 3,500 km by truck is used following the Plastic LCA method, assuming it is an intracontinental supply chain (Nessi, et al., 2021).

Use

- The use phase considers the transportation from the restaurant to the user for both systems. The transportation from restaurant to final user is defined to be 5 km (62% by car; 5% by van; and 33% no impact modelled), following the Plastic LCA method (Nessi, et al., 2021).
- The cleaning of the reusable containers is modelled in two phases: a pre-washing by the user and a second wash using professional dishwashers once the box is back in a service centre.
- Cleaning the takeaway box before returning it can vary a lot since it is on the consumer side. Several methods could be utilised: handwashing, dishwashing machine, or none. As no specific data was obtained regarding the share of each of the methods from a user behaviour perspective, an equal share is assumed for each method. For each method there are also several factors that can differ, e.g., model/year of dishwasher (which will impact the efficiency of water and energy consumption), use of soap and water while handwashing. Therefore, the following assumptions were made:
    - Handwashing and dishwashing energy, water, and washing-up liquid values were obtained from Porras et al. (2020) and were allocated based on the total number of dishes loaded, to obtain a value per item. For the manual hand washing a combination for running tap water and water bath was assumed, while for the dishwashing machine a normal stainless-steel machine was used. Table 11 summarised the values used.
    - The electricity required is modelled with the Nordic mix.
    - The washing up liquid used for the dishwashers was modelled assuming the same chemical composition from a datasheet of capsules for dishwashers (Procter & Gamble, 2016).
    - The dishwasher or the sink used to wash the takeaway container is not consider in the system boundaries and is therefore not accounted on this study.
- The same distance and transportation methods as the transportation from restaurant to the user is assumed for returning the container back to the restaurant, since according to interviewed companies providing reusable packaging services in the Nordic countries, usually the cleaning service is carried out by the restaurants.
- Additionally, once the container is returned back to a restaurant, it is assumed that it is required to be cleaned in a professional dishwasher to ensure meeting hygiene requirements. Average values for water, energy and soap were extracted from literature/energy labels to model this process, as seen in Table 11.

Table 11 Inventory data for modelling washing services.

Parameter	Energy (kWh)	Water (L)	Soap (g)	Source
Pre-washing				
Manual	0.03	0.62	0.34	Porras et al. (2020)
Dishwasher	0.02	0.17	0.19	Porras et al. (2020)
Washing service				
Professional dishwasher	0.077	0.038	0.08	(de Jong, 2023)

- The reuse rate was established to be 10 times according to the 90% return rate established for the base case.

End-of-life

- At the end of its lifetime, the containers are assumed to be transported to a waste management facility where recycling or incineration is assumed to occur.

5.2.2 E-commerce bag

The life cycle stages of the systems are described below. For more details on the LCI, such as specific values and dataset collection please refer to Appendix H.

Raw material extraction and manufacturing

- The production is assumed to take place in Europe.
- For the Single Use Plastic (SUPL) system the sole Raw material is the LDPE resin (virgin), which is then extruded to a foil and formed into a bag
- For the Single Use Paper (PUPA) system the raw material consists of kraft paper (virgin), which is then converted into the paper bag is included
- For the reusable System the main raw material is Polypropylene (virgin) which is extruded and then woven into the woven bag. Further a Velcro-like closure system is included assuming the same production steps.

Distribution

- For the three systems, the product is transported from the production plant to the location of use, which in this case is assumed to be in the Nordics. A distance of 3,500 km by truck is used following the Plastic LCA method, assuming it is an intracontinental supply chain (Nessi, et al., 2021).

Use

- Shipping
  - The packaging is sent from a distribution centre to the final consumer. This transport is assumed to be 250 km, followed by the local distribution to the consumer. The transportation is defined to be 5 km (62% by car; 5% by van; and 33% no impact modelled), following the Plastic LCA method (Nessi, et al., 2021).
- Reverse logistics (reusable packaging)
  - Once used, the bag can be returned to a local mailbox or parcel shop. The same distances as for the previous shipping are assumed.
- Service center (reusable packaging)
  - The cleaning process includes the bags are inspected and possibly cleaned with a cleaning agent if needed, then transported back to the retailer, where they are reused. Some bags might not pass inspection and will be discarded e.g., if they are damaged or somehow not fit for being send back out.
- The baseline number of uses was established to be 4 times, i.e., 75% return rate for the base case.

End-of-life

- At the end of its lifetime, the bags are assumed to be transported to a waste management facility where recycling or incineration occur. The distribution between these options was adjusted according to Nordic statistics.
- Any repurposing or upcycling of the bags is excluded as part of this study.

5.3 Nordic statistics used in the study

The use phase and End-of-life treatment of the product systems is modelled for the Nordic countries. The foreground system was informed by the most recent statistics. Please prefer to Appendix D for more details.

5.4 Software and database for background data

The LCA model for this study is developed with iPoint-systems Umberto 11.10.1, using background data from Ecoinvent[10] (version 3.9.1) system model "Allocation, cut-off by classification".

10. https://www.ecoinvent.org

6. Life Cycle Impact Assessment Results

By using the base case models for all systems, impact results are provided, and main contributors to the results are presented per each impact category. The relevant comparative assertion is shown as "aggregated total" values in the respective figures, thus accounting for all positive and negative impact contributions within a system.

The baseline impact assessment results are presented for both the takeaway container and e-commerce bags, including the results for each impact category of the baseline systems and a contribution analysis for each life cycle stage for each system.

The analysis and interpretation of results is done following a consistent terminology, as presented in Table 12.

Note that the definition of the terminology to describe the relative difference between the compared systems is used consistently between all impact categories. This notation does not incorporate the uncertainty behind the results that could vary greatly between the different indicators, induced for example through methodological choices within the study, but also by the applied impact calculation methodology which have different levels of certainty, *cf.* the discussion on the robustness of the used impact categories in section 4.2.4.

Table 12 Terminology for results interpretation.

Relative difference in %	Terminologies in comparative assertion and interpretation of results
<5%	**marginal** difference
5-10%	**minor** difference
10-20%	**noticeable** difference
20-30%	**moderate** difference
30-50%	**significant** difference
>50%	**very significant** difference

The results of the comparison between the case studies are classified in the following three robustness categories.

Note that this is the definition of this study to describe the findings of the base case and sensitivity analyses. This notation does not incorporate the uncertainty induced through methodological choices within the study.

- Impact categories that show *high robustness* of results, where the comparison between the two systems is not dependent on underlying assumptions;
- Impact categories that show *medium robustness* of results, where the comparison between the two systems slightly depend on underlying assumptions;
- Impact categories that show *low robustness* of results, where the comparison between the two systems strongly depend on underlying assumptions.[11]

6.1 Takeaway containers base case comparison results

The following sections present the potential impacts per category and allow for a comparison between the two systems. Moreover, a contribution analysis is facilitated by presenting contributions from certain life cycle stages within the respective systems. For each impact category, the most important emissions are reported, as well as the most relevant sources of impacts on LCI level.

6.1.1 Takeaway containers overall results

The results of the base case are provided in Table 13 for all impact categories, excluding the three categories that constitute the Climate change total (Climate change, biogenic, Climate change, fossil; Climate change, land use and land use change) as climate change, biogenic and climate change, land use and land use change represent less than 5% of the climate change total impacts, and therefore most of the impacts from Climate change total are attributed to Climate change, fossil.

11. This assessment is done depending on the respective sensitivity analyses, however as a rule of thumb the results have low robustness if less than 2/3 of all tested sensitivity setups show the same results as the base case comparison.

Table 13 Results from base case (Takeaway) The results are compared by the difference between base case re-sults (subtracting the results of the Reusable system from the results of the Single use system) as percentage of the reusable system. The beneficial system per impact category is shaded in light green.

EF Impact category	Single-use system Base case	Reusable system Base case	Comparison and difference between base case results as percentage of the reusable
EF-Acidification [mol H+ equivalents]	6.19E-04	3.77E-04	The **reusable system** shows **significant** benefits (- 39%)
EF-Climate change, total [kg CO2-Equivalents]	2.63E-01	1.47E-01	The **reusable system** shows **significant** benefits (- 44%)
EF-Eutrophication, freshwater [kg N equivalents]	4.04E-05	2.14E-05	The **reusable system** shows **very significant** benefits (- 47%)
EF-Eutrophication, marine [kg P equivalents]	1.37E-04	8.13E-05	The **reusable system** shows **significant** benefits (- 41%)
EF-Eutrophication, terrestrial [mol N equivalents]	1.32E-03	8.09E-04	The **reusable system** shows **significant** benefits (- 39%)
EF-Ionising radiation, human health [kBq U235 equivalents]	2.27E-02	1.89E-02	The **reusable system** shows **noticeable** benefits (- 17%)
EF-Land use [pt]	2.75E-01	3.49E-01	The **single use system** shows **moderate** benefits (+ 27%)
EF-Ozone depletion [kg CFC11 equivalents]	1.63E-09	1.58E-09	The **reusable system** shows **marginal** benefits (+ 3%)

EF-Particulate matter [disease incidence]	7.12E-09	4.52E-09	The **reusable system** shows **significant** benefits (- 37%)
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	5.75E-04	3.57E-04	The **reusable system** shows **significant** benefits (- 38%)
EF-Resource use, fossils [MJ]	5.04E+00	2.73E+00	The **reusable system** shows **significant** benefits (- 46%)
EF-Resource use, minerals and metals [kg Sb equivalents]	6.87E-07	4.30E-07	The **reusable system** shows **significant** benefits (- 37%)
EF-Water scarcity [m3 world-Eq deprived]	5.42E-02	5.73E-02	The **single use system** shows **minor** benefits (+6%)

The reusable system shows lower impacts than the single-use takeaway container in all the reported impact categories, besides Land use and Water scarcity where the single-use takeaway container shows lower impact.

The relative results are also presented in Figure 10 to facilitate the interpretation of the results. The results are normalised based on the system with the highest impact for each impact category.

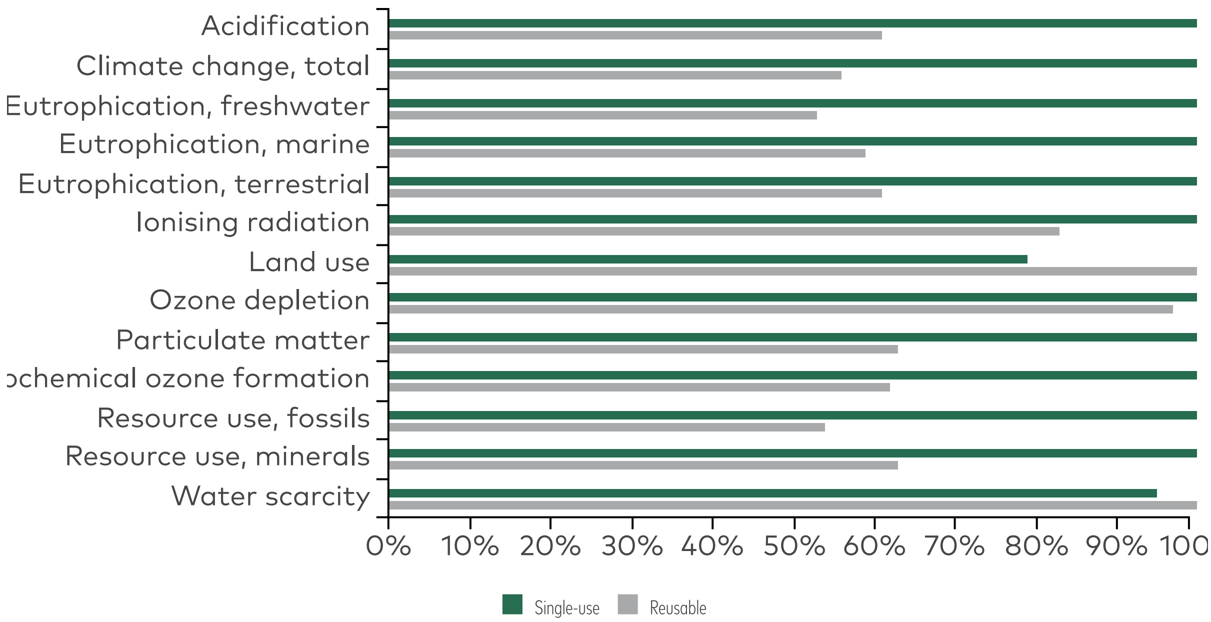

Figure 10 Results of both systems, single use and reusable, normalised to the highest impact for each impact cate-gory (Takeaway).

6.1.2 Takeaway containers contribution analysis

An environmental hotspot analysis was conducted for the single use and reusable systems in order to understand which life cycle stages contribute the most for each impact category.

Single-use takeaway container system

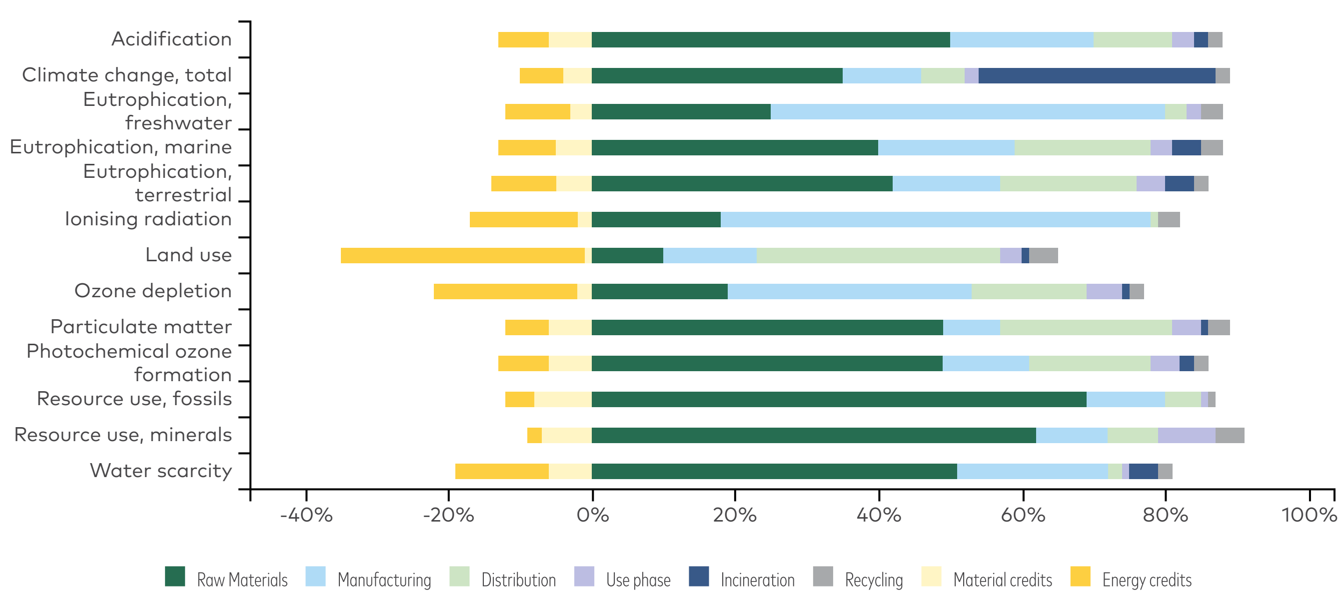

Figure 11 Single-use system contribution analysis by life cycle stage (Takeaway).

The **Raw Materials** life cycle stage contributes from 10% (Land use) to 69% (Resource use, fossils) to the environmental impacts, being one of the most impacting impact categories, specifically from the polypropylene granulate.

The **Manufacturing** life cycle stage contributes from 8% (Particulate matter) to 60% (Ionising radiation) to the environmental impacts, mainly due to electricity used during production.

The **Distribution** life cycle stage contributes from 1% (Ionising radiation) to 34% (Land use) to the environmental impacts.

The **Use** phase life cycle stage contributes from close to no contribution, 0% (Ionising radiation) to 8% (Resource use, minerals) to the environmental impacts.

The **Incineration** life cycle stage contributes from 0% (Ionising radiation) to 33% (Climate change, total) to the environmental impacts.

The **Recycling** life cycle stage contributes from 1% (Resource use, fossils) to 4% (Land use) to the environmental impacts.

Additional to the environmental burden the credits from material recycling and recovery of energy from incineration at end of life decrease the total environmental burden.

The **Material credits** life cycle stage contributes from 1% (Land use) to 8% (Resource use, fossils) to the environmental impacts.

The **Energy credits** life cycle stage contributes from 2% (Resource use, minerals) to 34% (Land use) to the environmental impacts.

Reusable takeaway container.

The results of the reusable packaging baseline can be seen in Figure 12.

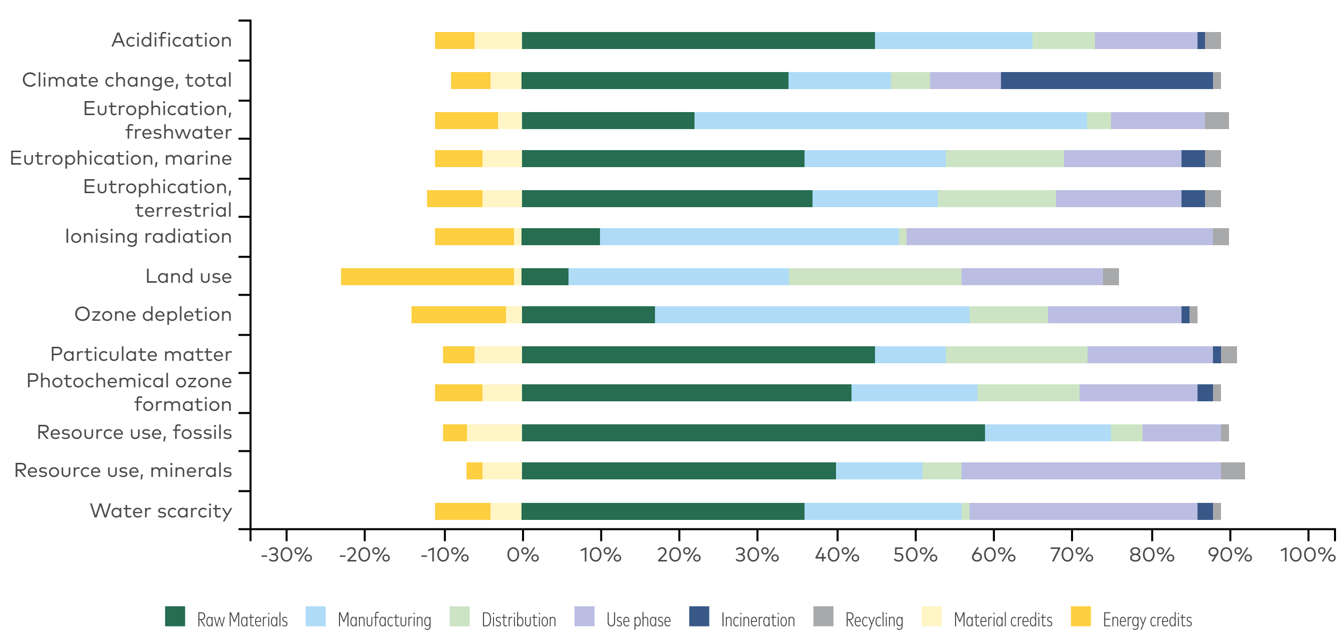

Figure 12 Reusable system contribution analysis by life cycle stage (Takeaway).

The **Raw Materials** life cycle stage contributes from 6% (Land use) to 59% (Resource use, fossils) to the environmental impacts.

The **Manufacturing** life cycle stage contributes from 9% (Particulate matter) to 50% (Eutrophication, freshwater) to the environmental impacts.

The **Distribution** life cycle stage contributes from 1% (Ionising radiation) to 22% (Land use) to the environmental impacts.

The **Use** phase life cycle stage contributes from 9% (Climate change, total) to 39% (Ionising radiation) to the environmental impacts. The use stage has a higher contribution to the life cycle compared to the single use system, mainly due to the take back logistics and electricity required for washing.

The **Incineration** life cycle stage contributes from 0% (Ionising radiation) to 27% (Climate change, total) to the environmental impacts.

The **Recycling** life cycle stage contributes from 1% (Resource use, fossils) to 3% (Eutrophication, freshwater) to the environmental impacts.

Additional to the environmental burden the credits from material recycling and recovery of energy from incineration at end of life decrease the total environmental burden.

The **Material credits** life cycle stage contributes from 1% (Land use) to 7% (Resource use, fossils) to the environmental impacts.

The **Energy credits** life cycle stage contributes from 2% (Resource use, minerals) to 22% (Land use) to the environmental impacts.

It is observed that even though the reusable container is heavier and therefore uses a higher quantity of raw material and processing than the single-use, all life cycle stages of the reusable container (except the use phase) contribute less to the whole life cycle than the single-use. This is due to the number of uses, since it is reused the impacts of these stages are divided into the number of cycles.

6.2 E-commerce base case comparison results

The following sections present the potential impacts per category and allow for a comparison between the systems. Moreover, a contribution analysis is facilitated by presenting contributions from certain life cycle stages within the respective systems. For each impact category, the most important emissions are reported, as well as the most relevant sources of impacts on LCI level.

6.2.1 E-commerce overall results

Overall results and comparison for the E-commerce base cases (single use plastic bag and reusable bag) are given in Table 14.

Table 14 Results from base cases "Single use plastic bag system" and "Reusable bag system". The results are compared by the difference between base case results (subtracting the results of the Reusable system from the results of the Single use system) as percentage of the reusable system. The beneficial system per impact category is shaded in light green.

EF Impact category	Single use plastic bag system - Base case	Reusable bag system – Base case	Comparison and difference between base case results as percentage of the reusable
EF-Acidification [mol H+ equivalents]	1.48E-04	3.63E-04	The **single use system** shows **very significant** benefits. (-59%)
EF-Climate change, total [kg CO2-Equivalents]	6.18E-02	1.34E-01	The **single use system** shows **very significant** benefits. (-54%)
EF-Eutrophication, freshwater [kg N equivalents]	6.90E-06	2.11E-05	The **single use system** shows **very significant** benefits. (-67%)
EF-Eutrophication, marine [kg P equivalents]	3.52E-05	8.39E-05	The **single use system** shows **very significant** benefits. (-58%)
EF-Eutrophication, terrestrial [mol N equivalents]	3.45E-04	8.42E-04	The **single use system** shows **very significant** benefits. (-59%)
EF-Ionising radiation, human health [kBq U235 equivalents]	3.39E-03	1.04E-02	The **single use system** shows **very significant** benefits. (-68%)
EF-Land use [pt]	1.01E-01	3.91E-01	The **single use system** shows **very significant** benefits. (-74%)
EF-Ozone depletion [kg CFC11 equivalents]	2.08E-10	1.08E-09	The **single use system** shows **very significant** benefits. (-81%)

EF-Particulate matter [disease incidence]	1.79E-09	4.55E-09	The **single use system** shows **very significant** benefits. (-61%)
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	1.65E-04	3.76E-04	The **single use system** shows **very significant** benefits. (-56%)
EF-Resource use, fossils [MJ]	1.03E+00	2.57E+00	The **single use system** shows **very significant** benefits. (-60%)
EF-Resource use, minerals and metals [kg Sb equivalents]	1.89E-07	6.19E-07	The **single use system** shows **very significant** benefits. (-69%)
EF-Water scarcity [m3 world-Eq deprived]	2.42E-02	4.65E-02	The **single use system** shows **significant** benefits. (-48%)

Table 14 shows that the single use system (plastic) presents lower environmental impacts in all impact categories compared to the reusable bag system.

Overall results and comparison for the E-commerce base cases (single use paper bag and reusable bag) are given in Table 15.

Table 15 Results from base cases "Single use paper bag system" and "Reusable bag system". The results are com-pared by the difference between base case results (subtracting the results of the Reusable system from the results of the Single use system) as percentage of the reusable system. The beneficial system per impact category is shaded in light green.

EF Impact category	Single use paper bag system - Base case	Reusable bag system – Base case	Comparison and difference between base case results as percentage of the reusable
EF-Acidification [mol H+ equivalents]	4.42E-04	3.63E-04	The **reusable system** shows **moderate** benefits. (22%)
EF-Climate change, total [kg CO2-Equivalents]	1.00E-01	1.34E-01	The **single use system** shows **moderate** benefits. (-25%)
EF-Eutrophication, freshwater [kg N equivalents]	1.09E-04	2.11E-05	The **reusable** system shows **very significant** benefits. (417%)
EF-Eutrophication, marine [kg P equivalents]	5.58E-04	8.39E-05	The **reusable** system shows **very significant** benefits. (566%)
EF-Eutrophication, terrestrial [mol N equivalents]	1.61E-03	8.42E-04	The **reusable** system shows **very significant** benefits. (91%)
EF-Ionising radiation, human health [kBq U235 equivalents]	-1.86E-03	1.04E-02	The **single use system** shows **very significant** benefits. (-118%)
EF-Land use [pt]	1.12E+01	3.91E-01	The **reusable system** shows **very significant** benefits. (2756%)
EF-Ozone depletion [kg CFC11 equivalents]	2.86E-09	1.08E-09	The **reusable system** shows **very significant** benefits. (165%)
EF-Particulate matter [disease incidence]	6.56E-09	4.55E-09	The **reusable system** shows **significant** benefits. (44%)
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	5.39E-04	3.76E-04	The **reusable system** shows **significant** benefits. (43%)
EF-Resource use, fossils [MJ]	1.16E+00	2.57E+00	The **single use system** shows **very** significant benefits. (-55%)
EF-Resource use, minerals and metals [kg Sb equivalents]	4.12E-07	6.19E-07	The **single use system** shows **significant** benefits. (-33%)
EF-Water scarcity [m3 world-Eq deprived]	4.18E-02	4.65E-02	The **single use system** shows **noticable** benefits. (-10%)

Table 15 shows that the single use system (paper) presents lower environmental impacts in the categories Climate change total, Ionising radiation, Resource use fossils, and Resource use minerals and metals. In all other categories the reuse system presents lower environmental impacts than the single use system (paper).

The relative results are also presented in Figure 13 to facilitate the interpretation of the results. In the figure the results are normalised based on the system with the highest impact for each impact category.

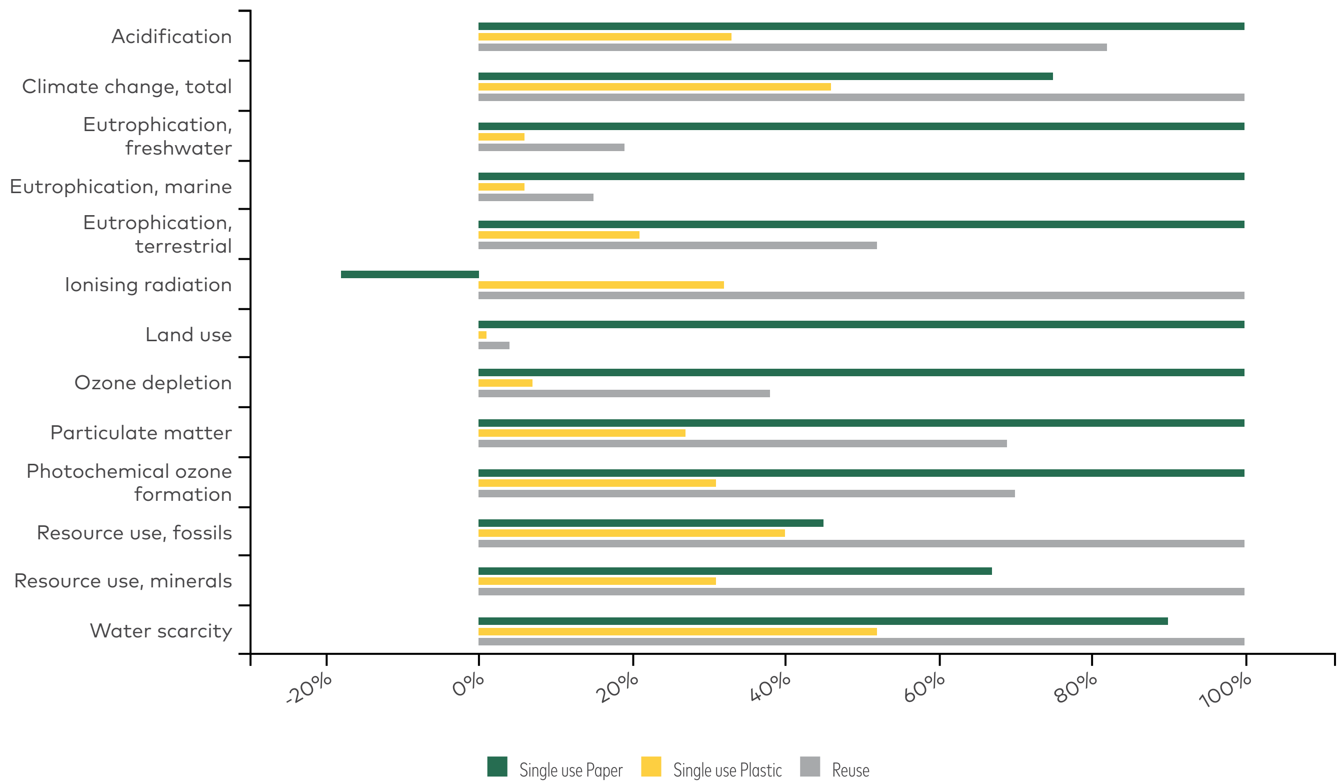

Figure 13 Results of the three studied systems, single use paper and plastic and reusable, normalised to the high-est impact for each impact category.

6.2.2 E-commerce contribution analysis

The contribution of each life cycle stage is reviewed for all assessed impact categories in Figure 14 (single use plastic bag) Figure 15 (single use paper bag) Figure 16 (reusable bag). Please refer to Appendix J for the result table and the contribution figures excluding credits.

Single use plastic system

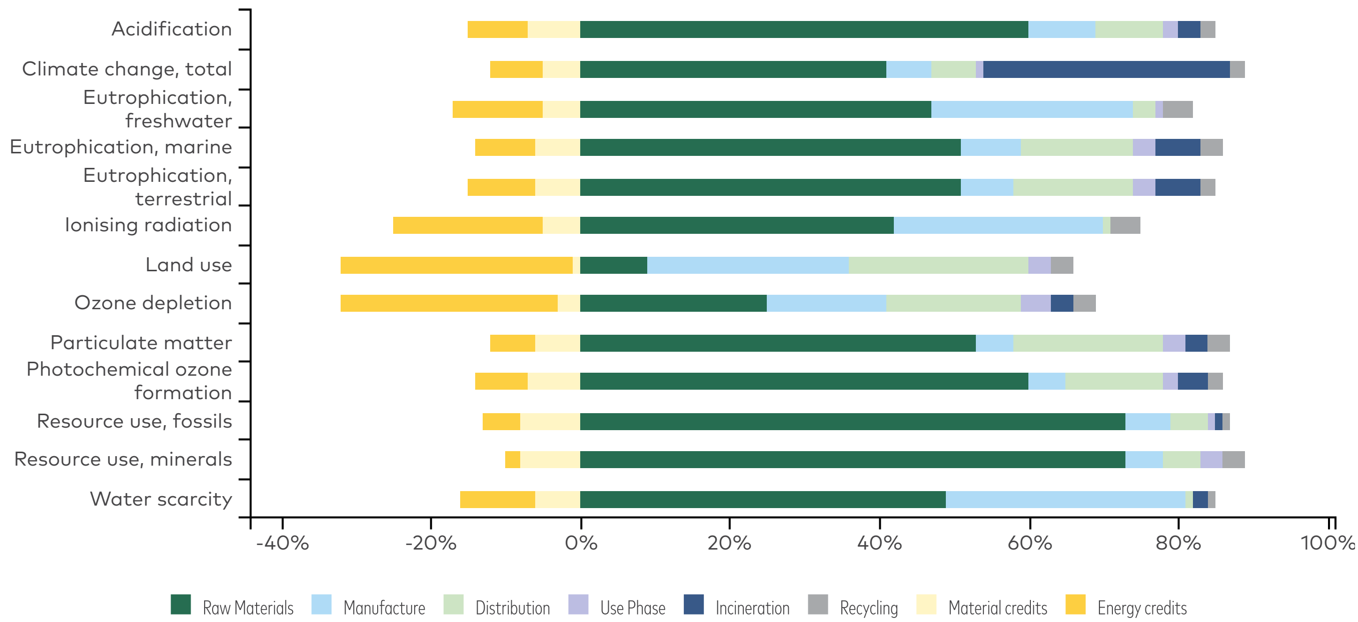

Figure 14 Single-use plastic system contribution analysis by life cycle stage (E-commerce) (total environmental impact).

The figure shows the total environmental impact including credits. When looking at just the total environmental impact the following can be observed per life cycle stage

The **Raw Materials** has on average the highest impact on the life cycle emissions. The life cycle stage contributes from 9% (Land use) to 73% (Resource use, fossils) to the total environmental impact.

The **Manufacture** life cycle stage contributes from 5% (Resource use, minerals) to 32% (Water scarcity) to the environmental impact. On average the manufacturing has the second highest impacts among the impact categories.

The **Distribution** life cycle stage has the third largest contribution on the life cycle impact. It contributes from 1% (Water scarcity) to 25% (Land use) to the total environmental impact. Distribution is modelled with the same LCI for all case studies.

The **Use Phase** life cycle stage has comparably little impact on the environmental profile, from less than 1% (Water scarcity) to 4% (Ozone depletion) to the total environmental impact.

The **Recycling** life cycle stage contributes from 1% (Water scarcity) to 4% (Eutrophication, freshwater) to the total environmental impact.

The **Incineration** life cycle stage contributes from less than 1% (Ionising radiation) to 33% (Climate change, total) to the total environmental impact, whereby climate change is sticking out from otherwise maximal 6% (Eutrophication, terrestrial).

Additional to the environmental burden the credits from waste treatment at end of life decrease the total environmental burden.

The **Material credits** decrease the environmental impact by 1% (Land use) to 8% (Resource use, minerals) compared to the total environmental impact.

The **Energy credits** decrease the environmental impact by 2% (Resource use, minerals) to 31% (Land use) compared to the total environmental impact.

Single use paper system

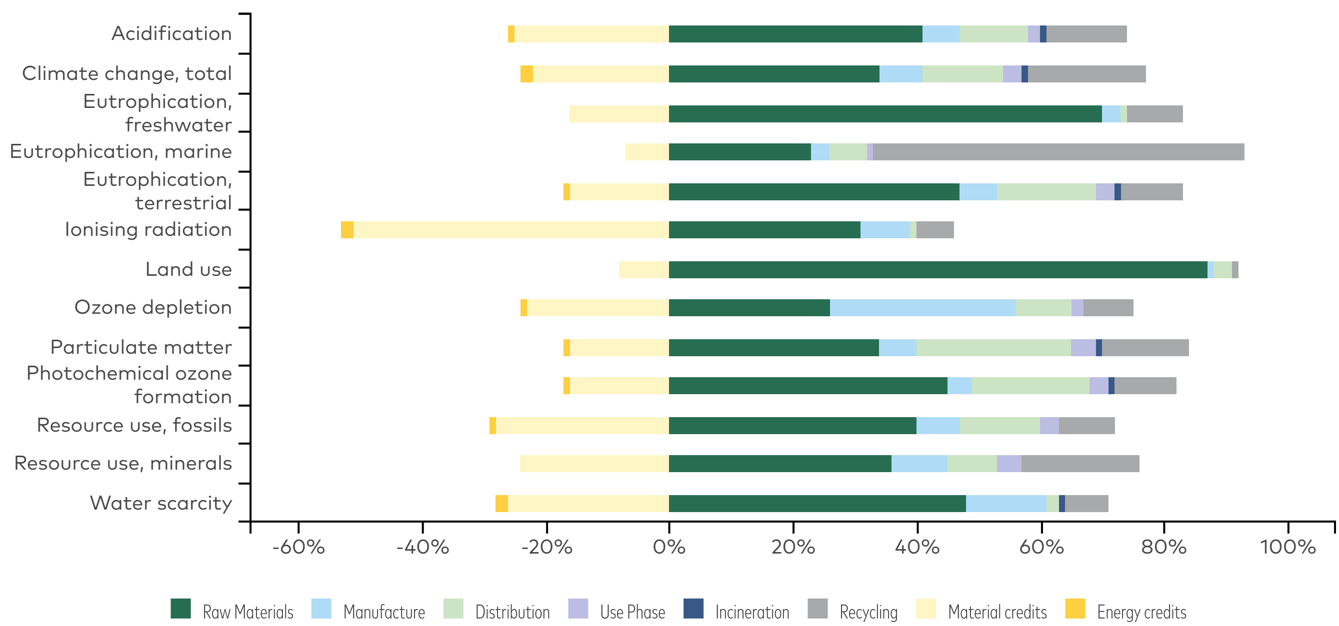

Figure 15 Single-use paper system contribution analysis by life cycle stage (E-commerce) (total environmental impact).

The figure shows the total environmental impact including credits. When looking at the environmental burden the following can be observed per life cycle stage

The **Raw Materials** has on average the highest impact on the life cycle emissions. The life cycle stage contributes from 23% (Eutrophication, marine) to 87% (Land use) to the total environmental impact.

The **Manufacturing** life cycle stage contributes from 1% (Land use) to 30% (Ozone depletion) to the total environmental impact. In most impact categories it has the third largest contribution.

The **Distribution** life cycle stage contributes from 1% (Eutrophication, freshwater) to 25% (Particulate matter) to the total environmental impact, constituting the second largest impact in most categories. Distribution is modelled with the same LCI for all case studies.

The **Use Phase** life cycle stage contributes has comparably little impact on the environmental profile from less than 1% (Land use) to 4% (Resource use, minerals) to the total environmental impact.

The **Recycling** life cycle stage contributes from 1% (Land use) to 60% (Eutrophication, marine) to the total environmental impact, whereby Eutrophication, marine is sticking out from otherwise maximal 14% (Climate change, total).

The **Incineration** life cycle stage contributes relatively little, from less than 1% (Land use) to 1% (Eutrophication, terrestrial) to the total environmental impact.

Additional to the environmental burden the credits from waste treatment at end of life decrease the total environmental impact.

The **Material credits** dominate the credits, decreasing the environmental burden by 7% (Eutrophication, marine) to 51% (Ionising radiation) compared to the total environmental impact.

The **Energy credits** decrease the environmental burden from less than 1% (Eutrophication, marine) to 2% (Ionising radiation) compared to the total environmental impact.

Reusable plastic system

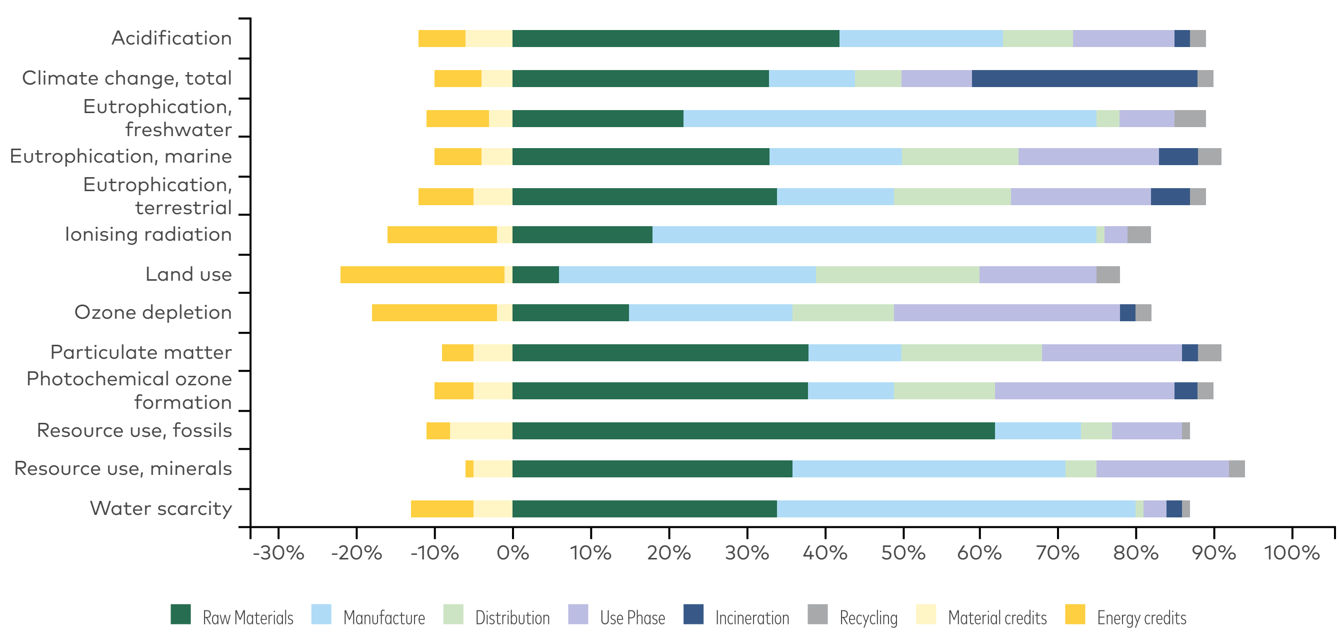

Figure 16 Reusable system contribution analysis by life cycle stage (total environmental impact).

The figure shows the total environmental impact including credits. When looking at the environmental burden the following can be observed per life cycle stage

The **Raw Materials** life cycle stage contributes most in most impact categories, impacting from 6% (Land use) to 62% (Resource use, fossils) to the total environmental impact.

The **Manufacture** life cycle stage contributes second most in the impact categories from 11% (Photochemical ozone formation) to 57% (Ionising radiation) to the total environmental impact. Compared to the single use system the manufacturing of the reusable system has higher impacts due to a more complex manufacturing processes, i.e., first extrusion and then weaving.

The **Distribution** life cycle stage contributes from 1% (Ionising radiation) to 21% (Land use) to the total environmental impact. The **Use Phase** life cycle stage contributes from 3% (Water scarcity) to 29% (Ozone depletion) to the total environmental impact. Both life cycle stages have similar impact, both dominated by transports.

The **Recycling** life cycle stage contributes from 1% (Resource use, fossils) to 4% (Eutrophication, freshwater) to the environmental impact.

The **Incineration** life cycle stage contributes from less than 1% (Ionising radiation) to 29% (Climate change, total) to the total environmental impact.

Additional to the environmental burden the credits from waste treatment at end of life decrease the total environmental impact.

The **Energy credits** decrease the total environmental impact by 1% (Land use) to 8% (Resource use, fossils) compared to the total environmental impact. The **Material credits** decrease the environmental burden by 1% (Resource use, minerals) to 21% (Land use) compared to the environmental burden. Both credits have similar importance to the total environmental impact.

6.3 Sensitivity analysis

The following sections present the performed sensitivity analyses, investigating the influence of critical parameters on the results and the comparative analyses. In this regard, only one parameter (or assumption) is changed per system. This is aimed at keeping transparency and ensure traceability of results. Critical assumptions and their potential effect on the base case comparison are evaluated, and detailed results are presented per sensitivity analysis and compared to the relevant related counterpart. The performed sensitivity analyses are based on both the contribution analysis of the base case comparison and the identified variability regarding critical parameters.

6.3.1 Visualisation of the sensitivity analysis results

Results of the sensitivity analysis is shown in the following charts. The charts have two parts:

- if the impacts of the reusable system are lower than of the single use system in a selected impact category, the bars are shown in the upper part of the chart
- if the impacts of the single use system are lower than of the reusable system in a selected impact category, the bars are shown in the lower part of the chart.

For each impact category the results of related sensitivity analyses for both product systems are compared. In the comparison the results of the reusable system are related to the single use system relevant for the sensitivity case.[12] The bars in the charts effectively show the percentual difference of the two systems, e.g., single use base case results are compared to reusable base case results, and the single use system and reusable system results with the same A factor (CFF), or recycling rate are compared. The following denomination in the figure's legend is used to identify which cases are compared:

A. The base case results of both cases are compared to each other.
B. The results of the sensitivity analysis of the single use system is compared to the base case of the reusable system.
C. The results of the sensitivity analysis of the reusable system is compared to the base case of the single use system.
D. The respective same sensitivity settings of both systems are compared to each other.

With this type of visualisation, robustness can be visualised as follows:

- When a parameter is not crucial and does not change the results of the analysis, the bar of the correspondent product is visualised in the same side of the chart than the base case comparison (either upper or lower part). This means that, to some extent and depending on the percentage variation of the results, the results due to the variation of the selected parameter could be considered robust.

12. The results are compared by the difference between the two results, i.e., subtracting the results of the Reusable system from the results of the Single use system, and then related as percentage of the Reusable systems result.

- When a parameter is crucial and changes the results of the analysis, the bar of the correspondent sensitivity result is visualised in the opposite side of the chart than the base case comparison (either upper or lower part). This means that the results due to the variation of the selected parameter could be considered not robust.

The charts only show the smaller differences between the two systems to ensure readability of the robustness. Thus, the charts might cut off bars if they exceed a certain difference. All nominal results are given in Appendix K (takeaway) and Appendix L (E-commerce) in table form.

6.3.2 Takeaway container's sensitivity analysis

A summary of the sensitivity analysis performed for the production of the takeaway containers can be found in Table 16, Table 17 and Table 18.

Table 16 Summary of production related sensitivity analyses for the takeaway container case.

Sensitivity group	Domain of parameter change	Base cases	Sensitivity analysis
TA1	Packaging net weight	Single use: 59 grams Reusable: 267 grams	Net weight decrease by 10%
TA2			Net weight increase by 10%

Table 17 Summary of use phase related sensitivity analyses for the takeaway container case.

Sensitivity group	Domain of parameter change	Base cases	Sensitivity analysis
TA3	Reuse rate	RR=90%	Break-even analysis
TA4	Retail to final client, transport	62%: 5 km, car 5%: 5 km, van 33%: 5 km, no impact, i.e., walking or biking.	100%: 5 km, car
TA5			100%: 5 km, van
TA6			100%: 5 km, no impact
TA7	Pre-wash	33%: Dishwasher 33%: Handwash 33%: No wash	100%: Dishwash
TA8			100%: Handwash
TA9			100%: No wash

Table 18 Summary of sensitivity analyses related to CFF for the takeaway container case.

Sensitivity group	Domain of parameter change	Base cases	Sensitivity analysis
TA10	Recycling allocation in CFF	A = 0.5	A = 0
TA11			A = 1
TA12	EoL statistics	End-of-life plastic packaging: R2 = 30.93% R3 = 69.07%	R2 = 0; R3 = 1
TA13			R2 = 1; R3=0
TA14	Energy recovery allocation in CFF	B=0	B = 1

6.3.3 Takeaway breakeven reuse rate

Impacts associated to the reusable system depend on the number of uses. The break-even points and number of uses at which point the environmental burdens of the reusable system are lower than the single use system were calculated in parallel. The number of uses was rounded up to the next integer.

Break-even points are calculated by determining the reuse rate at which point the environmental burdens of the two system are equal. The results for each impact category are presented in Table 19.

The following situations are possible:

- For a number of uses lower than break-event points given in the table, the single use system presents lower impacts than the reusable system.
- For a number of uses higher than break-event points given in the table, the single use system presents higher impacts than the reusable system.

Table 19 Break-even point for number of uses required for the system to have lower environmental impacts than a single-use takeaway container for all impact categories.

	Break even point	
Impact category	Reuse rate	Number of uses
EF-Acidification [mol H+ eq]	82%	6
EF-Climate change, total [kg CO2-eq]	81%	6
EF-Eutrophication, freshwater [kg N eq]	80%	5
EF-Eutrophication, marine [kg P eq]	81%	6
EF-Eutrophication, terrestrial [mol N eq]	82%	6
EF-Ionising radiation, human health [kBq U235 eq]	86%	8
EF-Land use [pt]	93%	14
EF-Ozone depletion [kg CFC11 eq]	89%	10
EF-Particulate matter [disease incidence]	83%	6
EF-Photochemical ozone formation - human health [kg NMVOC eq]	82%	6
EF-Resource use, fossils [MJ]	80%	6
EF-Resource use, minerals and metals [kg Sb eq]	80%	6
EF-Water scarcity [m3 world-eq deprived]	91%	11

6.3.4 Results of the Takeaway containers sensitivity analysis

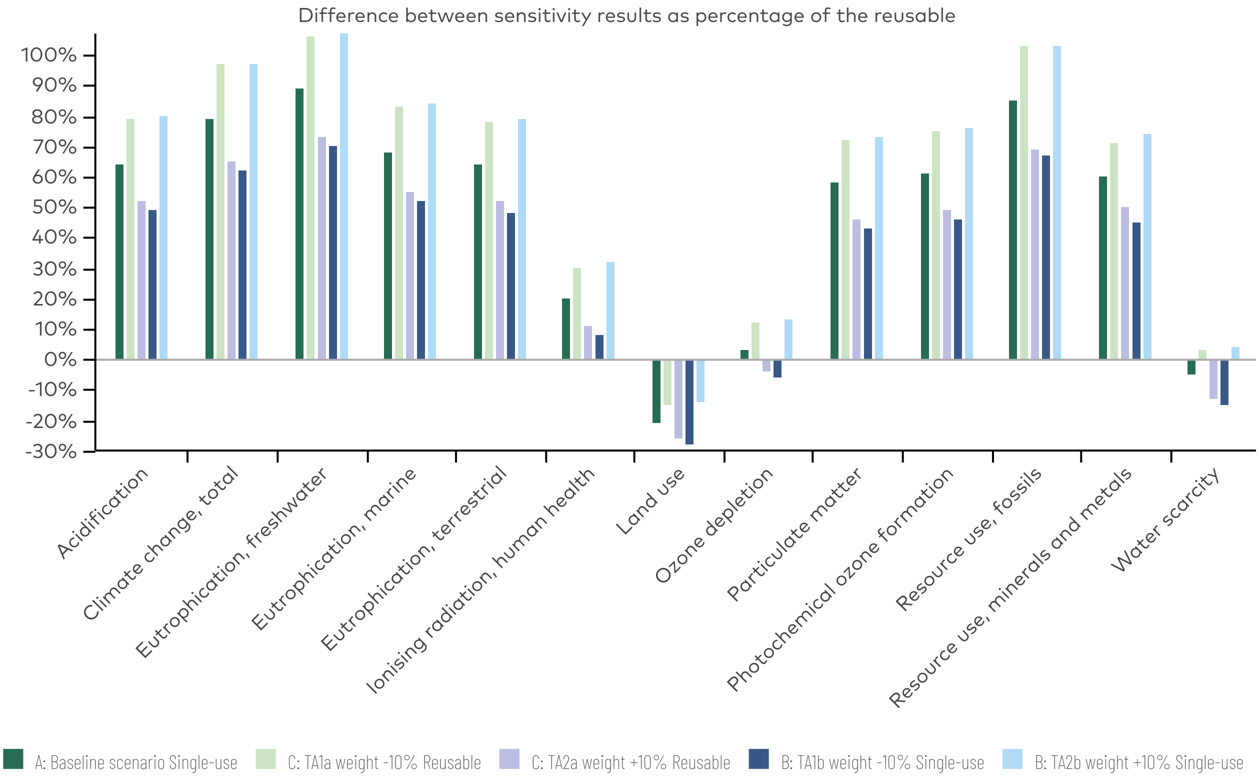

Figure 17 Production related sensitivity analyses for the Takeaway comparison, refer to section 6.3.1 on how to read this figure.

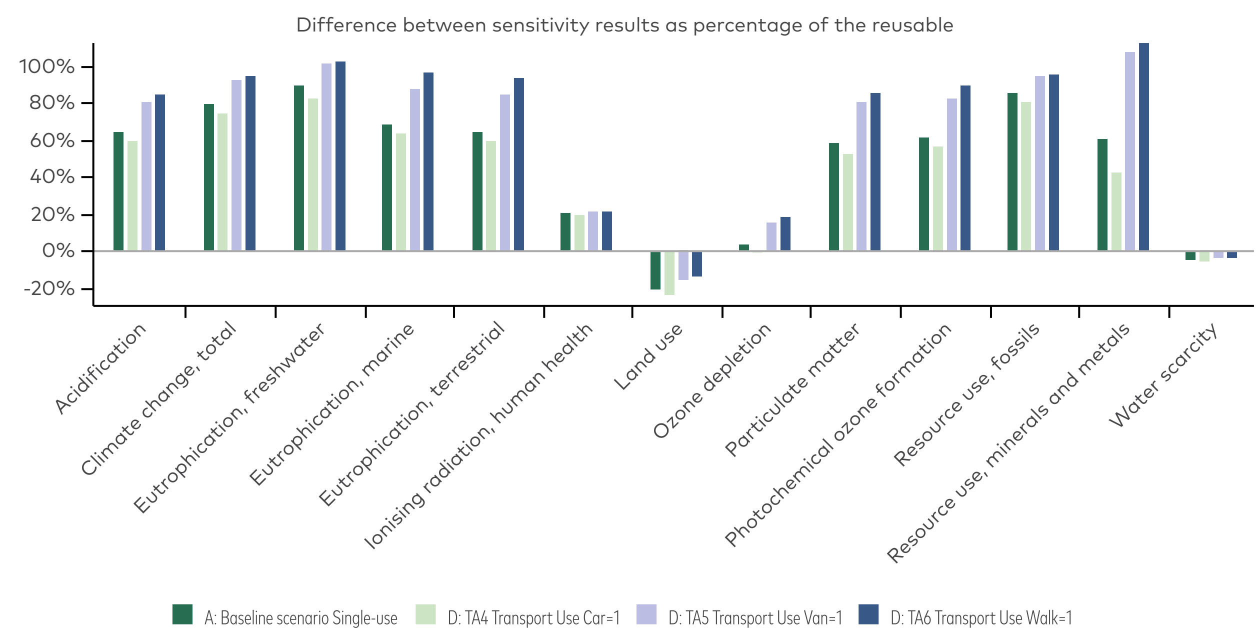

Figure 18 Use phase (transport) related sensitivity analyses for the Takeaway comparison, refer to section 6.3.1 on how to read this figure.

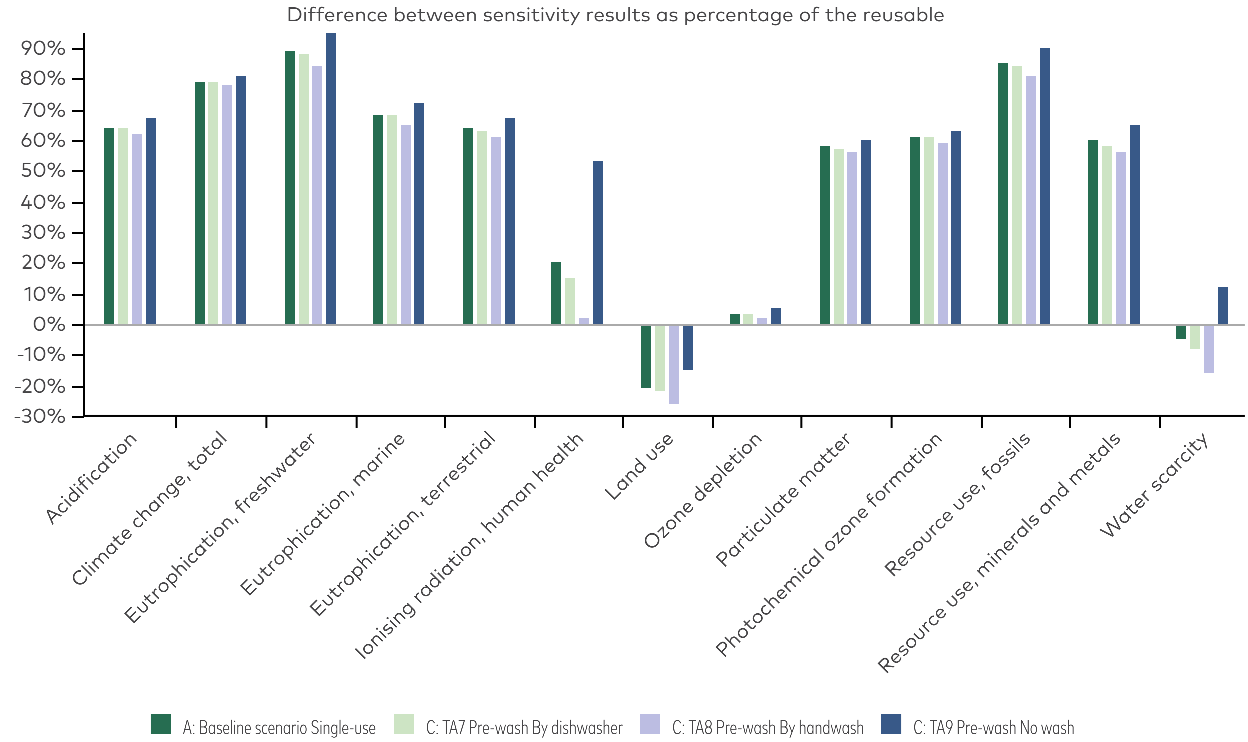

Figure 19 Use phase (pre-washing method for the reusable contaner) related sensitivity analyses for the Takea-way comparison, refer to section 6.3.1 on how to read this figure.

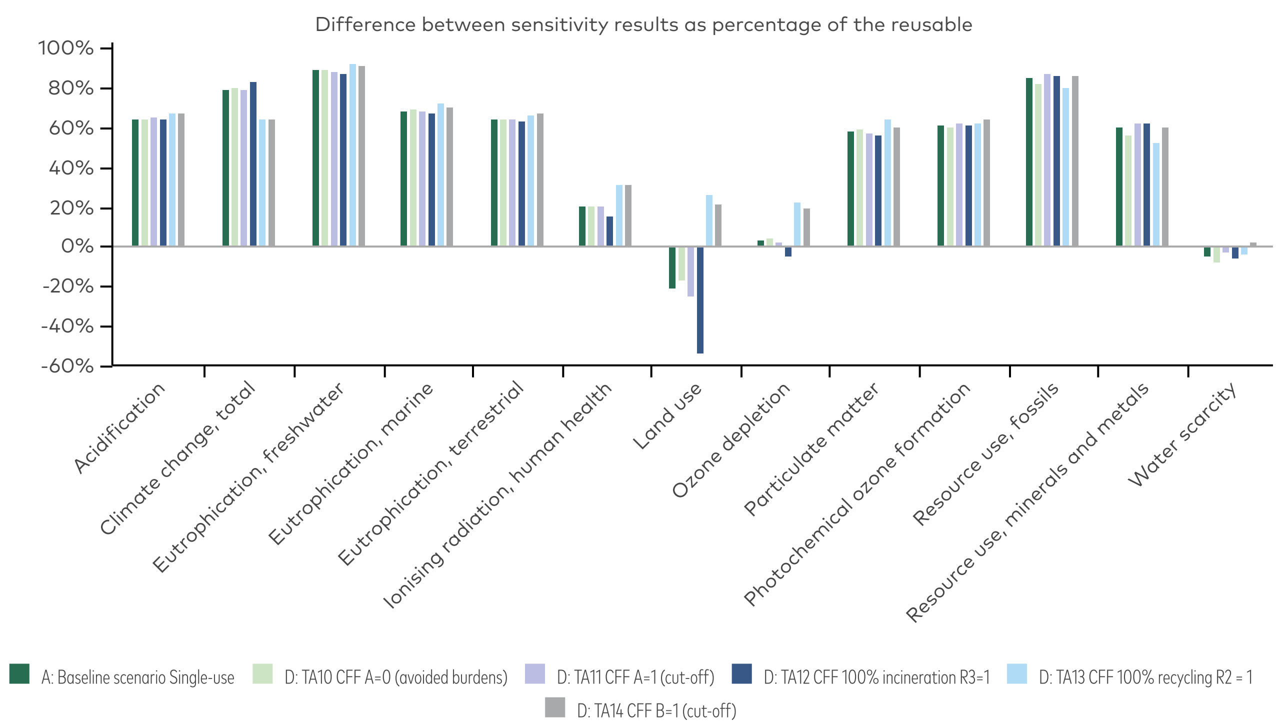

Figure 20 CFF implementation related sensitivity analyses for the Takeaway comparison, refer to section 6.3.1 on how to read this figure.

6.3.5 E-commerce sensitivity analysis

Table 20 gives an overview of all production and product related sensitivity analyses performed for e-commerce.

Table 20 Summary of production related sensitivity analyses for the e-commerce case.

Sensitivity group	Domain of parameter change	Base cases	Sensitivity analysis
EC1	Packaging net weight	SUPL (LDPE): 12g SUPA (Paper): 65g Reusable: 118g	Net weight increase by +10%
EC2			Net weight decrease by -10%
EC3.1	Packaging raw material	SUPL and Reusable: 100% virgin granulate (R1=0)	100% recycled material (R1=1)
EC3.2		Paper sack with plastic liners	100% kraft paper

Table 21 gives an overview of all use phase related sensitivity analyses performed for e-commerce.

Table 21 Summary of use phase related sensitivity analyses for the e-commerce case.

Sensitivity group	Domain of parameter change	Base cases	Sensitivity analysis
EC4 & EC5	Reuse rate	Reusable: 25% (4 uses)	Break-even analysis
EC10	Retail to final client, transport	62%: 5 km, car 5%: 5 km, van 33%: 5 km, no impact i.e., walking or biking.	100%: 5 km, car
EC11			100%: 5 km, van
EC12			100%: 5 km, no impact

Table 22 gives an overview of all CFF related sensitivity analyses performed for e-commerce.

Table 22 Summary of sensitivity analyses with regard to CFF implementation for the e-commerce case.

Sensitivity group	Domain of parameter change	Default parameters for CFF application in the base cases	Sensitivity analysis
EC6	Allocation in CFF	Plastics: A = 0.5 Paper: A = 0.2	A = 1
EC7	Allocation in CFF		A = 0
EC8	EoL statistics	End-of-life plastic packaging: R2 = 30.93% R3 = 69.07%	R2 = 0 R3 = 1
EC9		End-of-life paper packaging: R2 = 80.77% R3 = 19.23%	R2 = 1 R3 = 0
EC13	Allocation in CFF	B = 0	B = 1

6.3.6 E-commerce break-even point

Impacts associated to the reusable system depend on the number of uses. The break-even points and number of uses at which point the environmental burdens of the usable system are lower than the single use system were calculated in parallel. The number of uses was rounded up to the next integer.

Table 23 gives break-even points for the reusable system per each impact category for both single use systems. The following situations are possible:

- For a number of uses lower than break-event points given in the table, the single use system presents lower impacts than the reusable system
- For a number of uses higher than break-event points given in the table, the single use system presents higher impacts than the reusable system

Table 23 Break-even point (number of uses) for e-commerce (base case assumption is 4 uses). Single use paper and single use plastic respectively compared to the reusable packaging.

	Break-even point			
	Single use paper		Single use plastic	
Impact category	number of uses	reuse rate	number of uses	reuse rate
EF-Acidification [mol H+ eq]	4	69%	14	93%
EF-Climate change, total [kg CO2-eq]	6	82%	11	90%
EF-Eutrophication, freshwater [kg N eq]	the reusable system always shows benefits		16	93%
EF-Eutrophication, marine [kg P eq]	the reusable system always shows benefits		15	93%
EF-Eutrophication, terrestrial [mol N eq]	2	46%	16	94%
EF-Ionising radiation, human health [kBq U235 eq]	the single use system always shows benefits		14	93%
EF-Land use [pt]	the reusable system always shows benefits		140	99%
EF-Ozone depletion [kg CFC11 eq]	2	2%	the single use system always shows benefits	
EF-Particulate matter [disease incidence]	3	61%	17	94%
EF-Photochemical ozone formation - human health [kg NMVOC eq]	3	60%	18	94%
EF-Resource use, fossils [MJ]	11	90%	13	92%
EF-Resource use, minerals and metals [kg Sb eq]	7	85%	28	96%
EF-Water scarcity [m3 world-eq deprived]	5	78%	8	87%

6.3.7 Results of the E-commerce sensitivity analysis (Single use plastic and reusable system)

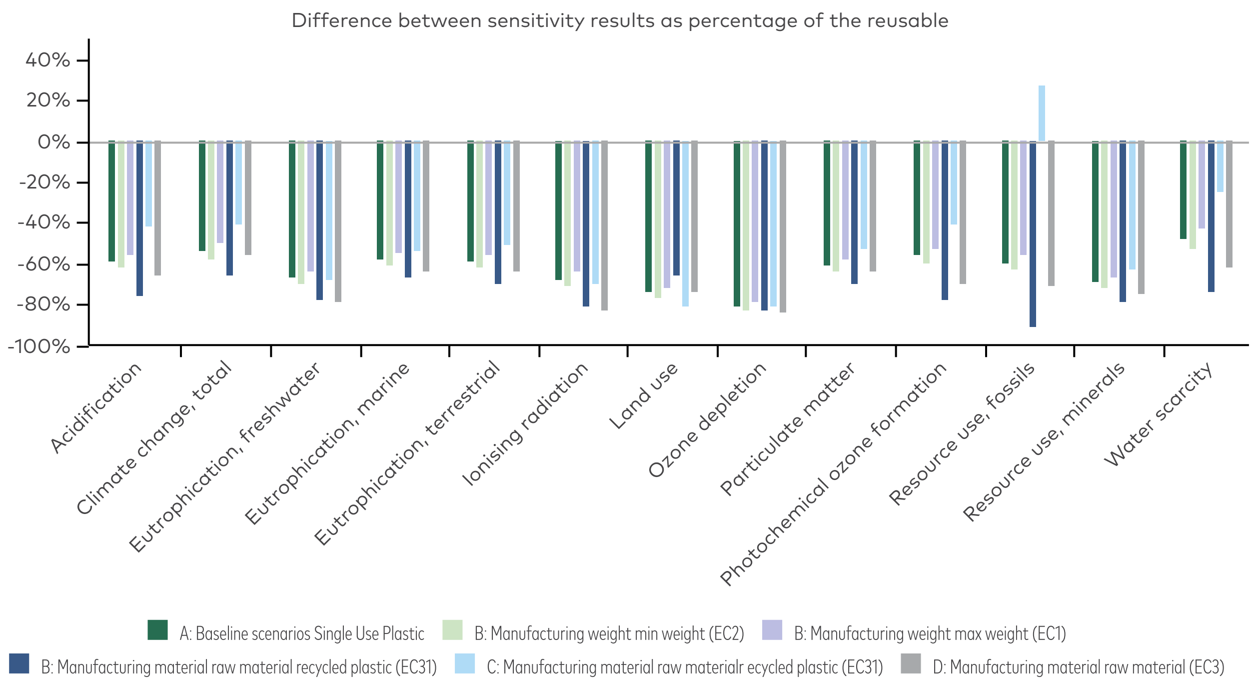

Figure 21 Production related sensitivity analyses for the e-commerce comparison (Single use plastic), (refer to section 6.3.1 on how to read this figure).

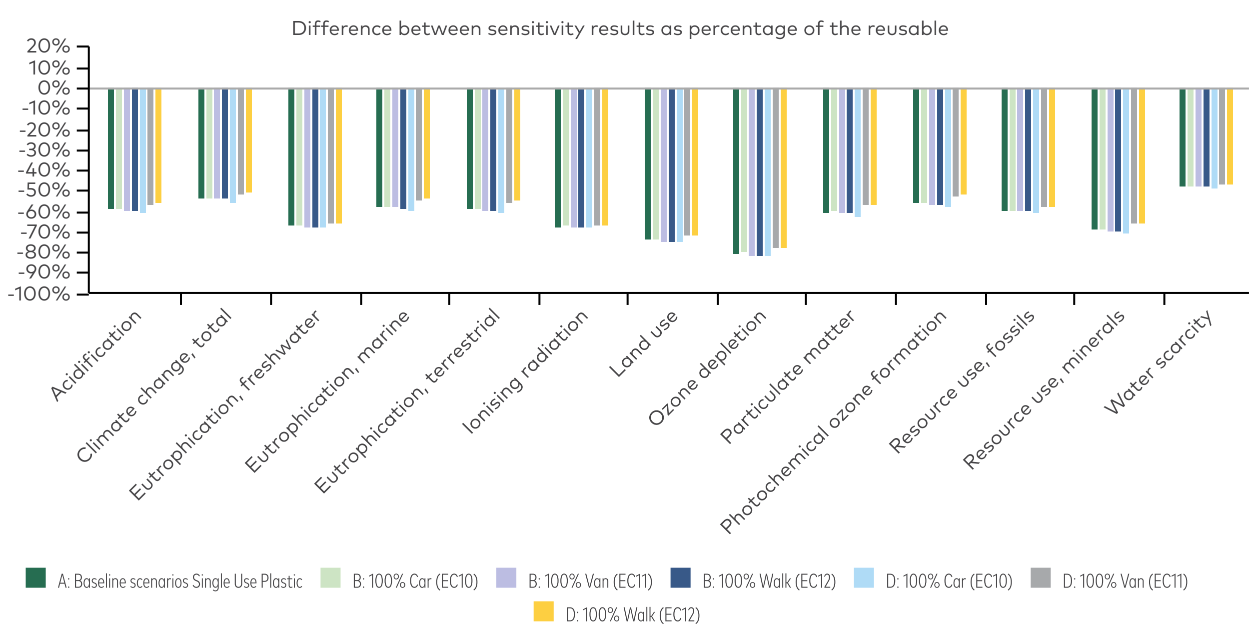

Figure 22 Use phase related sensitivity analyses for the e-commerce comparison (Single use plastic), refer to sec-tion 6.3.1 on how to read this figure.

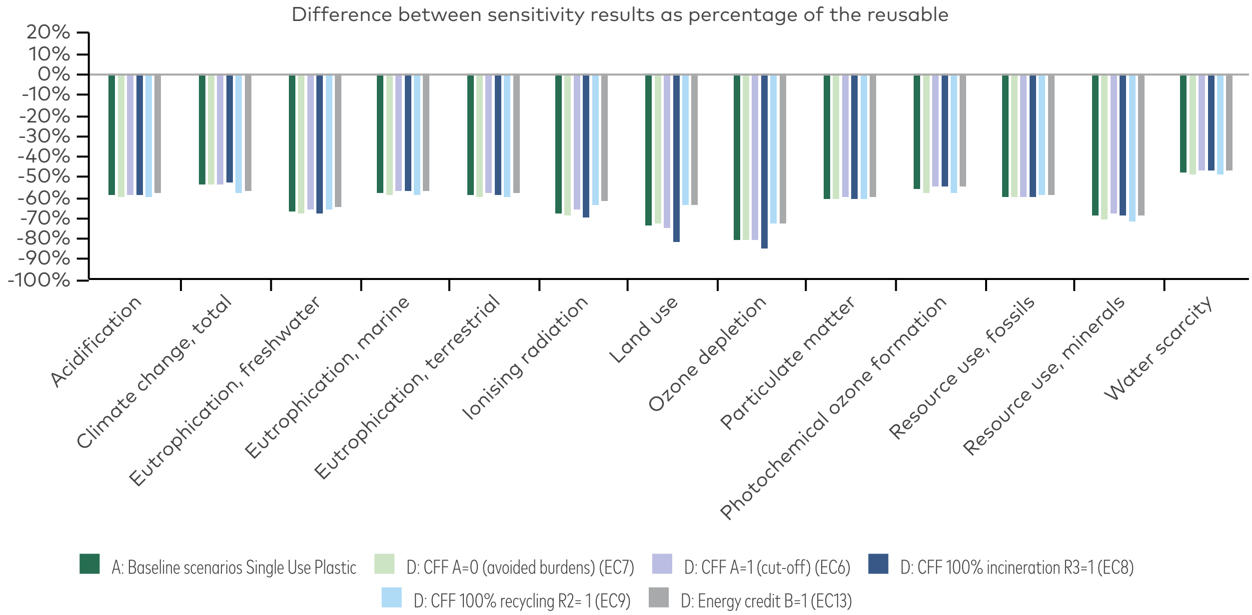

Figure 23 CFF implementation related sensitivity analyses for the e-commerce comparison (Single use plastic), refer to section 6.3.1 on how to read this figure.

6.3.8 Results of the E-commerce sensitivity analysis (Single use paper and reusable system)

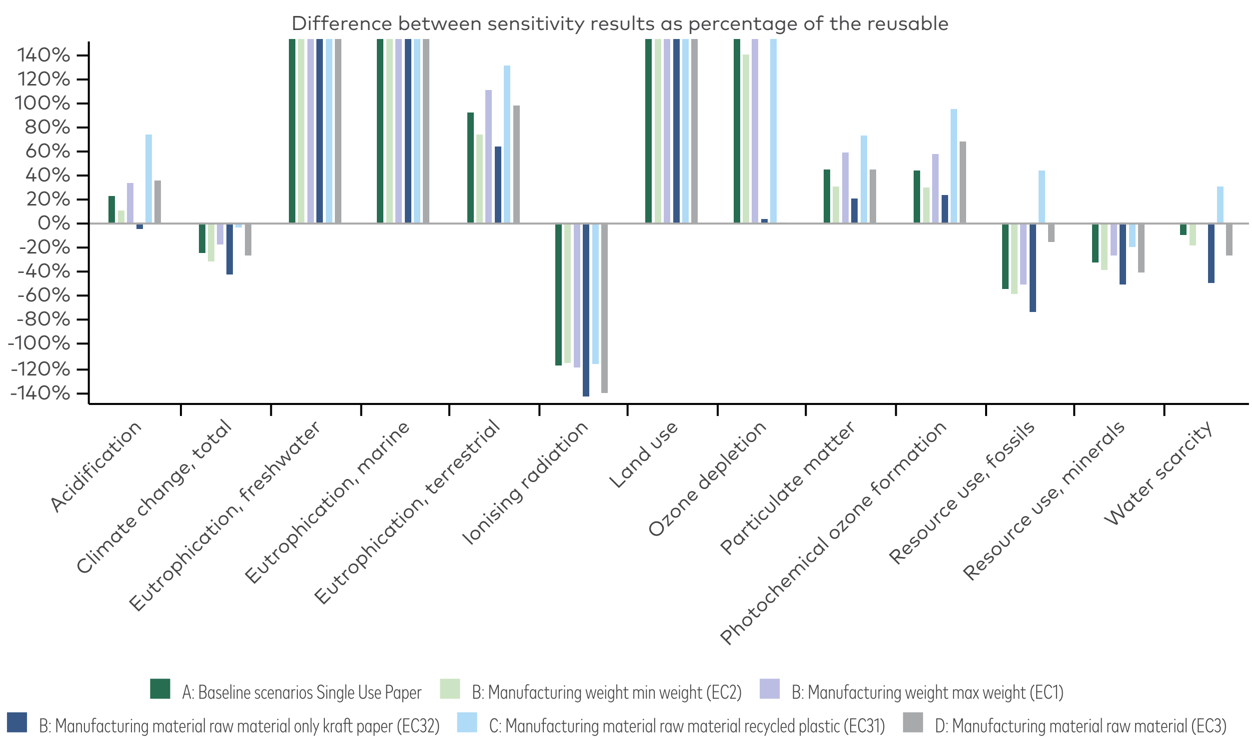

Figure 24 Production related sensitivity analyses for the e-commerce comparison (Single use paper), refer to sec-tion 6.3.1 on how to read this figure.

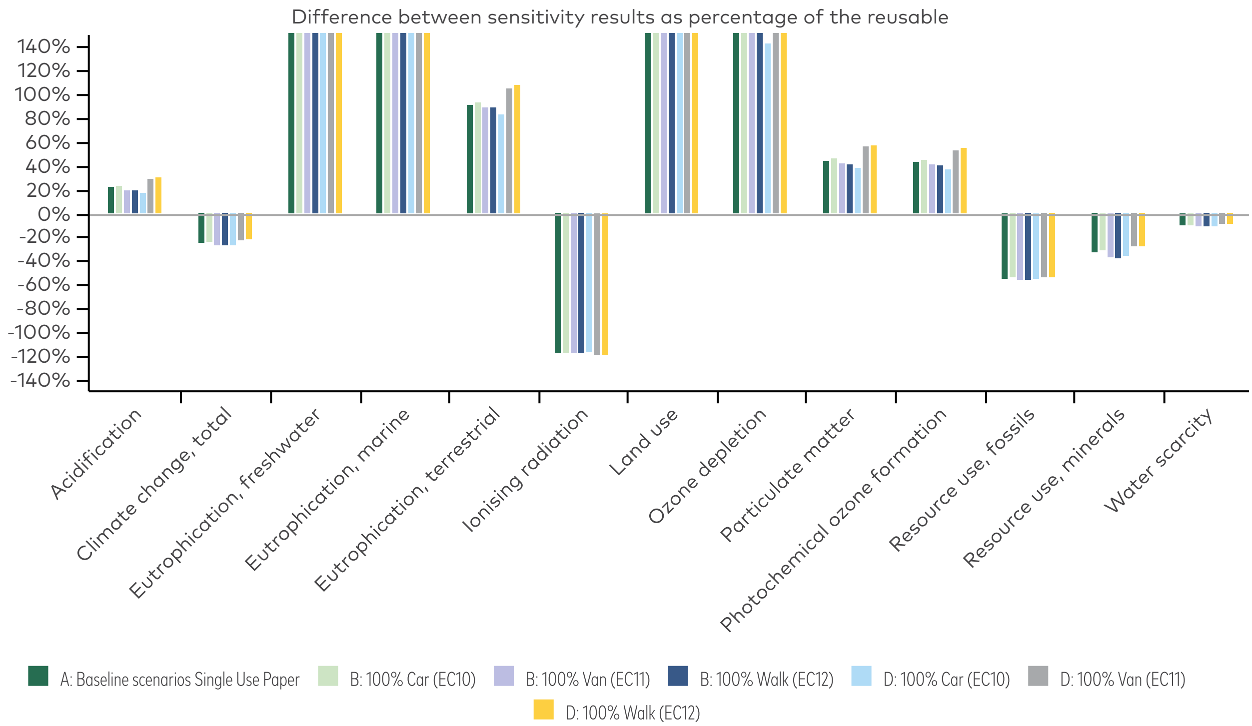

Figure 25 Use phase related sensitivity analyses for the e-commerce case (Single use paper), refer to section 6.3.1 on how to read this figure.

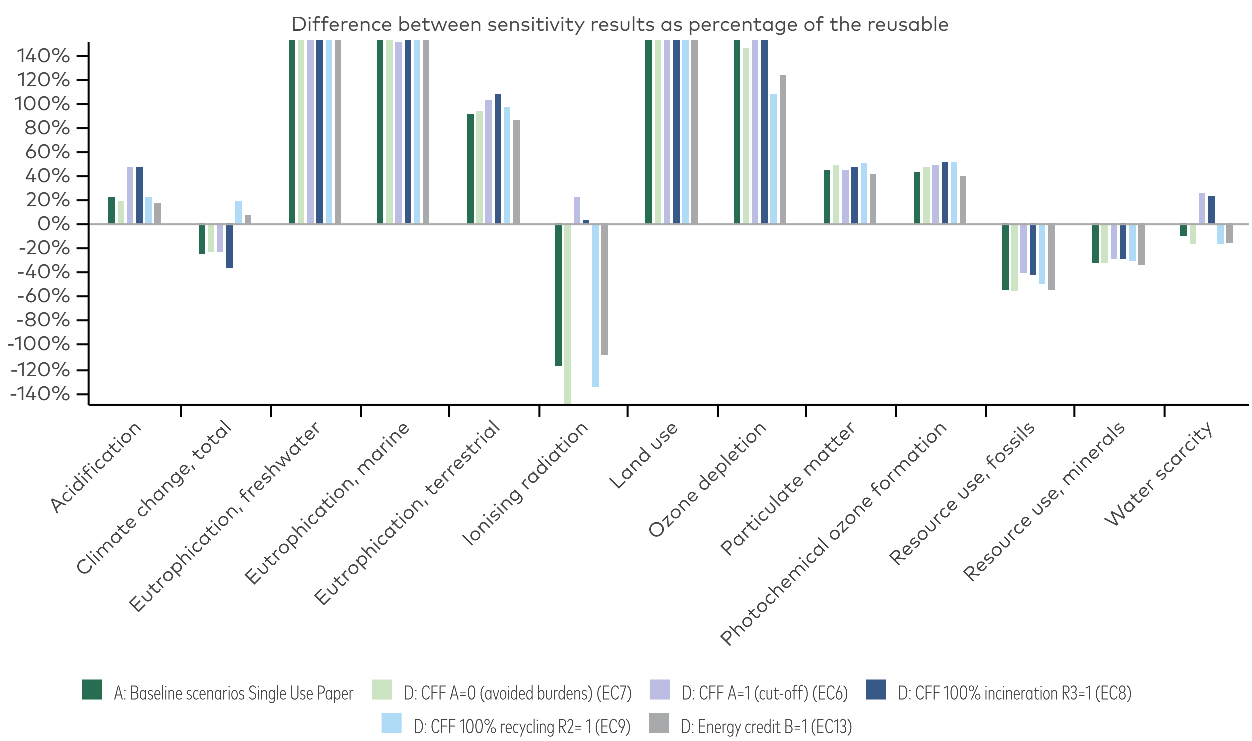

Figure 26 CFF implementation related sensitivity analyses for the e-commerce case (Single use paper), refer to section 6.3.1 on how to read this figure.

7. Interpretation

7.1 Takeaway containers relevant findings

For the takeaway containers, the base case indicates that the reusable container system has potentially lower impacts than the single-use. In the contribution analysis it was observed that the life cycle stages dominating the impacts of the single use container were the raw materials and manufacturing, which when aggregated contributed to 47-81% of the environmental impacts, with exception of land use category where the main hotspot was the distribution stage with 34% of the impacts. While for the reusable container, the impacts are more distributed among the life cycle stages, where the raw materials contribute with 6-59% of the impacts, the manufacturing stage has a range from 9-50%, the use phase shows higher contributions than the single-use, ranging from 9-39%.

The overall results are discussed for each impact categories, by using classification on robustness and terminology of Table 12 of the previous section. The interpretation of results and robustness, are summarised in Table 24:

- For **acidification**, the reusable takeaway container shows *significant* environmental benefits in the base case (39%) and the sensitivity analyses. It is concluded that the results have a high robustness.

- For **climate change, total**, the reusable takeaway container shows *significant* environmental benefits in the base case and most of the sensitivity analyses. The results show very significant benefits when the weight of the single use packaging increases (TA2b), when the weight of the reusable packaging decreases (TA1a) and when modeling no impacts during the use phase transportation (TA6). It is concluded that the results have a high robustness.
- For **freshwater eutrophication**, the reusable takeaway container shows *significant* environmental benefits in the base case and most of the sensitivity analyses. The sensitivity analyses show very significant environmental benefits when the transportation method to the end-user has no impacts or a van is used (TA5 and TA6), by increasing the weight of the single use packaging (TA2b) and by reducing the weight of the reusable packaging (TA1a). The results are considered of high robustness.
- For **marine eutrophication**, the reusable takeaway container shows *significant* environmental benefits in the base case and most of the sensitivity analyses. The results show major benefits when modeling a no impact transport method in the use phase. It is concluded that the results have a high robustness.

- For **terrestrial eutrophication,** the reusable takeaway container shows *significant* environmental benefits across the base case and all tested sensitivity analyses. It is concluded that the results have a high robustness.
- For **ionizing radiation**, the reusable takeaway container shows a noticeable benefit compared to the single use system for the base case. Across the sensitivity analyses the reusable system has *moderate* benefits compared to the single use system in three setups: when the weight of the reusable container is reduced (TA1a), when the single-use weight increases (TA2B) when R2=1 and when B=1 for the reusable system (TA13 and TA14). Additionally, the reusable system shows *significant* benefits when choosing not to pre-wash the container. The results are considered of high robustness.
- For **land use**, the results show a different trend, as distribution has a higher contribution to the impacts, mainly due to the land use change from road construction. There are moderate environmental benefits from the single use system. The sensitivity shows opposite results (reusable showing higher environmental benefits than single use) in two setups, R2=1 and B=1 (TA13 and TA14). The results show medium robustness, but it must also be considered that the impact category scores with low robustness from the EF 3.1 categorisation (see Table 8).
- For **ozone depletion**, there are marginal benefits for the reusable takeaway container in the base case. However, the sensitivity analysis shows opposite results (i.e., the single use system has lower impacts than the reusable system in this impact category), when increasing the weight of the reusable (TA2a), decreasing the weight of the single use packaging (TA1b), when using car transportation in the use phase and by using incineration as the end-of-life scenario (TA12)
- For **particulate matter and photochemical ozone formation**, the reusable takeaway container shows *significant* environmental benefits across the base case and all tested sensitivity setups. It is concluded that the results have a high robustness.
- For **resource use, fossils**, there are significant benefits for the reusable takeaway container in the base case. This holds across the sensitivity analyses, except for the sensitivity setups TA1a and TA2b, with the variance of weights, where the impacts of the reusable containers seem to have very significant benefits. It is concluded the results have high robustness.
- For **resource use, minerals and metals**, there are significant benefits for the reusable takeaway containers. This result holds across the sensitivity analyses, except for the cases where van or no impact transportation mode is used for the transportation between the restaurant and the final user (Sensitivity setups TA5 and TA6). The robustness of the results is considered high.

- For **water scarcity**, the single use system shows minor benefits in the base case comparison. In the pre-washing sensitivity analysis, choosing to handwash the container shows a noticeable benefit for the single use system, while by not washing the container shows noticeable benefits in favor of the reusable packaging. Additionally, decreasing the weight of the reusable packaging or increasing the weight of the single use packaging also shows benefits for the reusable container. The robustness of the results is considered medium.

More general the performed sensitivity analyses indicate that:

- A variance in the weight reveals the container weight to be one of the parameters that causes a higher change on the results of all impact categories. The weight factor carries a significant impact on the system, as this parameter directly influences various aspects, including material requirements, transportation, and the management of materials at their end-of-life stage. Nevertheless, it is important to consider that even if a reduction in the weight of reusable containers can increase its environmental benefits, it might also result in a reduction of its durability, which might have an impact on the number of times the container is reused, that can lead to a counter-active effect. However, the potential durability of the container was not part of the scope of study.
- The break-even point suggests that after 6 uses the reusable container turns to be less impacting than the single use system for most of the impact categories, except for land use, water scarcity, ozone depletion and ionising radiation, which require from 8-14 uses in order for the environmental impacts of the reusable container to be lower than of the single use option.
- The CFF values show limited influence on the overall results, but disclose some sensitivity across some impact categories:
    - For the adoption of **A=1 (cut-off approach)** and **A=0 (avoided burdens)** results of getting no credits and full credit, respectively, of the recycled material in both systems. The effect in the two systems is similar and does not show a difference in the comparison conclusions.
    - For the adoption of **R3=1 (container treated in incineration at its EoL)** and **R2=1 (container recovered as recycling)** the two systems have the same effect, where no discernible disparities emerge in the overarching conclusion, except for land use. In the case of land use, recycling the container shows contrary results than the base case (the reusable container is indicated to be a better option than the single use container), as more credits are achieved by material recovery and the impacts from incinerating plastics are avoided. Consequently, the

reusable system consistently demonstrates reduced environmental impacts. Nevertheless, when analysing the environmental impact for each sensitivity setups relative to the base case, incineration of the containers results in an increase of environmental impacts across a range of impact categories. On the contrary, the treatment involving recycling exhibits a decrease in impacts across most impact categories, except for freshwater eutrophication, ionizing radiation, land use, and ozone depletion.

  - For the adoption of **B=1 (cut-off approach)** the results do not show variations to the base case comparison, except for two opposite results, i.e., lower impacts for the reusable container, for land use and water scarcity.

- For the transportation method in the used phase (delivery), the results show the highest benefits when the packaging is transported by methods without combustion of fuel involved, as for example by bike or walking, followed by transportation by van, and lastly by car. The results are influenced by the methodology of the datasets used, as the van impacts are allocated to the van based on the weight of the container and distance (tkm), while the car impacts are allocated by the volume of the container. Nevertheless, the variance in the transportation didn't change the conclusion of the comparison, meaning that the reusable option still performed as less impacting than the single use one in the same categories as in the base case with any of the three options (with exception of car use in ozone depletion). This represents an uncertainty in the results, as it is believed that using a car specifically for picking and returning a unit of a takeaway container without allocating the impacts per volume would result in higher environmental impacts which could change the conclusions of the study, however this should be further researched.
- The alternative showing the lowest impacts is by not washing the container, as no resources are used. This is also the only sensitivity setup of the three evaluated, where the reusable container shows less impacts regarding water scarcity than the single-use alternative. However, this conclusion does not consider the potential risks of bacteria growth, which can be unsanitary. The second method resulting in less impacts is by the use of a dishwasher; this is mainly due to dishwashers being more efficient in the use of water and energy than handwashing.

Table 24 Summary of results of the comparison of the single use takeaway container results against the reusable takeaway container. In case the reusable system shows benefits the comparison cell per impact category is shaded in light green.

EF Impact category	Comparison and difference between base case results as percentage of the reusable	Robustness of the results
EF-Acidification [mol H+ equivalents]	The **reusable system** shows **significant** benefits (MU is -39%)	high robustness
EF-Climate change, total [kg CO2-Equivalents]	The **reusable system** shows **significant** benefits (MU is -44%)	high robustness
EF-Eutrophication, freshwater [kg N equivalents]	The **reusable system** shows very **significant** benefits (MU is -47%)	high robustness
EF-Eutrophication, marine [kg P equivalents]	The **reusable system** shows **significant** benefits (MU is -41%)	high robustness
EF-Eutrophication, terrestrial [mol N equivalents]	The **reusable system** shows **significant** benefits (MU is -39%)	high robustness
EF-Ionising radiation, human health [kBq U235 equivalents]	The **reusable system** shows noticeable benefits (MU is -17%)	high robustness
EF-Land use [pt]	The **single use system** shows **moderate** benefits (MU is +27%)	medium robustness
EF-Ozone depletion [kg CFC11 equivalents]	The **reusable system** shows **marginal** benefits (MU is +3%)	medium robustness
EF-Particulate matter [disease incidence]	The **reusable system** shows **significant** benefits (MU is -37%)	high robustness
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	The **reusable system** shows **significant** benefits (MU is -38%)	high robustness
EF-Resource use, fossils [MJ]	The **reusable system** shows **significant** benefits (MU is -46%)	high robustness
EF-Resource use, minerals and metals [kg Sb equivalents]	The **reusable system** shows **significant** benefits (MU is -37%)	high robustness
EF-Water scarcity [m3 world-Eq deprived]	The **single use system** shows **minor** benefits (MU is +6%)	medium robustness

7.2 E-commerce relevant findings

7.2.1 Single use plastic (SUPL) and reusable system

The base case comparison of the single use plastic system and the reusable system shows that the single use plastic system predominantly has lower impacts. In both systems the **environmental hotspots** occur in the upstream stage, i.e., *raw material extraction and manufacturing* and *distribution* life cycle stage. Environmental impacts in the single use system are predominantly driven by the raw material, followed by the distribution. For the reusable system the trend is similar, yet *manufacturing* has a relatively more dominant role. Further the use phase has a higher impact due to more transports in the reverse logistics. As both packaging systems are made of plastic the environmental profiles of both systems are similar.

Together these upstream life cycle stages, i.e., *raw material extraction and manufacturing* and *distribution* contribute to between 59% and 97% of the impact for the single use system and between 57% and 96% of the impact of the reusable system.

Where relevant the overall results are discussed for each impact category, using classification on robustness and terminology of Table 12 of the previous section. The interpretation of results and robustness, are summarised in Table 25:

- For **most impact categories** the base case comparison indicates very significant environmental benefits for the single use system (SUPL), additionally showing **high robustness** across all impact categories. Thus, they are not discussed in detail.

The following two impact categories fall out of the overall observation.

- For **Resource use, fossils** the base case comparison has *very significant* environmental benefits for SUPL (59%). In one sensitivity comparison (*C: Manufacturing material raw material recycled plastic (EC3.1)*, i.e., if the reusable packaging is made of recycled material (R1=1) and the single use packaging is made of virgin material (R1=0)) the sensitivity analysis shows opposite results. This result is expected (part of the sensitivity definition) but gives the category a **medium robustness**.
- For **Water scarcity** the base case comparison has *significant* environmental benefits for SUPL (47%). However, the trend does not change across the impact categories.

Table 25 Summary of the comparison "Single use plastic bag system" against "Reusable bag system". In case the reusable system shows benefits the comparison cell per impact category is shaded in light yellow.

EF Impact category	Comparison and difference between base case results as percentage of the reusable	Robustness of the results
EF-Acidification [mol H+ equivalents]	The **single use system** shows **very significant** benefits. (-59%)	high robustness
EF-Climate change, total [kg CO2-Equivalents]	The **single use system** shows **very significant** benefits. (-54%)	high robustness
EF-Eutrophication, freshwater [kg N equivalents]	The **single use system** shows **very significant** benefits. (-67%)	high robustness
EF-Eutrophication, marine [kg P equivalents]	The **single use system** shows **very significant** benefits. (-58%)	high robustness
EF-Eutrophication, terrestrial [mol N equivalents]	The **single use system** shows **very significant** benefits. (-59%)	high robustness
EF-Ionising radiation, human health [kBq U235 equivalents]	The **single use system** shows **very significant** benefits. (-68%)	high robustness
EF-Land use [pt]	The **single use system** shows **very significant** benefits. (-74%)	high robustness
EF-Ozone depletion [kg CFC11 equivalents]	The **single use system** shows **very significant** benefits. (-81%)	high robustness
EF-Particulate matter [disease incidence]	The **single use system** shows **very significant** benefits. (-61%)	high robustness
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	The **single use system** shows **very significant** benefits. (-56%)	high robustness
EF-Resource use, fossils [MJ]	The **single use system** shows **very significant** benefits. (-60%)	medium robustness
EF-Resource use, minerals and metals [kg Sb equivalents]	The **single use system** shows **very significant** benefits. (-69%)	high robustness
EF-Water scarcity [m3 world-Eq deprived]	The **single use system** shows **significant** benefits. (-48%)	high robustness

7.2.2 Single use paper (SUPA) and reusable system

The base case comparison of the single use paper system and the reusable system indicates that the systems have benefits in selected impact categories, not one is predominantly better. In both systems the **environmental hotspots** occur in the upstream stage, i.e., *raw material extraction and manufacturing* and *distribution* life cycle stage. Environmental impacts in the single use system are predominantly driven by the raw material, followed by the distribution. For the reusable system the trend is similar, yet *manufacturing* has a relatively more dominant role. Further the use phase has a higher impact due to more transports in the reverse logistics.

Together these upstream life cycle stages, i.e., *raw material extraction and manufacturing* and *distribution* contribute to between 31%-91% of the impact for the single use system and between 57%-96% of the impact of the reusable system.

The overall results are discussed for each impact categories, by using classification on robustness and terminology of Table 12 of the previous section. The interpretation of results and robustness, are summarized in Table 26:

- For **Acidification**, the reusable system has environmental benefits across the base case comparison and all sensitivity scenarios. The base case comparison has *moderate* environmental benefits. In the sensitivity case where the SUPA is modelled with only the kraft paper dataset (B: Manufacturing material, raw material only kraft paper (EC3.2)) the relationship changes to a marginal benefit for the SUPA (**medium robustness**).
- For **Climate Change**, **total,** there are *moderate* environmental benefits for the SUPA system. The reusable system has 25% higher impacts than the SUPA system in the base case comparison. In the sensitivity analysis, three scenarios merit consideration, as they deviate to the base case results:
    - D: CFF 100% recycling R2= 1 (EC9); in which both packages are 100% recycled;
    - D: Energy credit B=1 (EC13); in which no credits are given for waste incineration.

  The results in this impact category are dominantly influenced by the virgin input and avoided material or energy production. Overall, this impact category has a **medium robustness**.
- For **Eutrophication, freshwater,** there are *very significant* environmental benefits for the reusable system. The SUPA has in all scenarios a more than 350% higher impact, due to different raw materials (**high robustness**).
- For **Eutrophication, marine,** there are *very significant* environmental benefits for the reusable system. The SUPA has in all scenarios a more than 150% higher impact, due to different raw materials (**high robustness**).

- For **Eutrophication, terrestrial**, there are *very significant* environmental benefits for the reusable system. The SUPA has in all scenarios a more than 63% higher impact, due to different raw materials (**high robustness**).
- For **Ionising radiation, human health**, there are *very significant* environmental benefits for single use system in the base case. This category is influenced by the material credit for the paper packaging. The following two scenario cases show different results.
  - D: CFF A=1 (cut-off) (EC6); in both systems the recycling impact is not considered and no material credits are given
  - D: CFF 100% incineration R3=1 (EC8); only energy credits and no material credits

  As the results are not consistent throughout all considered scenarios in this impact category, the comparison between the two systems slightly depends on underlying assumptions (**medium robustness**).
- For **Land use**, there are *very significant* environmental benefits for reusable system in the base case. The SUPA has in all scenarios a more than 1500% higher impact, due to different raw materials (**high robustness**).
- For **Ozone depletion**, there are *very significant* environmental benefits for reusable system in the base case. The base case comparison shows 165% higher impact for the SUPA system. The following sensitivity analysis deviate the base case results (**medium robustness**) the impact is reduced to a marginal difference:
  - B: Manufacturing material raw material only kraft paper (EC3.2); the reusable system has only a moderate environmental benefit if the paper packaging only consists of kraft paper
  - D: Manufacturing material raw material (EC3); as above the raw material of the paper bag influences the relationship. With the tested alternative the difference is not so high
- For **Particulate matter**, there are *significant* environmental benefits for the reusable system in the base case (the reuse system has 44% lower impacts than SUPA in the base case). The trend is consistent across all sensitivities (high robustness).
- For **Photochemical ozone formation**, there are *significant* environmental benefits for the reusable system in the base case (the reuse system has 43% lower impacts than SUPA in the base case). The trend is consistent across all sensitivities (**high robustness**).
- For **Resource use, fossils**, there are *significant* environmental benefits for single use system in the base case (the reuse system has 55% higher impacts than SUPA). This holds across the sensitivity tests, except for the following

sensitivity (**medium robustness**) where no virgin plastic material is used. The results indicate that the paper production requires more fossil resources higher the production of recycled plastic, which is not surprising. As the base case for all product systems are virgin raw materials the variation in the CFF factor A does not influence this results much.

- C: Manufacturing material raw material recycled plastic (EC3.1); *significant* higher impacts of the SUPA system when the reusable system is produced with recycled plastic;

- For **Resource use, minerals and metals**, there are *moderate* environmental benefits for single use system in the base case (SUPA has 33% lower impacts than the reusable system). The environmental benefits for the reusable system are consistent throughout all considered models in this impact category, and the comparison between the two systems is not dependent on underlying assumptions (**high robustness**).
- For **Water scarcity**, there are *minor* environmental benefits for the reusable system in the base case. Changes in material weight and allocation methods change the results (**medium robustness**).

Table 26 Summary of the comparison "Single use paper bag system" against "Reusable bag system". In case the reusable system shows benefits the comparison cell per impact category is shaded in light green.

EF Impact category	Comparison and difference between base case results as percentage of the reusable	Robustness of the results
EF-Acidification [mol H+ equivalents]	The **reusable system** shows **moderate** benefits. (22%)	medium robustness
EF-Climate change, total [kg CO2-Equivalents]	The **single use system** shows **moderate** benefits. (-25%)	medium robustness
EF-Eutrophication, freshwater [kg N equivalents]	The **reusable system** shows **very significant** benefits. (417%)	high robustness
EF-Eutrophication, marine [kg P equivalents]	The **reusable system** shows **very significant** benefits. (566%)	high robustness
EF-Eutrophication, terrestrial [mol N equivalents]	The **reusable system** shows **very significant** benefits. (91%)	high robustness
EF-Ionising radiation, human health [kBq U235 equivalents]	The **single use system** shows **very significant** benefits. (-118%)	medium robustness
EF-Land use [pt]	The **reusable system** shows **very significant** benefits. (2756%)	high robustness
EF-Ozone depletion [kg CFC11 equivalents]	The **reusable system** shows **very significant** benefits. (165%)	medium robustness
EF-Particulate matter [disease incidence]	The **reusable system** shows **significant** benefits. (44%)	high robustness
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	The **reusable system** shows **significant** benefits. (43%)	high robustness
EF-Resource use, fossils [MJ]	The **single use system** shows **very significant** benefits. (-55%)	medium robustness
EF-Resource use, minerals and metals [kg Sb equivalents]	The **single use system** shows **significant** benefits. (-33%)	high robustness
EF-Water scarcity [m3 world-Eq deprived]	The **single use system** shows **noticable** benefits. (-10%)	medium robustness

7.3 Discussion of assumptions and limitations

The results are influenced by methodological decisions, assumptions, and simplifications conducted along the study. This section collects the assumptions and limitations embedded in the reported life cycle assessment.

Reuse rate – Number of uses

It is evident that the choice of the number of uses influences the results of the reuse system. The studied case studies adopted a reuse rate of 90% (10 uses) for the takeaway system and 75% (4 uses) for the E-commerce packaging. In conversation with private operators no coherent statistic could be developed, further no default value could be retrieved from the plastic LCA method, (Nessi, et al., 2021, section 4.4.11.5). No publication could be found with information regarding average rotation timeframe of reusable takeaway or e-commerce packaging, average lifespan of these or evaluation of available reuse scheme. Further research is finally envisaged for evaluating number of uses of reusable systems in comparative works between single-use and multiple-use products. The factor was studied by a breakeven analysis to give an indication which reuse rates have to be achieved to reduce the environmental burden of packaging systems through reuse.

Functional Limitations of the studied Packaging Solutions

The aim of this study was to examine and compare the performance of single-use and reusable packaging solutions, specifically for food takeaway and clothing e-commerce. In this evaluation, the primary function of these packaging solutions, containing and transporting goods, was the main focus. Secondary usage, such as storage of food leftovers or returning online purchased clothes, were not included in this analysis. Furthermore, additional functionalities such as print/advertising and enhanced protection were also not considered.

Both single-use and reusable solutions have different functional attributes and a direct comparison of all potential aspects of their functionality is not feasible. This is a fundamental limitation recognized by the authors. The study assumed packaging solutions were always used in their conventional applications as takeaway containers or e-commerce clothing packages. Differences in function should be remembered when applying this study's results to policy-making decisions.

Additionally, the reuse rate is the only parameter which can be considered to evaluate the performance of the studied systems in the functional unit. Parameters such as breakage or damaged good were assumed to be part of the reuse rate, as if the package is damaged it would be not used again. Future studies may expand on this by considering the secondary uses of packaging, the additional functionality that packaging can provide and further performance parameters. This could enable a more holistic understanding of the potential environmental impacts and benefits offered by different packaging solutions. This study provides a solid basis and methodology for such future research, providing an understanding of the broad comparison between generic single-use and reusable packaging solutions.

Comparison of generic products

The packaging solutions represent generic products as available on the market and are entirely modelled with secondary data. As such the life cycle of the packaging solutions are modelled with average specifications and with generic material input, a generic production process and country/ region specific electricity mixes. Real products on the market likely will use materials, processes, or electricity mixes that have an environmental profile different than the respective generic data. Different sensitivity results were calculated, i.e., weight differentiations for all systems and in case of E-commerce where the systems use different materials also the recycled content (value R1) and datasets of the materials were tested (EC3.1 and EC3.2). Besides these, no sensitivity result could be calculated due to modelling limitations regarding the available generic background data. This limitation is however in line with the stated goal of the study, as generic products could be represented.

It should be noted that real-life products may use different materials, processes during the life cycle or electricity mixes with varying environmental profiles. Therefore, the study's results should be viewed as indicative of a generic application, rather than specific real-world instances.

Use of secondary data

The models within this study were built upon the ecoinvent 3.9.1. database which represents the most recent and available database.

To inform the models and available packaging solutions the market was screened, but the processes were modelled with generic processes. Also studies in literature have based their models and assumptions on secondary data for the packaging solutions (as in this study), a potential step forward would be collecting more primary data at industry level. This might be relevant in future works.

Use of Plastic LCA method

Where relevant for this study default values followed guidance of the Plastic LCA method (Nessi, et al., 2021). Assumptions regarding the distribution and use phase, e.g., distances, mode of transport and allocation procedures are based on an official methodology, creating more robust assumptions. However, these assumptions also contribute to the uncertainty of the study, as these are parameters that vary depending on the user.
The study does not claim to be compliant to the Plastic LCA method, but just informed in some assumption for the foreground system. Specific product systems in reality might have different foreground and background systems. This limitation is however in line with the stated goal of the study, as generic products could be represented.

Use of the CFF as allocation method

It should be noted that the use of the CFF, as well as the use of its default values (e.g., A, B), could have relevant effects on the overall results in comparative assertions, especially when considering recycling and incineration EoL treatment. The use of default values may lead to controversial results, as, in general and by applying default values, EoL treatment via recycling shows, in general, higher emissions than treatment via incineration (by considering credits of avoided material, as well as avoided energy production). This is for both the A factor influencing recycling and the B factor influencing incineration and the connected material and energy credits. As pointed out in literature it has the main risk of "giving incorrect incentives": the CFF "assigns the full net benefits of energy recovery to incinerated products" while it assigns only 50% of net environmental benefit of recycling. Approaches for calculating more appropriate B values have been proposed.[13] As the later is not a standard procedure in sensitivity analysis applied to the CFF, and as it is still part of the ongoing research, the impacts of these factors were studied by choosing the extreme values of A=0 and A=1 as well as B=1 for sensitivity analyses. This aspect merits further investigation to assign proper burdens for EoL treatment, and improvement on the definition of geographically adjusted default values in the CFF might deserve further improvement in future works.

The CCF was implemented for the main flows crossing the system boundaries. Besides these the model builds upon datasets from the Ecoinvent cut-off system model and the allocation within these datasets was not adjusted to the CFF.

Biogenic carbon emissions

In LCAs two approaches that consider biogenic carbon cycle could be taken. The first approach considers biogenic carbon dioxide removal and release. This approach is taken, for example, in the EN 15408 methodology, where all biogenic inputs and outputs elementary flows are accounted. Therefore, biogenic carbon dioxide uptake is considered as credit, and biogenic carbon dioxide, as well as biogenic methane, are considered as impacts. The second approach considers only biogenic emissions to air other than CO_2 (e.g., methane). This approach is used in the EF 3.1 methodology based on IPCC 2013 report (AR5). Since this study is presented via EF 3.1 impact categories, it includes only biogenic methane emissions in the Climate Change biogenic impact category.

For evaluating environmental burdens (LCIAs following EF 3.1) of paperboards, only the fossil carbon emissions are considered. This approach builds upon the assumption of a managed forest landscape that maintains or increases the carbon stock, i.e., the biogenic carbon emissions are considered to be balanced by the uptake of the growing biomass.

13. See, e.g., Tomas Ekvall report (2021), available at the Swedish Life Cycle Center Website: https://www.lifecyclecenter.se/publications/factor-b-in-the-circular-footprint-formula-abstract-setac-europe-2021/

Geographical choices

The geography for the manufacturing phase of the products was assumed to be taking place in a European context for the single use and reusable systems. However, this is an assumption which is not always the case, as many of these types of products are supplied from the Asian market. This geographical location was assumed to be the same for both systems to avoid introducing any bias in the results.

Choice of datasets

The datasets were chosen from the selected database following the developed data quality requirements (cf. section 4.2.5). The best available datasets were chosen. The LCI tables may be found in Appendix G (takeaway) and Appendix H (e-commerce). However, the LCI of the chosen datasets is not included as the datasets are licensed by the Ecoinvent database.

Impact categories

This study assesses the potential environmental impact solely according to the EF 3.1 impact assessment method, as was preconditioned by the setup of the study by the Nordic Council of Ministers. All value choices and subjective choices embedded in this method are thus carried on to this study. For more detail on the method the reader may be referred to the European Platform on LCA (EPLCA).

It should be pointed out that Life Cycle Impact Assessment (LCIA) methods used within this study possess their own inherent robustness. As a corollary, discrete differences in diverse indicators from these methods are not directly comparable. Therefore, they should be interpreted cautiously and within the proper context.

According to the ISO 14044, no normalization and weighting should be done in LCAs of comparative nature. Therefore, it must be noted that each of the impact categories has different units and metrics and cannot be compared between each other. The four impact categories of robustness level III that are presented should be considered carefully, i.e., the results for Land Use, Water Use, Resource Use – minerals and metals, and Resource use – fossils.

8. Conclusions and Recommendations

The goal of the study is to gain knowledge and identify aspects that make single use and re-use packaging a better or worse option according to its environmental impacts. Through a systems perspective, this study provides reflections on both single-use and re-use product systems, comparing them with the LCA methodology based on the equivalency of their functions. For this purpose, environmentally decisive life-cycle stages and processes within the compared systems are modelled as disclosed in this study. It should thus be acknowledged that this study indicates benefits based on how the systems are modelled.

At the conclusion of this Life Cycle Assessment (LCA) study, it warrants particular emphasis that the precise numeric values developed by the assessment should not be the primary foundation for decision-making. These numerical representations should be used cautiously, considering the represented conditions and inherent variability of individual situations. This means interpreting these numbers necessitates a comprehensive understanding beyond their face value. The attested environmental benefits of certain product systems, as assessed by this study, are necessarily tied to specific preconditions, effectively implying that each case warrants an individualistic and separate consideration. Therefore, the conclusions derived from this study are relative rather than universally applicable, highlighting the importance of context in LCA studies. Given this limitation, sensitivity analyses were conducted to validate the conclusions further and test the robustness of the evaluation. These analyses intend to safeguard the findings and add an extra buffer of credibility by accounting for potential variability and assumptions. Further, the presented results are limited to the respective LCIA method and need to be considered independently from each other. No normalisation or weighting was conducted due to the comparative nature of the study. Therefore, it is impossible to compare results between impact categories or derive a "final single score" for each of the assessed systems. Further, the LCIA results do not predict impacts on category endpoints, the exceeding of thresholds, safety margins, or risks.

Besides the represented condition that can differ in reality, it is also important to remember that the conclusions drawn are influenced by methodological choices made at the start of the study. For instance, adopting a consequential LCA instead of the attributional LCA with CCF could potentially yield divergent results, reinforcing that LCA outcomes also depend on the methodology chosen.

In essence, while this study provides valuable information for decision-making, it is paramount to appreciate the breadth and depth of variables influencing the conclusions. This LCA study should spark insightful discussion and serve as a robust foundation for a more comprehensive examination of the product systems under consideration.

8.1 Conclusions for the takeaway container analysis

The LCA of takeaway containers revealed that the reusable container system typically has less environmental impact than the single-use system across multiple impact categories. The assessment indicates that the reusable container system is potentially the environmentally preferred option over the single-use system for 11 out of 13 impact categories. The analysis results show that the most contributing life cycle stages to single-use packaging are the raw materials and manufacturing life cycle stages. In contrast, the impacts of the reusable container are more evenly distributed among raw materials, manufacturing, and use phases. Recycling and incineration do not significantly contribute to the life cycle impacts, except for the latter in the climate change impact category. Meanwhile, credits from materials and energy recovery constitute up to 34% and 22% for the single-use and reusable systems, respectively.

Fourteen sensitivity analyses focussing on production, use phase, and end-of-life were implemented to assess the robustness of the results. These include weight, transportation from the service point to the final user, pre-washing method, reuse rates, and changes in the end-of-life modelling parameters.

Most sensitivity analysis results correlate with the base case, where the reusable container is potentially the less impacting option compared to the single use in most of the impact categories. The observed variations are dependent on the design of the container, consumer behaviour, and modelling choices:

- Variations of the different containers used in both single-use and reusable systems were tested by altering the weight. The weight was tested to evaluate the effects it has on the system. It was concluded that weight causes a change in the environmental impacts as it directly influences the whole system's life cycle and is considered a crucial factor for the system. Even though the weight of the reusable container is higher than the single-use one, higher reuse rates mean less raw materials per packaging as these are allocated over all uses. An increase in the weight of the single-use container or a decrease in the weight of the reusable container results in increased environmental benefits for the reusable system.
- Regarding factors affected by consumer behaviour, the following parameters were tested:

    - The variation of the reuse rate suggests that the break-even point where the reusable system is less impactful is reached at around 6 uses of the reusable container. However, for the reusable container to perform better in all impact categories, 14 uses are required.
    - Even though the use phase transportation and pre-washing did not substantially influence the system, it can be concluded that opting for no cleaning and transport methods such as walking or biking are environmentally preferred options. Conversely, handwashing and transportation by car resulted in the highest environmental impacts.
    - Furthermore, recycling plastic containers is a more favourable treatment than incineration for both systems' end-of-life phases.
- Modelling choices tested include credits for energy and materials recovery at the end-of-life stage. Even with a reduction of environmental impacts associated with the containers when modelling with avoided burden (e.g., A=0, B=0), results continue to favour the reusable container over the single-use system.

The correct configuration of the reusable system is crucial for the reusable container to result in the preferred option over the single-use system. The configuration could be to incentivise the users to return the containers to make sure there are guidelines for the best practices, like avoiding double washing, returning containers as soon as possible, and using low/no emission transport methods such as walking or biking.

To summarise, this study aimed to portray a realistic configuration for a takeaway container service in the Nordic countries. The reusable option emerged as the preferred option over the single-use system. The results demonstrate high robustness in 10 out of the 13 impact categories, while the remaining three show medium robustness (these three include the 2 impact categories where the single-use system was preferred).

8.2 Conclusions for the e-commerce analysis

The results of the LCA of single-use plastic and paper bags and the reusable woven plastic indicate that the majority of life cycle impacts for all systems come from the upstream life cycle stages—namely, raw material extraction and manufacturing.

The comparative assessment results of single-use plastic and paper bags vs. reusable woven plastic suggest that single-use plastic (SUPL) packaging consistently outperforms its reusable counterpart in the examined indicators. In contrast, the reusable system shows some advantages compared to the single-use paper system (SUPA).

For single-use plastic packaging, all 13 investigated impact categories show environmental benefits—12 categories exhibit high robustness, while one shows medium robustness. For single-use paper packaging, environmental benefits are observed in 5 out of 13 impact categories—one displaying high robustness and four medium. The reusable system presents lower environmental impacts in 8 out of 13 categories, with six demonstrating a high robustness level and two medium.

Sensitivity analysis results are consistent with the base case comparison—offering medium to high robustness—examining variations concerning production-related choices, consumer behaviour, and modelling decisions. Individual assumptions alter the relationship between the compared systems to an extent but not across a majority of impact categories simultaneously. Variations in transporting the package to the final client do not influence the results remarkably.

In all three systems, the upstream impacts constitute the hotspot. The upstream impacts of the reusable systems is larger due to a more complex and robust packaging solution compared to the single-use packaging. The main impact on the conclusions comes from the reuse rate, as these upstream impacts can be distributed across multiple uses. The breakeven analysis shows that the reuse rate factor clearly influences the relationship between the single-use and reuse systems. The study adopted a baseline of 4 uses (75% reuse rate). However, more uses or lower upstream impacts could alter the results, which depends on how the reuse system is designed. As an example, the results for all sensitivity setups are calculated with a baseline of 10 uses (90% reuse rate).[14] While results for this higher reuse rate presented a shift in some impact categories, they remained robust overall. This suggests again that the results are quite robust, and the reuse rate has to be higher than the respective break-even points to show clear benefits.

8.3 Overall conclusion and recommendations that could be derived from this study

Emerging policies focus on transitioning from single-use to reusable packaging. This study aimed to deepen understanding of the relative environmental impacts and potential benefits of reusing packaging in a Nordic context. The examined systems were single-use and reuse systems for e-commerce bags used in transport packaging and takeaway containers from the food and beverage sector. Even though the systems have different functional units and systems, there are some main overlaps in the conclusions.

The results of the base case comparison did not always result in the reusable option being the most environmentally beneficial across impact categories. Yet, the sensitivity analyses show how the results can benefit the reusable option by varying

14. This is similar to the baseline approach for the reusable system in the takeaway study and closer to the breakeven point of the reuse solution with the single-use plastic solution. For more details on the results, please refer to 0.

specific parameters. Therefore, the results of base case comparisons and sensitivity analyses indicate potential environmental benefits for reusable options when tweaking these parameters, i.e., packaging design, reuse systems, transports and end-of-life treatment.

When designing reusable packaging, several aspects should be considered simultaneously to allow the packaging solutions to have a longer lifetime (longevity) while decreasing the material resources needed to produce it: 1) It is important to manufacture durable packaging that can withstand multiple reuse cycles. 2) It is important to make the packaging as light as possible. 3) The recyclability of the used materials should be considered to allow for material credits. 4) The use of recycled material has the potential to reduce the environmental impact.[15]

When establishing reusable systems, the goal should be to increase the reuse rates effectively. With higher reuse rates, the environmental benefits of reusable packaging could outweigh those of single-use counterparts. To facilitate this, efficient systems must be developed. This involves incentivising final users to choose reusable packaging and ensuring accessible collection, return, and cleaning processes for operating companies. Collaboration between key market stakeholders is crucial to bring about this change. This can be illustrated by considering the case of takeaway containers. Here, container manufacturers, companies providing reusable containers, takeaway restaurants, and takeaway delivery service companies could work in partnership to enhance the operation of reusable systems. As these efficient systems get implemented, and the concept of reusable packaging becomes more familiar to people, reuse rates are expected to increase.

The system was modelled with production in a European context, showing impacts on the distribution life cycle stage for most impact categories. Even though the impacts are not that high, the results emphasise the importance of using the local supply chain, which can lead to less energy-intensive transportation methods and shorter truck journeys.

Additionally, the waste disposal stage was also shown to be relevant when performing the sensitivity analysis. Proper separation and treatment of the packaging at its end-of-life can reduce the environmental impact of both single-use and reusable packaging. It can ensure that the disposed material can be optimally utilised to provide the highest benefits in its recovery process. Therefore, it is important to promote the proper handling of waste to reduce waste generation while conserving resources and contributing to a more circular economy society.

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15. The effect of using recycled material (tested for e-commerce in EC3) shows limited impact on the results. However the trend is prevalent and the conclusion depends on the specific recycling processes and on the environmental performance of primary-materials production. Still, even if recycled material is used the weight and reuse rate is important.

In summary, the study found that several factors influence the comparison between single-use and reusable packaging. The influencing stakeholders range from solution providers and package manufacturers to consumers and the overall system context provided by governmental policies and environmental awareness. The complexity of reducing environmental impacts lies in managing these factors. Nonetheless, with the correct setup, reusable packaging potentially poses lower environmental impacts than single-use options. Therefore, improving such solutions is crucial to enhance the overall environmental performance of packaging on the market. This might sometimes mean avoiding packaging altogether rather than replacing single-use packaging with reusable alternatives.

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Appendix A. Proposed political targets

Re-use and refill targets set up in the proposed regulation (European Parliament, 2023).

	From 1 January 2030	From 1 January 2040
Large household appliances (such as refrigerators, freezers, washing machines, clothes dryers or dish washing machines)	Share of products made available in reusable transport packaging 90 %	
Cold or hot beverages (filled into a container at the point of sale for take-away)	Share of beverages made available in reusable packaging or by enabling refill 20 %	Share of beverages made available in reusable packaging or by enabling refill 80 %
Take-away ready-prepared food (intended for immediate consumption with no need of any further preparation, and typically consumed from the receptacle)	Share of products made available in reusable packaging or by enabling refill 10 %	Share of products made available in reusable packaging or by enabling refill 40 %
Alcoholic beverages (beer, carbonated alcoholic beverages, fermented beverages other than wine, aromatised wine products and fruit wine, products based on spirit drinks, wine or other fermented beverages mixed with beverages, soda, cider or juice)	Share of products made available in reusable packaging or by enabling refill 10 %	Share of products made available in reusable packaging or by enabling refill 25 %
Wine (except sparkling wine)	Share of products made available in reusable packaging or by enabling refill 5 %	Share of products made available in reusable packaging or by enabling refill 15 %
Non-alcoholic beverages	Share of products made available in reusable packaging or by enabling refill 10 %	Share of products made available in reusable packaging or by enabling refill 25 %
Transport packaging (pallets, plastic crates, foldable plastic boxes, pails and drums for conveyance or packaging)	Share of packaging used that is reusable 30 %	Share of packaging used that is reusable 90 %
Transport packaging (e-commerce) Operators using transport packaging for the transport and delivery of non-food items sold via e-commerce	Share of such packaging used is reusable packaging 10 %	Share of such packaging used is reusable packaging 50 %
Transport packaging (pallet wrappings and straps)	Share of such packaging used that is reusable packaging 10 %	Share of such packaging used that is reusable packaging 30 %
Grouped packaging (boxes, excluding cardboard, used outside of sales packaging to create a stock-keeping unit)	Share of such packaging used is reusable packaging within a system for reuse 10 %	Share of such packaging used is reusable packaging within a system for reuse 25%

Appendix B. Case studies selection

Transport packaging

The Packaging and Packaging Waste Directive proposal is setting targets for some relevant reusable packaging system for 2030 and 2040. For the commercial and industrial sector, two of the most ambitious targets are for good sold using pallets, crates, foldable boxes pails and drums with a 30% target by 2030, and 90% by 2040. Additionally, a target of 10% of non-food goods sold via e-commerce packaging was set for 2030, and of 50% by 2040.

This was used to prioritise the possible packaging systems to include in these assessments. Some of relevant systems found can be found in Table 27.

Table 27 Reusable packaging systems within transport packaging.

Product	Country	Concept
	Denmark	**Re-zip** Packaging for e-commerce When buying online, customers choose circular packaging. After delivery customer returns the packaging to the nearest drop point, which will be delivered to a cleaning hub and be prepared for next shipment.
	Finland	**Repack** Packaging for e-commerce Business leases the RePack bags, and customers get the chance to choose circular packaging on their checkout. One it is delivered; customers return the empty pack to the Repack hub. They also take care of reverse logistics and cleaning
	Denmark	Dansk Emballage Packaging like pallets, tanks, drums, canisters Customer orders pick-up stating previous content. Dansk Emballage picks it up and takes care of the cleaning

Sweden

[Svenska Retursystem](#)
Food crates and pallets
System for the food industry's supply chain like food producers, wholesalers, stores and restaurants based on shared pallets and crates.

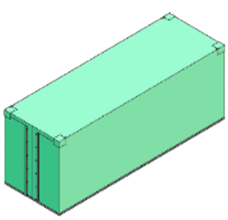
Svenska Retursystem delivers empty crates and pallets to producers which fill them and deliver to wholesalers. Wholesalers deliver to stores and/or restaurants. Between each turn, the boxes return to the facilities to their logistics facilities to be washed, checked and repaired.

When crates are no longer usable, the plastic gets grinded into granulates that then become new crates.

Norway

Packoorang:
Reusable mailer bag that is made from 100% recycled polyester packaging, durable enough to last 50-100 reuses. It is padded and weatherproof and comes with optional sealing, keeping products safer. It shapes around the content inside saving shape and costs.

Palloorang:
A reusable pallet wrapper, can be reused 500+ times,



Norway

Looping
Reusable Module cover for contractors modules
Their first product Modulcover has 80% of the market for contractor modules in Norway. They offer covers for wood and steel modules to protect them during storage and transportation, avoiding the use of single use plastic. They claim to save around 10 tonnes of plastic every year

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Denmark

Clip Lock
Reusable transport box
Reusable transport box, which consists of plywood panels held together with detachable spring steel clips. After delivery, the transport box can be flat-packed which can reduce up to 80% space and returning costs.

Five different types of products were found: packaging solutions for e-commerce, pallets, transport packaging, transport box, and cover for contractor modules. Based on the literature review done, 8 LCAs were found for reusable crates, with 2 of them being from Nordic solutions. There were also two LCAs on e-commerce packaging, but only one being from the Nordic countries. No previous LCAs were found for the reusable transport packaging for contractors and for the reusable transport box.

E-commerce

In Europe e-commerce grew with a grow rate of 13% in 2021. However, in 2022 the growth has stabilised (Ecommerce Europe, 2022). In the Nordics, e-commerce increased 2% in 2019, with an average of 62% of Nordic residents shopping online per month (Postnord, 2019). A report by Nordea on e-commerce and the shopping behaviour after the Covid-19 pandemic shows card transaction data from 10 million customers, showing an increase in online transactions from 5% in 2011 to 20% in 2021, which has decrease to around a 14% in 2022, yielding a lower-than expected boost. Nonetheless, they also estimate a potential rise to up to 30% by 2027. IKEA reported 26% of their sales took place online in 2021, increasing by 73%.

Additionally, statistics were searched on e-commerce against retailer sales packaging, but not much research has been conducted in this field.

Takeaway and beverages sector

In the same way for transport packaging, the packaging and packaging waste directive has set targets for the food and beverage industry for hotels, restaurants, and catering services. A target of 20% was placed for beverages containers (cold and hot) at the point of sale for takeaway for reuse and refill systems by 2030, and 80% by 2040, as well as 10% of packaging food for takeaway must be sold in reusable packaging by 2030 and 40% by 2040. Therefore, these were considered of significant relevance.

The following systems were found within this sector.

Product	Country	Concept
 	Denmark	Kleenhub Cups in steel and bowls in plastic (PP or TPE). Download an app, scan NFC card at the counter and register your borrow, then you have 10 days to return the packaging in any café within the network
	Finland	Kamupak Order from any coffee shops in their network and pay a deposit, once you are done return it to any shop of your choice, and get your deposit back, get a new one of receive digital credit.
	UK	**CupClub** Returnable cup from recycled PE You go to your favourite coffee shop – at the moment that will be in offices and university campuses. You order your coffee with the Cupclub product. The barista will remind you to put the cup in one of the collection points when you're done, and that's it. Our orders are directly with the retailer; consumers don't pay any extra
	Denmark	**New Loop** Returnable plastic cup Pay a deposit and deliver the cup back to one of the shops
	Switzerland, Denmark, Germany, among others	**ReCIRCLE** Container, cups Pay a deposit for a container or cup and return it to someone in their network to get a refund or a new, clean product.

The main reusable packaging products found in the Nordic within the takeaway and beverage sector consist of cups and containers. Different reusables takeaway services exist; on-the-go, where customers reach the restaurant and take out their food on reusable food packaging or home delivery, where customers order their food online and it is delivered by a courier on reusable packaging. The most common scheme for reusable takeaway in the Nordics was found to be on-the-go. However, no LCAs were found for any of these solutions. From outside the Nordics, there were more studies found on reusable cups than on takeaway containers. Which is why we would suggest focussing on the reusable food takeaway containers.

Other solutions outside of the Nordics

Additionally, a list of reusable packaging solutions from other countries was included to showcase solutions still not available in Nordic countries

Product	Country	Concept
	France	**Living Packets** "THE BOX" is a reusable, robust and foldable packaging that eliminates all packaging waste, with integrated sensors that allow you to know at any time where and in what state your package is. Use THE BOX for shipments and returns. Send products in it, load a label, and give it to your carrier. The recipient is informed of the shipment of the package by email and can unlock it upon receipt.
	Italy	**Zero Impack** Order lunch from the selection of restaurants every day and receive your meal in a reusable containers. Your meal will be delivered directly at your office. The container can be returned in the Zero Impack drop-off bins located at your company.
	Chile, USA, UK	**Algramo** Algramo offers to customers in Chile affordable quantities of everyday products without single-use, non-recyclable packaging. Targeting economies where recycling infrastructure is limited and small packaging items such as sachets often end up in the environment, Algamo introduces a reusable packaging system with dispensers and affordable containers.

USA

OZZI

The OZZI Solution is a closed-loop system that starts with a participant receiving a container by a one-time purchase to get into the program or being granted their first container by dining services. The participant will then fill their container with food and eat in or take their meal to go.

Once they are done with the meal, the used O2GO container is returned to an OZZI machine. At this point, the container is dropped into a collection cart, which creates an easy system for dining services to clean them.

Belgium

Fillbee

This returnable six-pack fits in existing crates or can be used stacked on a pallet. With this shelf-ready packaging, reusable bottles can last up to 50 return trips, eliminating packaging waste completely.

USA, UK, France, Canada

Loop

Loop is a platform where you can use your products and return empty containers by scheduling a free pickup online or returning them to retail partners. Loop cleans the empty packaging to reuse it. It can be distributed both online, and in-store

Czech Republic

MIWA

MIWA introduces a digital solution that connects all stakeholders along the value chain – from the farm that produces the food to the customer that buys it. It allows anyone with a mobile phone to order any desired amount of a product to be delivered in reusable packaging to either their nearest store or directly to their home.

Appendix C. Point of substitution

The point of substitution (PoS) corresponds to the point in the supply chain where secondary materials substitute primary materials. Below the approach to the two material groups present in this study are presented.

Plastic products

Four plastic grades are considered in this study, i.e., the inputs are virgin LDPE and virgin PP in the base case analysis and recycled LDPE and PP in the sensitivity analysis. The PoS for plastic products is identified at the level of recycled polymer granulate replacing virgin polymer resin of the same material (in accordance with the Plastic LCA method).

In this study the PoS is thus set at the secondary granulate after the recycling process. Potential changes of material quality are considered through the CFF parameters Qsin/Qp and Qsout/Qp.

Paper products

The PoS (functional equivalence) for paper products is identified at the level of recycled pulp, as output of the wastepaper recycling. The recycled pulp is *wet pumpable pulp* ready to pump into the paper machine. It is assumed that the wet pumpable pulp is substituted by virgin pulp. However, the available data for virgin pulp in databases (e.g., Ecoinvent) is linked to the production of market pulp (*dry market pulp*). Therefore, it is assumed that the *wet pumpable pulp* is substituted by *dry market pulp*, understood to be inline with the current PEFCR[16] guidelines for intermediate paper products.

16. https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_Intermediate%20paper%20product_Feb%202020.pdf

Appendix D. Nordic statistics

To inform the foreground system of the conditions in the Nordics the following statistics were used.

End-of-life treatment of packaging in the Nordics

The final treatment of both plastic and paper packaging is modelled as in the statistics below. The R2 value (recycling output rate) describes the output of the recycling process. For the used statistics of plastics (Recycling rates of packaging waste for monitoring compliance with policy targets, by type of packaging) this is in line with what the statistics describe: "Recycling rate of plastic packaging waste counts exclusively material that is recycled back into plastic (material recycling / generation)". For paper packaging the applied "recycling" rate describes the input to the recycling process, which is then treated according to the dataset with a respective output of secondary material (considering fibre loss).

As landfilling of both plastic and paper is not common for waste generated in the studied Nordic it was decided with the steering committee that the remaining material is modelled as energy recovery, even if the Eurostat statistics do not show clear on the R3 value.

Table 28 Share of end-of-life treatments for the four studied countries for plastic packaging (Eurostat, 2023).

	Recycling (R2)	Incineration (R3)	Landfill (1-R2-R3)
Denmark	22.90%	77.10%	0.00%
Finland	39.40%	60.60%	0.00%
Norway	27.90%	72.10%	0.00%
Sweden	33.50%	66.50%	0.00%
Average	30.93%	69.08%	0.00%

Table 29 Share of end-of-life treatments for the four studied countries for paper packaging (Eurostat, 2023).

	Recycling (R2)	Incineration (R3)	Landfill (1-R2-R3)
Denmark	69.30%	30.70%	0.00%
Finland	98.20%	1.80%	0.00%
Norway	77.60%	22.40%	0.00%
Sweden	78.00%	22.00%	0.00%
Average	80.78%	19.23%	0.00%

Energy production in the Nordics

The production of the packaging solutions are modelled for European geography such that available European electricity mixes were used in the production processes. However, in the EoL the avoided energy production from energy recovery was modelled for the Nordic geography, using the energy production in the studied countries to inform the shares. Further the European waste incineration datasets present a share of replaced energy production not representative for Nordic conditions in which the energy output is rather optimised for heat production than electricity production. Thus, the produced energy was summed up and redistributed according to Nordic conditions, such that 86% of the exported energy is heat and 14% of the exported energy is electricity.[17]

The electricity mix for the studied region is modelled with the shares presented in Table 30. The electricity was modelled with the respective "market for electricity, medium voltage" dataset for the four countries (Ecoinvent 3.9.1).

17. These statistics were identical for Danmark and Sweden during 2022 and thus judged to be reliable, see for more detail https://www.vestfor.dk/fjernvarme/hvad-er-fjernvarme/ and https://www.avfallsverige.se/media/whafyutn/svensk_avfallshantering_2022.pdf. The redistribution method is judged to be conservative as heat production is by trend more efficient than electricity production, such that the exported energy may be higher if more heat is exported. This assumption was applied uniformly over all case studies.

Table 30 Electricity mix, Nordics. Share of the electricity production of the studied countries (reference year 2022) (IEA, 2023).

	Total (GWh)	Share
Denmark	33 043	7.70%
Finland	71 711	16.60%
Norway	157 962	36.60%
Sweden	168 600	39.10%

The heat mix for the studied region is modelled according to the statistics presented Table 31. The respective shares of displaced heat, i.e., heat production without waste incineration are presented in the section below with the dataset selection. For the modelling only the energy sources with more than 1% share are modelled. The shares of the remaining energy sources are adjusted accordingly.

Table 31 Heat mix, Nordics. Heat production of the studied countries, share of avoided heat production and da-taset collection (reference year 2022) (IEA, 2023).

Production [TJ]	Coal	Oil	Biofuels	Waste	Other sources	Natural gas	Geo-thermal	Solar thermal
Denmark	9025	558	73240	28512	12834	14057	27	2282
Finland	39598	6072	23109	86126	13566	23923	-	-
Norway	339	698	7751	11103	10636	473	-	-
Sweden	7190	3996	3851	98618	52481	39245	-	-
Share for avoided heat production in a Nordic mix								
Denmark	2.6%	0.2%	21.2%	-	3.7%	4.1%	0.0%	0.7%
Finland	11.5%	1.8%	6.7%	-	3.9%	6.9%	0.0%	0.0%
Norway	0.1%	0.2%	2.2%	-	3.1%	0.1%	0.0%	0.0%
Sweden	2.1%	1.2%	1.1%	-	15.2%	11.4%	0.0%	0.0%
Dataset selection								
Denmark	(1)	-	(3)	-	(4)	(7)	-	-
Finland	(1)	(2)	(3)	-	(5)	(7)	-	-
Norway	-	-	(3)	-	(5)	-	-	-
Sweden	(1)	(2)	(3)	-	50%(5) 50% (6)	(7)	-	-

Dataset name, geography selected for respective geography

(1) heat and power co-generation, hard coal
(2) heat and power co-generation, oil
(3) heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014
(4) heat and power co-generation, biogas, gas engine
(5) treatment of blast furnace gas, in power plant
(6) treatment of coal gas, in power plant
(7) heat and power co-generation, natural gas, conventional power plant, 100MW electrical

Appendix E. Reusable packaging operators

Table 32 Data obtained from reusable packaging operators in Europe.

	Kamupak (Finland)	Kleenhub (Denmark)	Vytal (Sweden)	reCIRCLE (Switzerland/ Denmark)	Recup/ Rebowl (Germany)	Pyxo (France)	Bumerang (Spain)	Retoornado (Spain)
Raw materials for your packaging	pp-plastic	PP bowl and Lid with TPE and PP	Polyprolyne	Polybutyl enterephthalat with 30% of Glassfibers	Polypropylene	Mainly PP, also Tritan and recyclable glass (verre sodo-calcique)	Polypropylene	Polypropylene
Volume of packaging	500 ml; 1.2 L; 1.7 l	1250 ml	750, 1250 mL	BOX 1M: 1200ml BOX 2M: 1000ml BOX 1S: 600ml BOX MENU L: 900ml	Cups: 200ml, 300ml 400ml 500ml, Bowls: 550 ml, 590 + 320 ml, 1100 ml	From 120mL to 1500mL, mainly 750mL	Cups -> 200-500ml, Bowls -> 500-1250ml, Trays -> 700-1500ml	Small box 38 x 28 x 8 cm Medium box 42 x 28 x 12 cm Large box 42 x 32.5 x 15 cm

Weight of packaging (min. and max. weight)	from 48 g; 107 g; 118 g	266 grams	x, 266 grams	BOX 1M: 220g BOX 2M: 254g BOX 1S: 159g BOX MENU L: 268g (including Lids)	Min: 7 gram lid for the cups or 30 gram for the smallest cup Max: 219 gram for bowl with separation including lid	Average for 750mL : 120g	Cups -> 15*-30g, Bowls -> 87 - 180g (with lid)	from 350g up to 550g
Durability of product	100 times	200 times	138 to 142 times	200 washing cycles or more. We just checked up to 200 uses. But, more could also be possible regarding washing. Since, not washing is the issue but the usage (knife and fork) is the problem	Cups: 1000 cycles Bowls: 500 cycles	Our oldest container yet has done 130 cycles, but it means it can live longer	Cups -> 500-1000* cycles, Bowls -> 200-500 cycles	From 20 up to 40 uses in normal conditions. Depending on the the content delivered in our boxes, the durability can be improved or reduced.
Production process	Injection moulding	Injection moulding	Injection molding, EUROPEAN	Injection moulding	-	For plastic : injection	PP injection	PP injection sheets that are transformed into boxes.

Country of pro- duction/ Transport method	Sweden	Germany/ Holland	Germany	Switzerland. The granule is from Italy and the Netherlands and soon Sweden.	We are producing everything in Germany The trans- portation methods are DHL Green with vans and DB Schenker with semi trucks	Netherlands, Germany, France – initial transport mainly truck	Netherlands and Germany Truck transport palle- tized with standard EU Pallet	We are import- ing from Asia right now (coming into containers via sea) and making short runs within Spain (transported via truck in EUR pallets).
Reuse rate (number of reuse cycles)	90%	95%	99.3%, it is free if they return it before 14 days	In theory, people buy a box and after finising the meal, people return it to the restaurant. Restaurant washes and sells the BOX again. In reality, only 20% do so. 80% buy a box once, and then keep it at home or office and take it with them when they go to the restaurant.	We are currently working on reliable reuse rates (for durability please see above)	Our return rate (everytime we lend a container, what are the odds it comes back in 14 days) is between 92 and 98%. The older the network is, the higher this rate becomes.	99.5% thanks to our digital penalty system	Right now with closed circuits, return rate is 100%

Reuse process	App; When borrowing, the user agrees to return the dishes within 14 days to one of our partner restaurants. Multiple dishes can be borrowed at once.	App, borrow a cup or container by scanning the NFC card at the counter, you have 10 days to return packaging or restaurant within the network	Download app, Ask for Vytal and order your takeaway in reusable, lend it with the QR code free of charge and return within 14 days	Since we do not track, we do not know. But, we have products in circulation that were produced in 2016.	We are currently working on reliable reuse rates (for durability please see above)	It is usually washed internally by the restaurant (only 4% of restaurants outsource it today but for large scale schemes it will be mainly outsourced)	Return-on-the-go (as Ellen Macarthur Foundation classification). Transportation for return is considered non existent as our consumers are the ones returning the containers to our partners.	Customer has to return their subscription stuff in the same box as it was received.
Cleaning/ washing: i) water (amounts of water and temperature), ii) detergent (chemical composition and amounts)	Done by restaurants	Done by restaurants	Restaurants have to clean it/ users to rinse it/ Industry washing.	Restaurant and end-users do the washing so differs very much.	We don't have detailed information on that. The products are in general heat resistant up to 85°C	For restaurants that wash internally, water consumption : average of 6 l/cycle. One cycle is between 10 and 25 items.	As we don't offer central washing we don't know, however we know most of our partners have industrial washing from companies	We are working clothing industry so no need to wash with water. Only in spot we need to clean with some wet cloths.

End-of-life	Returned to plastic recycling in Finland, where the material is recycled (Lassila & Tikanoja)	At the moment there are not so many, but they collect them back and reuse them	Plan: sell material back to the raw material supplier, regrinded. They are returned and stored	Lids: Downcycling into concrete spacers. (Cups and transparent BOXes will also be downcycling) aubergine BOXes hopefully recycling into new BOXes (Permission not yet granted)	The products can be 100% recycled. Our producer takes old or damaged products back for recycling.	Recycling mainly for PP and glass, downcycling for Tritan (construction industry)	Recycling with PP injector in Barcelona area, 20km transportation with trucks in palletized. In 3 years we haven't been able to get enough containers to recycle.	We still haven't had waste, but the goal is to send to a recycling PP plant to make it reusable again for same purpose.

Appendix F. Circular Footprint Formula factors

Table 33 Summary of the CFF factors used in the base case CFF implementation. The cells marked in light green are studied in the sensitivity analysis.

Parameters	LDPE foil	Paper	Polypropylene
A	0.5	0.2	0.5
B	0	0	0
Qsin/Qp	0.75	0.85	0.9
Qsout/Qp	0.75	0.85	0.9
R1	0	0	0
R2	30.93%	80.78%	30.93%
R3	69.08%	19.23%	69.08%
E_D	none	none	none
$X_{ER, elec}$ * LHV (kWh)	0.632	0.233	0.478
$X_{ER,heat}$ * LHV (MJ)	13.966	5.151	10.577
$E_{recycled}$	market for polyethylene, high density, granulate, recycled	none	market for polyethylene, high density, granulate, recycled
$E_{recyclingEoL}$	polyethylene production, high density, granulate, recycled	treatment of waste paper to pulp, wet lap, totally chlorine free bleached	polyethylene production, high density, granulate, recycled
Ev	see in LCI table	see in LCI table	see in LCI table
E*v	same as Ev	same as Ev	same as Ev
E_{ER}	see in LCI table	see in LCI table	see in LCI table
$E_{se,heat}$	heat mix, Nordics	heat mix, Nordics	heat mix, Nordics
$E_{se,elec}$	electricity mix, Nordics	electricity mix, Nordics	electricity mix, Nordics

Appendix G. LCI tables takeaway

Single use takeaway container

Production

Raw materials	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source	Comments
PP bowl + lid	59	g	Scope of project - Based on product found in Amazon TIYA (2023) https://www.amazon.com/TIYA-Takeout-Food-Containers-Microwavable/dp/B09YVN84FC/ref=sr_1_14?keywords=glad%2B42%2Boz%2Bcontainers&qid=1696063979&sr=8-14&th=1	Secondary	Europe (RER)	polypropylene production, granulate (RER)	Ecoinvent 3.9.1 Cutoff	Default scenario
Process	**Value**	**Unit**	**Source**	**Type of data**	**Geographical coverage**	**Dataset**		**Comments**
Extrusion and thermoforming	calculated in model	g	Scope of project	Secondary data	Europe (RER)	extrusion of plastic sheets and thermoforming, inline (RER)	Ecoinvent 3.9.1 Cutoff	

Distribution

Trans-portation method	Distance	Unit	Source	Type of data	Geographi-cal cover-age	Dataset	Source	Com-ments
Road, truck, >32 t, EURO 4	3500	km	Plastic LCA method	Secondary	Intraconti-nental (Europe)	transport, freight, lorry >32 metric ton, EURO4 - RER - transport, freight, lorry >32 metric ton, EURO4	Ecoinvent 3.9.1 Cutoff	Default scenario

Use

Trans-portation	Value	Unit	Share	Type of data	Geographical coverage	Dataset	Source	Comments
No impact	5	km	33%	Plastic LCA method	-	-	Ecoinvent 3.9.1 Cutoff	
Car	5	km	62%	Plastic LCA method	RER	transport, passenger car (RER, market for transport, passenger car)	Ecoinvent 3.9.1 Cutoff	Considering volume of container to be 0.00125 m^3 and divided by 0.2 m^3, as suggested in plastic method
Round trip, by van (lorry <7.5t, EURO 3, utiisation ratio of 20%	5	km	5%	Plastic LCA method	RER	transport, freight, lorry 3.5-7.5 metric ton, EURO 3 (RER, market for transport, freight, lorry 3.5-7.5,metric ton, EURO3)	Ecoinvent 3.9.1 Cutoff	

End-of-life

	Recycling R2	Incineration R3	Landfill 1-R2-R3	Sources	Comments
Denmark	22,90%	77,10%	0,00%	https://ec.europa.eu/eurostat/databrowser/view/ENV_WASPAC__custom_7013298/default/table?lang=en	EUROSTAT (2020)
Norway	27,90%	72,10%	0,00%	https://ec.europa.eu/eurostat/databrowser/view/ENV_WASPAC__custom_7013298/default/table?lang=en	EUROSTAT (2020)
Finland	26,20%	73,80%	0,00%	https://ec.europa.eu/eurostat/databrowser/view/ENV_WASPAC__custom_7013298/default/table?lang=en	EUROSTAT (2020)
Sweden	33,50%	66,50%	0,00%	https://ec.europa.eu/eurostat/databrowser/view/ENV_WASPAC__custom_7013298/default/table?lang=en	EUROSTAT (2020)
Comments	27,63%	72,38%	0,00%		

Recycling

Process	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source
Plastic recycling	22,90%	%	ecoinvent dataset	Secondary data	Europe (RER)	polyethylene production, high density, granulate, recycled	0
Credit material	**Value**	**Unit**	**Source**	**Type of data**	**Geographical coverage**	**Dataset**	**Source**
Virgin PP	12,16	g	ecoinvent dataset	Secondary data	Europe (RER)	polypropylene production, granulate	0

Incineration

Process	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source
Incineration PP	77,10%	%			CH	treatment of waste polypropylene, municipal incineration with fly ash extraction	0

Credit energy	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source
Electricity credit	0,042	kWh	IEA	Secondary data	Nordics	Electricity mix Nordics	Mix developed in project
Heat credit	0,452	MJ	IEA	Secondary data	Nordics	Heat mix Nordics	Mix developed in project

Production

Raw materials	Value	Unit	Source	Type of data	Geographical coverage	Dataset (Ev)	Source	Com-ments
PP bowl	193	g	Based on kleenhub and vytal data	Primary data	Europe (RER)	polypropylene production, granulate - RER - polypropylene, granulate	Ecoinvent 3.9.1 Cut-off	
TPE part of lid	42,5	g	Based on kleenhub and vytal data	Primary data	Europe (RER)	acrylonitrile-butadiene-styrene copolymer (RER, acrylonitrile-butadiene-styrene copolymer production)	Ecoinvent 3.9.1 Cut-off	
PP part of lid	31,5	g	Based on kleenhub and vytal data	Primary data	Europe (RER)	polypropylene production, granulate - RER - polypropylene, granulate	Ecoinvent 3.9.1 Cut-off	

Process	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source
injection moulding	267	g	Scope of project	Secondary data	Europe (RER)	injection moulding - RER - injection moulding	Ecoinvent 3.9.1 Cut-off

Distribution

Trans-portation method	Distance	Unit	Source	Type of data	Geographi-cal cover-age	Dataset	Source	Com-ments
Road, truck, >32 t, EURO 4	3500	km	Plastic LCA method	Secondary	Intracon-tinental (Europe)	transport, freight, lorry >32 metric ton, EURO4 - RER - transport, freight, lorry >32 metric ton, EURO4	Ecoinvent 3.9.1 Cut-off	

Use

Washing	Type of washing	Value	Unit	Type of data	Geographical coverage	Dataset	Source	Comments
Hand washing	Soap	0,34	g	Secondary data	Europe (RER)	See full inventory in appendix	Porras, Gabriela & Keoleian, Gregory & Lewis, Geoffrey & Seeba, Nagapooja. (2020). A guide to household manual and machine dish-washing through a life cycle perspec-tive. Environmental Research Communi-cations. 2. 021004. 10.1088/2515-7620/ab716b.	Dataset selected based on Schowanek et al. 2018
	Electricity	0,03	kWh	Secondary data	Nordic mix	Nordic mix		
	Water	0,62	L	Secondary data	Europe (RER)	tap water (Europe without Switzerland)		
Dish-washing	Soap	0,19	g	Secondary data	Europe (RER)	See full inventory in appendix		
	Electri-city	0,02	kWh	Secondary data	Nordic mix	Nordic mix		
	Water	0,17	L	Secondary data	Europe (RER)	tap water (Europe without Switzerland)		
None								
Professio-nal dish-washer	Soap	0,0003	kg/kg container	Secondary	Europe (RER)	See full inventory in appendix	https://ivl.diva-portal.org/smash/get/diva2:1737773/FULLTEXT02.pdf	
	Electri-city	0,077	kWh/kg container	Secondary	Nordic mix	Nordic mix	-	
	Water	0,144	kg/kg container	Secondary	Europe (RER)	tap water (Europe without Switzerland)	-	

Trans-portation	Value	Unit	Share	Type of data	Geographical coverage	Dataset	Source	Comments
No impact	5	km	33%	Assumption based on Plastic LCA method	Europe (RER)	-		
Car	5	km	62%	Assumption based on Plastic LCA method	Europe (RER)	transport, passenger car (RER, market for transport, passenger car)	Ecoinvent 3.9.1 Cut-off	Considering volume of container to be 0.00125 m^3 and divided by 0.2 m^3, as sug-gested in plastic method
Round trip, by van (lorry <7.5t, EURO 3, utiisation ratio of 20%	5	km	5%	Assumption based on Plastic LCA method	Europe (RER)	transport, freight, lorry 3.5-7.5 metric ton, EURO 3 (RER, market for transport, freight, lorry 3.5-7.5,metric ton, EURO3)	Ecoinvent 3.9.1 Cut-off	

End-of-life

	Recycling	Incineration	Landfill	Sources	Comments
	R2	R3	1-R2-R3		
Denmark	22,90%	77,10%	-	https://ec.europa.eu/eurostat/databrowser/view/ENV_WASPAC__custom_7013298/default/table?lang=en	EUROSTAT (2020)
Norway	27,90%	72,10%	-	https://ec.europa.eu/eurostat/databrowser/view/ENV_WASPAC__custom_7013298/default/table?lang=en	EUROSTAT (2020)
Finland	26,20%	73,80%	-	https://ec.europa.eu/eurostat/databrowser/view/ENV_WASPAC__custom_7013298/default/table?lang=en	EUROSTAT (2020)
Sweden	33,50%	66,50%	-	https://ec.europa.eu/eurostat/databrowser/view/ENV_WASPAC__custom_7013298/default/table?lang=en	EUROSTAT (2020)

Recycling

Process	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source
Plastic recycling	27,63%		ecoinvent dataset	Secondary data	Europe (RER)	polyethylene production, high density, granulate, recycled	Ecoinvent 3.9.1 Cut-off
Credit material	**Value**	**Unit**	**Source**	**Type of data**	**Geographical coverage**	**Dataset**	**Source**
Virgin PP	66,38	g	ecoinvent dataset	Secondary data	Europe (RER)	polypropylene production, granulate	Ecoinvent 3.9.1 Cut-off

Incineration

Process	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source
Incineration PP	72,38%				CH	treatment of waste polypropylene, municipal incineration with fly ash extraction	Ecoinvent 3.9.1 Cut-off
Credit energy	**Value**	**Unit**	**Source**	**Type of data**	**Geographical coverage**	**Dataset**	**Source**
Electricity credit	0,010	kWh	IEA	Secondary data	Nordics	Electricity mix Nordics	Mix developed in project
Heat credit	0,204	MJ	IEA	Secondary data	Nordics	Heat mix Nordics	Mix developed in project

Soaps and detergents

Washing	Manual dishwashing product formulation	Concentration	Type of data	Geographical coverage	Dataset	Source
Hand-washing soap	Softened Water	83%	Secondary data: literature	Europe RER	RER: water, completely softened, at plant	Golsteijn, L., Menkveld, R., King, H. *et al.* A compilation of life cycle studies for six household detergent product categories in Europe: the basis for product-specific A.I.S.E. Charter Advanced Sustainability Profiles. *Environ Sci Eur* 27, 23 (2015).
	Ethanol denaturated	< 0.1%			RER: ethanol from ethylene, at plant	
	Phenoxyethanol	< 1%			RER: ethylene glycol, at plant	
	Propylene Glycol	< 0.1%			RER: propylene glycol, at plant	
	Surfactant system (anionic – non-ionic)*	0,1385			RER: ethoxylated alcohols*	
	NaOH	< 0.2%			RER: sodium hydroxide, 50% in H2O, production mix, at plant	
	NaCl	< 2%			RER: sodium chloride, powder, at plant	
	Perfume	< 0.5%			Empty process	
	Dye (2 types)	< 0.1%			Empty process	
	Preservatives	< 0.1%			Empty process	

Dishwasher tablet detergent	Sodium carbonate	50%	Secondary data: literature	Europe RER	RER: soda ash, light	Procter&Gamble. Yes Original Allt i Ett, kapslar for maskindisk, datasheet (2016)
	Sodium carbonate peroxide	20%			RER: soda ash, light	
	PEG/PPG Propylheptyl Ether	10%			RER: ethylene oxide	
	Sodium silicate	10%			RER: sodium silicate	
	Protease	<1%			RER: chemical, organic	

Appendix H. LCI tables E-commerce

CS1 - Single use e-commerce plastic bag

Production

Raw materials	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source	Comments
LDPE	12	g (net weight)	Scope of project	Secondary data	Europe (RER)	polyethylene, low density, granulate	Ecoinvent 3.9.1 Cutoff	Net weight
Process	**Value**	**Unit**	**Source**	**Type of data**	**Geographical coverage**	**Dataset**	**Source**	
extrusion, plastic film	calculated in model		Scope of project	Secondary data	Europe (RER)	extrusion, plastic film	Ecoinvent 3.9.1 Cutoff	

Distribution from factory to retail/distribution centre (DC) and from DC to final client

Trans-portation method	Distance	Unit	Source	Type of data	Geographi-cal cover-age	Dataset	Source	Comments
Road, truck, >32 t, EURO 4	3500	km	Plastic LCA method section 4.4.7.5	Secondary data	100% Intraconti-nental (Europe)	transport, freight, lorry >32 metric ton, EURO4 - RER - transport, freight, lorry >32 metric ton, EURO4	Ecoinvent 3.9.1 Cutoff	Default scenarios – from factory to retail/ distribution centre
Van	250	km	Plastic LCA method section 4.4.7.5	Secondary data	from DC to final client	market for transport, freight, lorry, unspecified	Ecoinvent 3.9.1 Cutoff	Default scenarios – from DC to final client

Use (from retail to final client)

Trans-port-ation	Value	Unit	Share	Source	Type of data	Geographical coverage	Dataset	Source	Comments
Walking/ Bike	5	km	33%	Plastic LCA method	Secondary data	-	none	Ecoinvent 3.9.1 Cutoff	Default scenarios – from retail to final client
Car	5	km	62%	Plastic LCA method	Secondary data	RER	market for transport, passenger car	Ecoinvent 3.9.1 Cutoff	Default scenarios – from retail to final client (allocation of 27 litre to 0.6 m3 trunk)
Round trip, by van	5	km	5%	Plastic LCA method	Secondary data	RER	market for transport, freight, lorry 3.5-7.5,metric ton, EURO3	Ecoinvent 3.9.1 Cutoff	Default scenarios – from retail to final client

Transport EoL

Transportation method	Distan-ce	Unit	Source	Type of data	Geographical coverage	Dataset	Source
municipal waste collection service	30	km	assumed from other datasets	Secondary data	RoW	municipal waste collection service by 21 metric ton lorry	Ecoinvent 3.9.1 Cutoff

Recycling

Process	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source
Plastic recycling	30,93%	%	Waste management statistics	Secondary data	Europe w/o CH	polyethylene production, high density, granulate, recycled	Ecoinvent 3.9.1 Cutoff
Credit material	**Value**	**Unit**	**Source**	**Type of data**	**Geographical coverage**	**Dataset**	**Source**
LDPE	calcula-ted in model		ecoinvent dataset	Secondary data	Europe (RER)	polyethylene, low density, granulate	Ecoinvent 3.9.1 Cutoff

Incineration

Process	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source
Incineration	69,08%	%	Waste management statistics	Secondary data	CH	treatment of waste polyethylene, municipal incineration with fly ash extraction	Ecoinvent 3.9.1 Cutoff
Credit energy	**Value**	**Unit**	**Source**	**Type of data**	**Geographical coverage**	**Dataset**	**Source**
Electricity credit	0,632	kWh	IEA	Secondary data	Nordics	Electricity mix Nordics	Mix developed in project
Heat credit	13,966	Mj	IEA	Secondary data	Nordics	Heat mix Nordics	Mix developed in project

CS2 - Single use e-commerce paper bag

Production

Raw materials	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Comments
Paper bag	65	g (net weight)	Scope of project		Europe (RER)	paper sack production (RER)	dataset includes LDPE and HDPE plastic liners, and different kind of glues, also used as cement sack, pet food sack or paper bag

Distribution from factory to retail/ distribution centre (DC) and from DC to final client

same as CS1

Use (from retail to final client)

same as CS1

Transport EoL

same as CS1

Recycling

Process	Value	Unit	Source	Type of data	Geographical coverage	Dataset
Paper recycling	80,78%	%	Waste management statistics	Secondary data	Europe (RER)	treatment of waste paper to pulp, wet lap, totally chlorine free bleached
Credit material	**Value**	**Unit**	**Source**	**Type of data**	**Geographical coverage**	**Dataset**
Pulp	calculated in model		ecoinvent dataset	Secondary data	RoW	chemi-thermomechanical pulp production

Incineration

Process	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source
Incineration	19,23%	%	Waste management statistics		CH	treatment of waste paperboard, municipal incineration with fly ash extraction	Ecoinvent 3.9.1 Cutoff

Credit energy	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source
Electricity credit	0,233	kWh	IEA	Secondary data	Nordics	Electricity mix Nordics	Mix developed in project
Heat credit	5,151	MJ	IEA	Secondary data	Nordics	Heat mix Nordics	Mix developed in project

CS3 - Reusable e-commerce bag

Production

Raw materials	Value	Unit	Source	Type of data	Geographical coverage	Dataset (Ev)	Source	Comments
Polypropylene	108	g (net weight)	Based on RePack data	Primary	Europe (RER)	polypropylene production, granulate	Ecoinvent 3.9.1 Cutoff	Net weight
Velcro	10	g (net weight)	Based on RePack data	Primary	Europe (RER)	nylon 6 (RER, market for nylon 6)	Ecoinvent 3.9.1 Cutoff	Net weight

Process	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source	
Extrusion	calculated in model				RER	extrusion, plastic film	Ecoinvent 3.9.1 Cutoff	
Weaving	calculated in model				GLO	weaving of synthetic fibre, for industrial use	Ecoinvent 3.9.1 Cutoff	
Weaving	calculated in model				GLO	market group for electricity, medium voltage	Ecoinvent 3.9.1 Cutoff	dataset regionalised with respectve electricity

Distribution from factory to retail/distribution centre (DC) and from DC to final client

same as CS1

Use

Washing	Input	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source	Comments
Professional washing	Natusol	0,002	kg	personal communication	primary data	Nordic	white spirit production	Ecoinvent 3.9.1 Cutoff	Repack: There are 3 types of returned bags, the clean ones, the dirty ones and the discarded ones. Only 67.7% of the returned bags are ditty and need to be cleaned; we use industrial grade dishwashing (Natusol) to clean them
	Electricity	none		personal communication	primary data	Nordic			
	Water	none		personal communication	primary data	Nordic			

Trans-port-ation	Value	Unit	Share	Source	Type of data	Geographical coverage	Dataset	Source	Comments
Walking/ Bike	5*2=10	km	33%	Plastic LCA method	Secon-dary data	-	none	Ecoinvent 3.9.1 Cutoff	Default scenarios – from retail to final client
Car	5*2=10	km	62%	Plastic LCA method	Secon-dary data	RER	market for transport, passenger car	Ecoinvent 3.9.1 Cutoff	Default scenarios – from retail to final client (allocation of 27 litre to 0.6 m3 trunk)
Round trip, by van	5*2=10	km	5%	Plastic LCA method	Secon-dary data	RER	market for transport, freight, lorry 3.5-7.5,metric ton, EURO3	Ecoinvent 3.9.1 Cutoff	Default scenarios – from retail to final client

Transport EoL

same as CS1

Recycling

Process	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source
Plastic recycling	30,93%	%	ecoinvent dataset	Secondary data	Europe (RER)	polyethylene production, high density, granulate, recycled	Ecoinvent 3.9.1 Cutoff

Credit material	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source
Virgin PP	calculated in model		ecoinvent dataset	Secondary data	Europe (RER)	polypropylene production, granulate	Ecoinvent 3.9.1 Cutoff
Nylon	calculated in model		ecoinvent dataset	Secondary data	Europe (RER)	nylon 6 (RER, market for nylon 6)	Ecoinvent 3.9.1 Cutoff

Incineration

Process	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source
Incineration PP	69,08%	%	ecoinvent dataset	Secondary data	CH	treatment of waste polypropylene, municipal incineration with fly ash extraction	Ecoinvent 3.9.1 Cutoff
Incineration Velcro	69,08%	%	ecoinvent dataset	Secondary data	CH	treatment of waste plastic, mixture, municipal incineration with fly ash extraction	Ecoinvent 3.9.1 Cutoff

Credit energy	Value	Unit	Source	Type of data	Geographical coverage	Dataset	Source
Electricity credit	0,478	kWh	IEA	Secondary data	Nordics	Electricity mix Nordics	Mix developed in project
Heat credit	10,577	MJ	IEA	Secondary data	Nordics	Heat mix Nordics	Mix developed in project

Appendix I. LCIA tables base case results – Take away

Single use system

Table 34 LCIA by life cycle stages of single use system for takeaway container.

Single use: Impact categories	Raw Materials	Manu-facturing	Distribution	Use Phase	Incineration	Recycling	Material credits	Energy credits	Agg. total
EF-Acidification [mol H+ equivalents]	4,15E-04	1,67E-04	8,84E-05	2,42E-05	1,47E-05	1,70E-05	-4,85E-05	-5,86E-05	6,20E-04
EF-Climate change, biogenic [kg CO2-Equivalents]	1,55E-04	1,69E-04	6,27E-06	3,31E-06	8,10E-07	1,93E-04	-1,82E-05	-1,24E-04	3,86E-04
EF-Climate change, fossil [kg CO2-Equivalents]	1,18E-01	3,78E-02	2,13E-02	6,93E-03	1,09E-01	4,82E-03	-1,38E-02	-2,13E-02	2,63E-01
EF-Climate change, land use and land use change [kg CO2-Equivalents]	2,90E-05	8,42E-05	1,01E-05	3,19E-06	3,75E-07	5,54E-06	-3,39E-06	-4,17E-05	8,73E-05
EF-Climate change, total [kg CO2-Equivalents]	1,18E-01	3,81E-02	2,13E-02	6,93E-03	1,09E-01	5,02E-03	-1,38E-02	-2,15E-02	2,63E-01
EF-Eutrophication, freshwater [kg N equivalents]	1,34E-05	2,91E-05	1,53E-06	9,15E-07	1,54E-07	1,75E-06	-1,56E-06	-4,83E-06	4,04E-05
EF-Eutrophication, marine [kg P equivalents]	7,29E-05	3,37E-05	3,35E-05	6,21E-06	7,39E-06	5,19E-06	-8,52E-06	-1,36E-05	1,37E-04

EF-Eutrophication, terrestrial [mol N equivalents]	7,72E-04	2,75E-04	3,58E-04	6,54E-05	7,55E-05	3,97E-05	-9,02E-05	-1,68E-04	1,33E-03
EF-Ionising radiation, human health [kBq U235 equivalents]	6,30E-03	2,06E-02	3,96E-04	1,46E-04	1,46E-05	9,75E-04	-7,36E-04	-5,06E-03	2,27E-02
EF-Land use [pt]	9,50E-02	1,26E-01	3,19E-01	3,28E-02	4,87E-03	3,52E-02	-1,11E-02	-3,25E-01	2,76E-01
EF-Ozone depletion [kg CFC11 equivalents]	5,67E-10	9,99E-10	4,69E-10	1,52E-10	3,09E-11	6,59E-11	-6,63E-11	-5,84E-10	1,63E-09
EF-Particulate matter [disease incidence]	4,51E-09	7,77E-10	2,20E-09	3,76E-10	8,84E-11	2,58E-10	-5,27E-10	-5,46E-10	7,13E-09
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	3,86E-04	9,51E-05	1,34E-04	2,91E-05	1,91E-05	1,43E-05	-4,51E-05	-5,68E-05	5,76E-04
EF-Resource use, fossils [MJ]	4,57E+00	7,54E-01	3,16E-01	9,17E-02	1,25E-02	6,50E-02	-5,35E-01	-2,36E-01	5,04E+00
EF-Resource use, minerals and metals [kg Sb equivalents]	5,23E-07	8,21E-08	5,92E-08	6,90E-08	3,21E-09	3,13E-08	-6,11E-08	-1,99E-08	6,87E-07
Water scarcity	4,57E-02	1,83E-02	1,62E-03	7,49E-04	3,72E-03	1,45E-03	-5,35E-03	-1,20E-02	5,42E-02

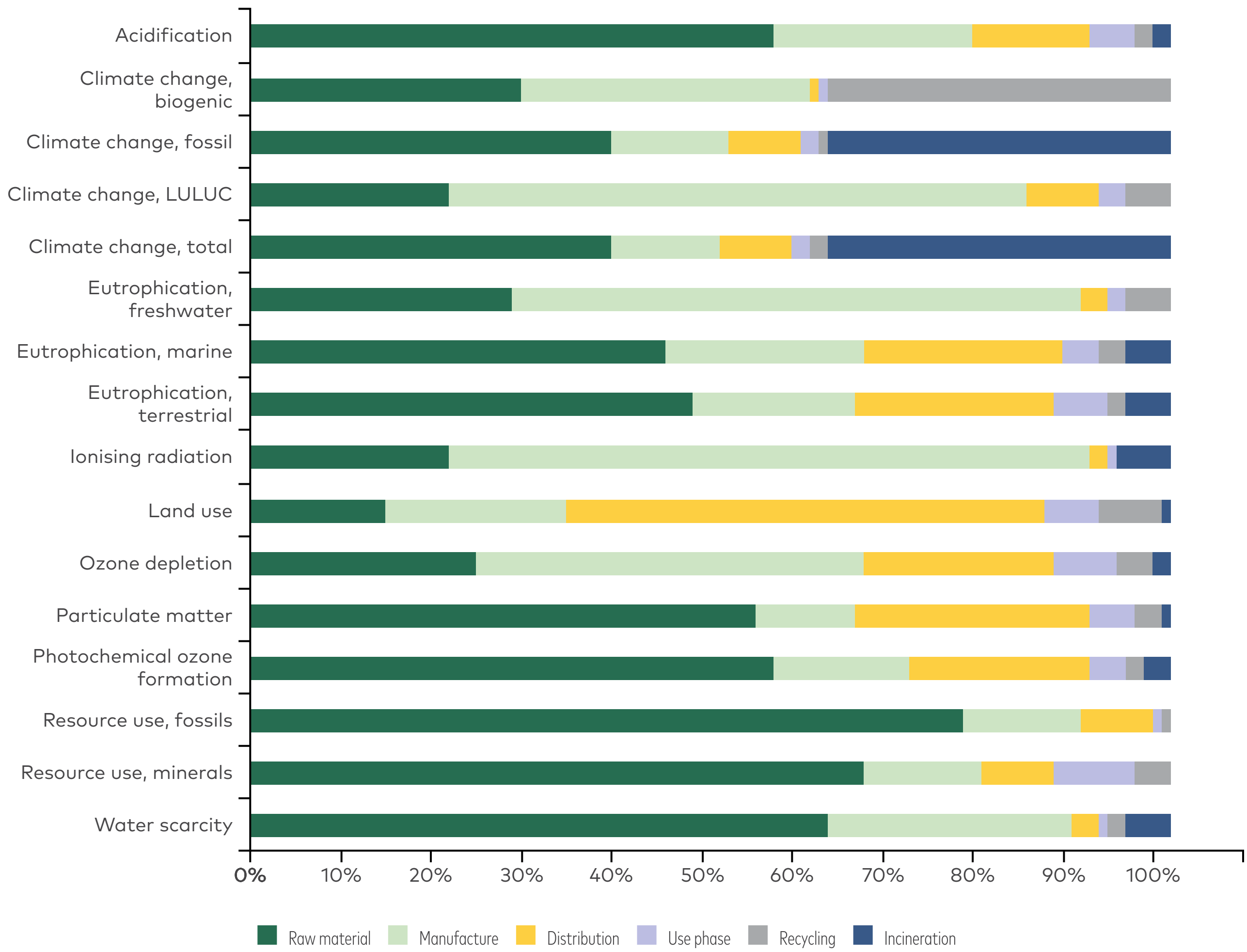

Figure 27 Contribution analysis single use takeaway packaging (only environmental burden, i.e., excluding credits).

Reusable takeaway container

Table 35 LCIA base case by life cycle stage of the reusable takeaway packaging.

Reusable container: Impact categories	Raw Materials	Manu-facturing	Distribution	Use Phase	Incineration	Recycling	Material credits	Energy credits	Aggr. Total
EF-Acidification [mol H+ equivalents]	2,15E-04	9,89E-05	3,99E-05	6,20E-05	6,42E-06	7,66E-06	-2,66E-05	-2,65E-05	3,77E-04
EF-Climate change, biogenic [kg CO2-Equivalents]	9,29E-05	8,56E-05	2,83E-06	3,24E-05	3,36E-07	8,73E-05	-1,15E-05	-5,61E-05	2,34E-04
EF-Climate change, fossil [kg CO2-Equivalents]	6,18E-02	2,40E-02	9,62E-03	1,69E-02	4,92E-02	2,18E-03	-7,64E-03	-9,64E-03	1,46E-01
EF-Climate change, land use and land use change [kg CO2-Equivalents]	1,10E-05	3,82E-05	4,56E-06	8,67E-05	1,16E-07	2,50E-06	-1,36E-06	-1,88E-05	1,23E-04
EF-Climate change, total [kg CO2-Equivalents]	6,19E-02	2,41E-02	9,63E-03	1,70E-02	4,92E-02	2,27E-03	-7,65E-03	-9,71E-03	1,47E-01
EF-Eutrophication, freshwater [kg N equivalents]	5,97E-06	1,36E-05	6,89E-07	3,25E-06	4,99E-08	7,91E-07	-7,37E-07	-2,18E-06	2,14E-05
EF-Eutrophication, marine [kg P equivalents]	3,75E-05	1,81E-05	1,52E-05	1,57E-05	3,27E-06	2,34E-06	-4,64E-06	-6,16E-06	8,13E-05

EF-Eutrophication, terrestrial [mol N equivalents]	3,87E-04	1,70E-04	1,62E-04	1,64E-04	3,34E-05	1,79E-05	-4,78E-05	-7,61E-05	8,10E-04
EF-Ionising radiation, human health [kBq U235 equivalents]	2,31E-03	9,21E-03	1,79E-04	9,31E-03	9,43E-06	4,40E-04	-2,85E-04	-2,28E-03	1,89E-02
EF-Land use [pt]	3,66E-02	1,82E-01	1,44E-01	1,20E-01	1,89E-03	1,59E-02	-4,53E-03	-1,47E-01	3,50E-01
EF-Ozone depletion [kg CFC11 equivalents]	3,73E-10	8,88E-10	2,12E-10	3,73E-10	1,57E-11	2,98E-11	-4,61E-11	-2,64E-10	1,58E-09
EF-Particulate matter [disease incidence]	2,57E-09	4,91E-10	9,94E-10	8,81E-10	3,56E-11	1,16E-10	-3,17E-10	-2,46E-10	4,52E-09
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	1,91E-04	7,27E-05	6,07E-05	6,75E-05	8,40E-06	6,45E-06	-2,36E-05	-2,56E-05	3,58E-04
EF-Resource use, fossils [MJ]	2,04E+00	5,35E-01	1,43E-01	3,36E-01	4,62E-03	2,93E-02	-2,52E-01	-1,07E-01	2,73E+00
EF-Resource use, minerals and metals [kg Sb equivalents]	2,01E-07	5,66E-08	2,68E-08	1,65E-07	1,14E-09	1,42E-08	-2,48E-08	-8,99E-09	4,31E-07
Water scarcity	2,72E-02	1,47E-02	7,33E-04	2,17E-02	1,21E-03	6,55E-04	-3,36E-03	-5,41E-03	5,73E-02

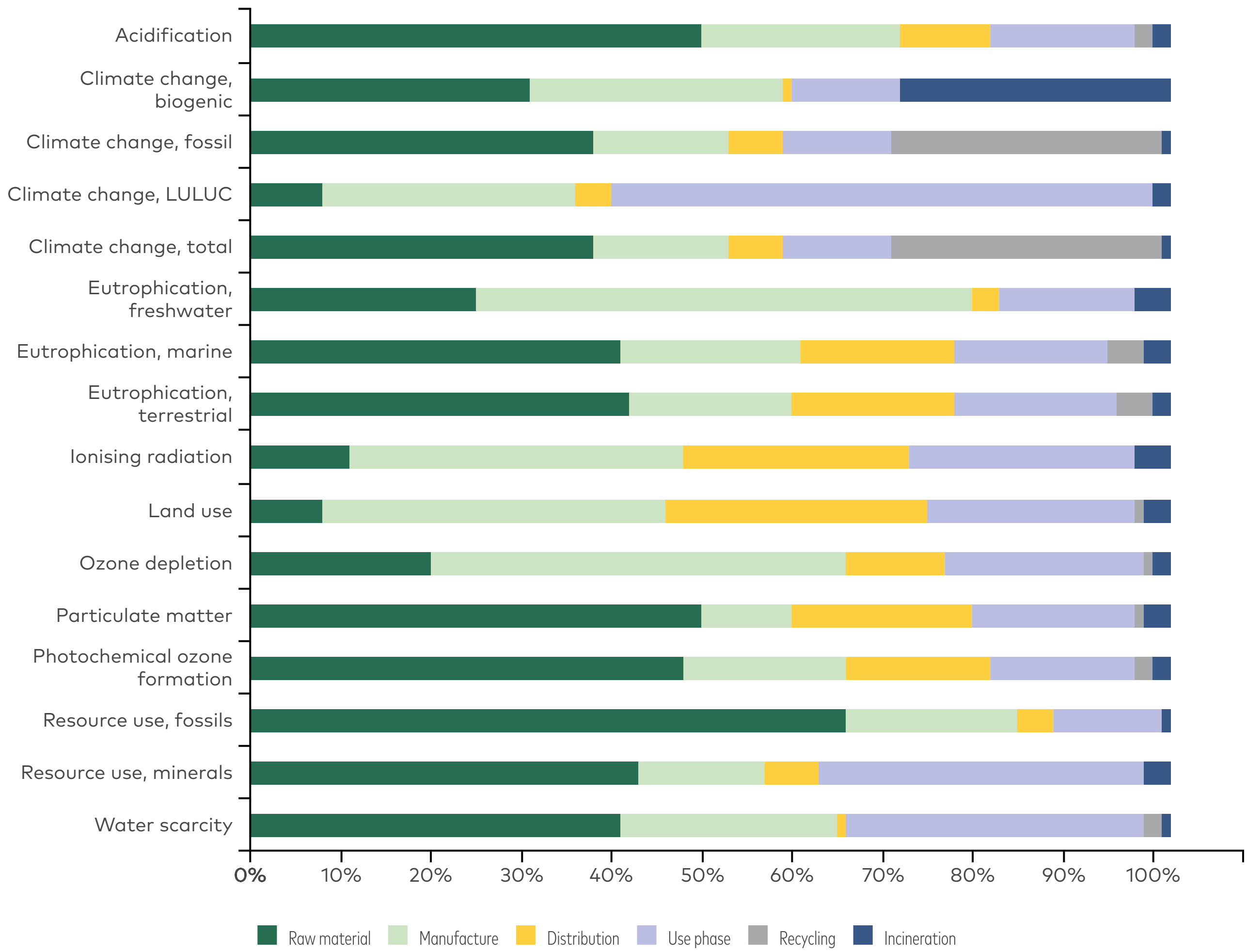

Figure 28 Contribution analysis reusable packaging (only environmental burden, i.e., excluding credits).

Appendix J. LCIA tables base case results – E-commerce

Single use plastic system

Table 36 LCIA base case single use plastic.

Impact categories	Raw Materials	Manufacture	Distribution	Use Phase	Recycling	Incineration	Material credits	Energy credits	Agg. total
EF-Acidification [mol H+ equivalents]	1,25E-04	1,97E-05	1,95E-05	4,03E-06	4,49E-06	5,52E-06	-1,43E-05	-1,62E-05	1,48E-04
EF-Climate change, biogenic [kg CO2-Equivalents]	4,76E-05	1,79E-05	1,38E-06	3,87E-07	5,05E-05	2,24E-07	-5,39E-06	-3,43E-05	7,82E-05
EF-Climate change, fossil [kg CO2-Equivalents]	3,28E-02	4,51E-03	4,69E-03	9,88E-04	1,27E-03	2,70E-02	-3,74E-03	-5,90E-03	6,17E-02
EF-Climate change, land use and land use change [kg CO2-Equivalents]	1,18E-05	1,02E-05	2,22E-06	4,69E-07	1,45E-06	9,74E-08	-1,34E-06	-1,15E-05	1,34E-05
EF-Climate change, total [kg CO2-Equivalents]	3,29E-02	4,54E-03	4,70E-03	9,89E-04	1,32E-03	2,70E-02	-3,75E-03	-5,94E-03	6,18E-02
EF-Eutrophication, freshwater [kg N equivalents]	5,02E-06	2,85E-06	3,36E-07	1,02E-07	4,59E-07	3,21E-08	-5,69E-07	-1,34E-06	6,90E-06

EF-Eutrophication, marine [kg P equivalents]	2,50E-05	4,08E-06	7,39E-06	1,35E-06	1,38E-06	2,71E-06	-2,85E-06	-3,77E-06	3,52E-05
EF-Eutrophication, terrestrial [mol N equivalents]	2,52E-04	3,67E-05	7,88E-05	1,44E-05	1,06E-05	2,78E-05	-2,87E-05	-4,66E-05	3,45E-04
EF-Ionising radiation, human health [kBq U235 equivalents]	2,84E-03	1,90E-03	8,72E-05	2,03E-05	2,55E-04	6,48E-06	-3,22E-04	-1,40E-03	3,39E-03
EF-Land use [pt]	2,69E-02	7,86E-02	7,02E-02	7,63E-03	9,33E-03	1,09E-03	-3,05E-03	-8,98E-02	1,01E-01
EF-Ozone depletion [kg CFC11 equivalents]	1,41E-10	8,76E-11	1,03E-10	2,17E-11	1,75E-11	1,49E-11	-1,59E-11	-1,61E-10	2,08E-10
EF-Particulate matter [disease incidence]	1,26E-09	1,28E-10	4,85E-10	7,50E-11	6,85E-11	6,27E-11	-1,44E-10	-1,51E-10	1,79E-09
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	1,37E-04	1,21E-05	2,96E-05	5,47E-06	3,82E-06	8,24E-06	-1,56E-05	-1,57E-05	1,65E-04
EF-Resource use, fossils [MJ]	1,02E+00	8,58E-02	6,96E-02	1,37E-02	1,71E-02	6,96E-03	-1,15E-01	-6,54E-02	1,03E+00
EF-Resource use, minerals and metals [kg Sb equivalents]	1,75E-07	1,12E-08	1,31E-08	6,57E-09	8,22E-09	8,11E-10	-2,00E-08	-5,50E-09	1,89E-07
Water scarcity	1,70E-02	1,09E-02	3,58E-04	9,02E-05	3,80E-04	6,62E-04	-1,93E-03	-3,31E-03	2,42E-02

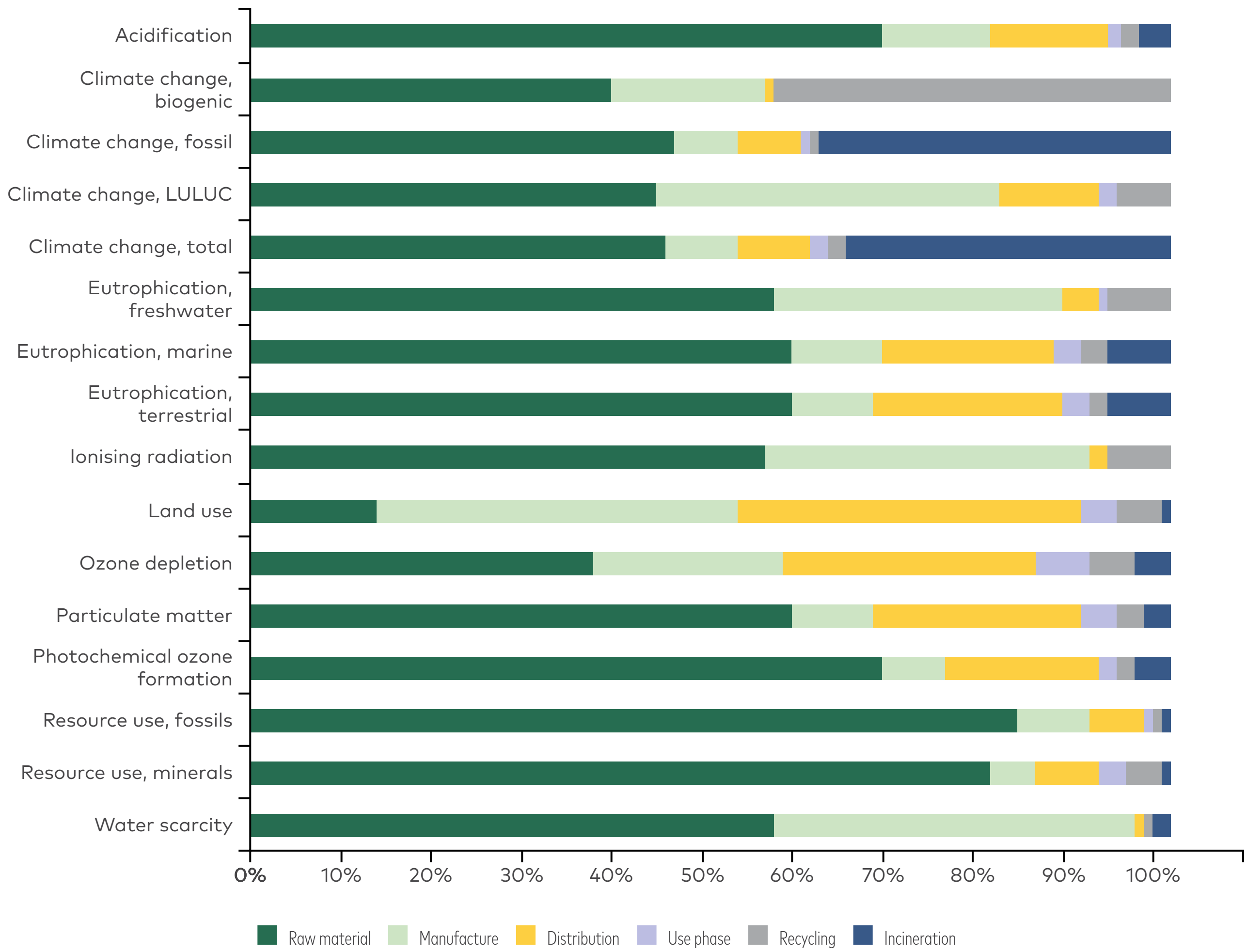

Figure 29 Contribution analysis single use plastic (only environmental burden, i.e., excluding credits).

Single use paper system

Table 37 LCIA base case single use paper.

Impact categories	Raw Materials	Manufacture	Distribution	Use Phase	Recycling	Incineration	Material credits	Energy credits	Agg. total
EF-Acidification [mol H+ equivalents]	3,85E-04	5,64E-05	9,89E-05	2,04E-05	1,21E-04	6,24E-06	-2,38E-04	-8,44E-06	4,42E-04
EF-Climate change, biogenic [kg CO2-Equivalents]	1,71E-03	1,23E-03	7,02E-06	1,96E-06	1,80E-02	4,70E-07	-1,09E-03	-1,79E-05	1,98E-02
EF-Climate change, fossil [kg CO2-Equivalents]	6,26E-02	1,14E-02	2,38E-02	5,02E-03	1,85E-02	1,34E-03	-4,08E-02	-3,07E-03	7,88E-02
EF-Climate change, land use and land use change [kg CO2-Equivalents]	2,59E-04	1,26E-03	1,13E-05	2,38E-06	3,22E-04	1,55E-07	-7,58E-05	-6,01E-06	1,78E-03
EF-Climate change, total [kg CO2-Equivalents]	6,46E-02	1,39E-02	2,38E-02	5,02E-03	3,68E-02	1,34E-03	-4,20E-02	-3,10E-03	1,00E-01
EF-Eutrophication, freshwater [kg N equivalents]	1,14E-04	5,34E-06	1,71E-06	5,15E-07	1,42E-05	4,90E-08	-2,60E-05	-6,97E-07	1,09E-04
EF-Eutrophication, marine [kg P equivalents]	1,48E-04	2,06E-05	3,75E-05	6,85E-06	3,90E-04	3,05E-06	-4,58E-05	-1,97E-06	5,58E-04

EF-Eutrophication, terrestrial [mol N equivalents]	1,14E-03	1,40E-04	4,00E-04	7,30E-05	2,43E-04	2,91E-05	-3,90E-04	-2,43E-05	1,61E-03
EF-Ionising radiation, human health [kBq U235 equivalents]	1,01E-02	2,66E-03	4,43E-04	1,03E-04	2,07E-03	1,05E-05	-1,65E-02	-7,29E-04	-1,86E-03
EF-Land use [pt]	1,17E+01	1,41E-01	3,56E-01	3,88E-02	8,01E-02	1,46E-03	-1,09E+00	-4,68E-02	1,12E+01
EF-Ozone depletion [kg CFC11 equivalents]	1,44E-09	1,70E-09	5,24E-10	1,10E-10	4,38E-10	2,67E-11	-1,29E-09	-8,41E-11	2,86E-09
EF-Particulate matter [disease incidence]	3,34E-09	5,48E-10	2,46E-09	3,81E-10	1,37E-09	9,50E-11	-1,55E-09	-7,86E-11	6,56E-09
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	3,68E-04	3,54E-05	1,50E-04	2,78E-05	8,39E-05	9,26E-06	-1,28E-04	-8,18E-06	5,39E-04
EF-Resource use, fossils [MJ]	1,09E+00	1,80E-01	3,53E-01	6,96E-02	2,40E-01	9,28E-03	-7,52E-01	-3,41E-02	1,16E+00
EF-Resource use, minerals and metals [kg Sb equivalents]	2,87E-07	6,80E-08	6,63E-08	3,34E-08	1,49E-07	1,27E-09	-1,90E-07	-2,87E-09	4,12E-07
Water scarcity	4,66E-02	1,27E-02	1,82E-03	4,58E-04	6,51E-03	9,76E-04	-2,55E-02	-1,73E-03	4,18E-02

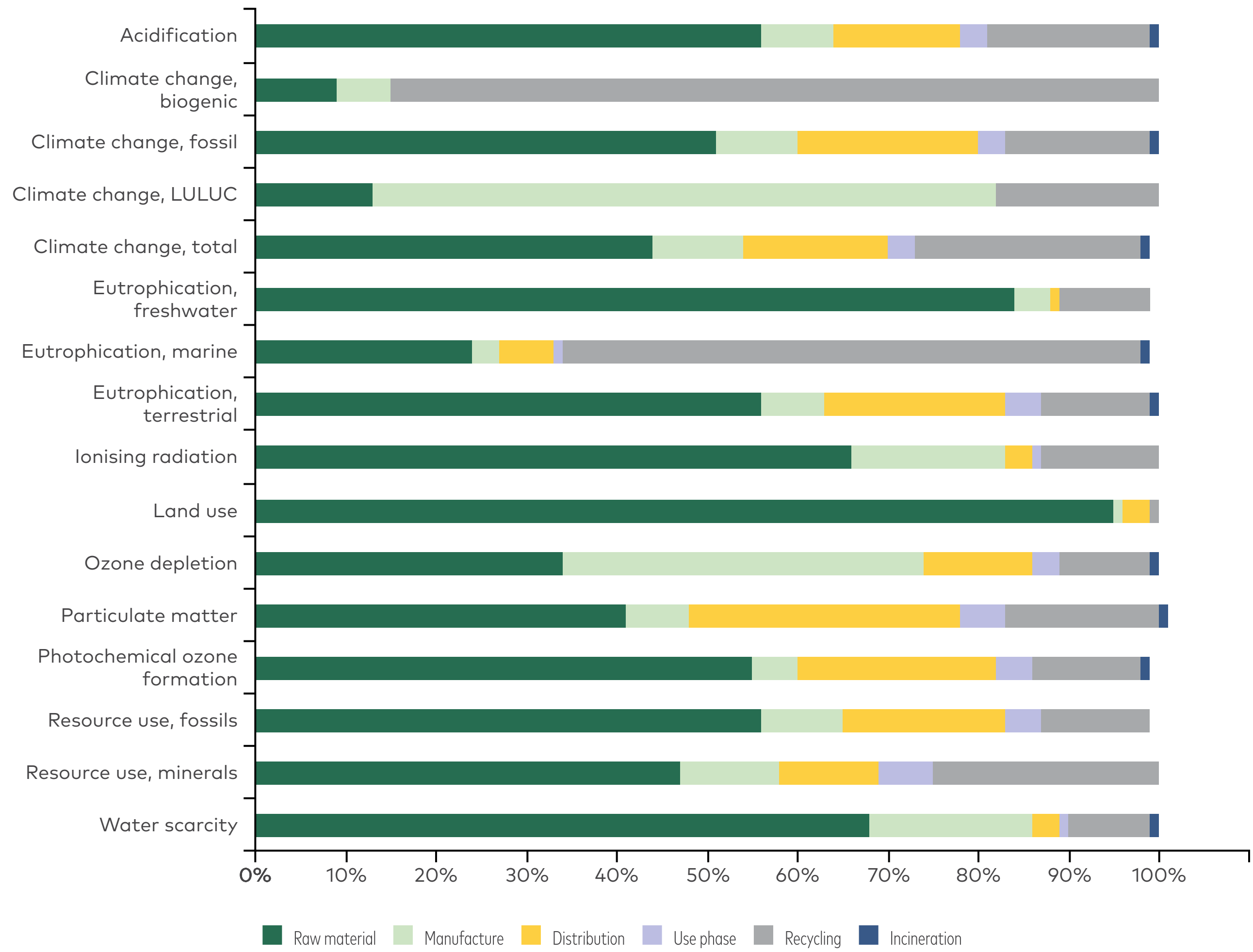

Figure 30 Contribution analysis single use paper (only environmental burden, i.e., excluding credits).

Reusable plastic system

Table 38 LCIA base case results reuseable.

Impact categories	Raw Materials	Manufacture	Distribution	Use Phase	Recycling	Incineration	Material credits	Energy credits	Agg. total
EF-Acidification [mol H+ equivalents]	1,95E-04	9,77E-05	4,08E-05	6,21E-05	9,30E-06	1,03E-05	-2,61E-05	-2,58E-05	3,63E-04
EF-Climate change, biogenic [kg CO2-Equivalents]	7,06E-05	8,33E-05	2,90E-06	8,19E-06	1,06E-04	3,92E-07	-9,45E-06	-5,48E-05	2,07E-04
EF-Climate change, fossil [kg CO2-Equivalents]	5,51E-02	1,89E-02	9,84E-03	1,57E-02	2,64E-03	4,88E-02	-7,39E-03	-9,41E-03	1,34E-01
EF-Climate change, land use and land use change [kg CO2-Equivalents]	1,30E-05	4,29E-05	4,66E-06	7,77E-06	3,03E-06	1,86E-07	-1,74E-06	-1,84E-05	5,14E-05
EF-Climate change, total [kg CO2-Equivalents]	5,52E-02	1,90E-02	9,84E-03	1,57E-02	2,75E-03	4,88E-02	-7,40E-03	-9,48E-03	1,34E-01
EF-Eutrophication, freshwater [kg N equivalents]	6,04E-06	1,43E-05	7,05E-07	1,97E-06	9,59E-07	5,96E-08	-8,09E-07	-2,13E-06	2,11E-05
EF-Eutrophication, marine [kg P equivalents]	3,47E-05	1,76E-05	1,55E-05	1,89E-05	2,85E-06	4,98E-06	-4,66E-06	-6,01E-06	8,39E-05

EF-Eutrophication, terrestrial [mol N equivalents]	3,66E-04	1,62E-04	1,65E-04	1,98E-04	2,18E-05	5,19E-05	-4,91E-05	-7,43E-05	8,42E-04
EF-Ionising radiation, human health [kBq U235 equivalents]	2,82E-03	8,97E-03	1,83E-04	5,36E-04	5,34E-04	1,16E-05	-3,77E-04	-2,23E-03	1,04E-02
EF-Land use [pt]	4,26E-02	2,25E-01	1,47E-01	1,03E-01	1,93E-02	2,11E-03	-5,70E-03	-1,43E-01	3,91E-01
EF-Ozone depletion [kg CFC11 equivalents]	2,55E-10	3,48E-10	2,16E-10	4,85E-10	3,62E-11	2,66E-11	-3,41E-11	-2,57E-10	1,08E-09
EF-Particulate matter [disease incidence]	2,12E-09	6,53E-10	1,02E-09	1,01E-09	1,41E-10	1,31E-10	-2,84E-10	-2,41E-10	4,55E-09
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	1,80E-04	5,27E-05	6,20E-05	1,08E-04	7,83E-06	1,57E-05	-2,41E-05	-2,50E-05	3,76E-04
EF-Resource use, fossils [MJ]	2,07E+00	3,74E-01	1,46E-01	3,03E-01	3,56E-02	1,39E-02	-2,78E-01	-1,04E-01	2,57E+00
EF-Resource use, minerals and metals [kg Sb equivalents]	2,51E-07	2,47E-07	2,74E-08	1,18E-07	1,72E-08	1,47E-09	-3,36E-08	-8,77E-09	6,19E-07
Water scarcity	2,12E-02	2,90E-02	7,50E-04	1,62E-03	7,94E-04	1,21E-03	-2,84E-03	-5,28E-03	4,65E-02

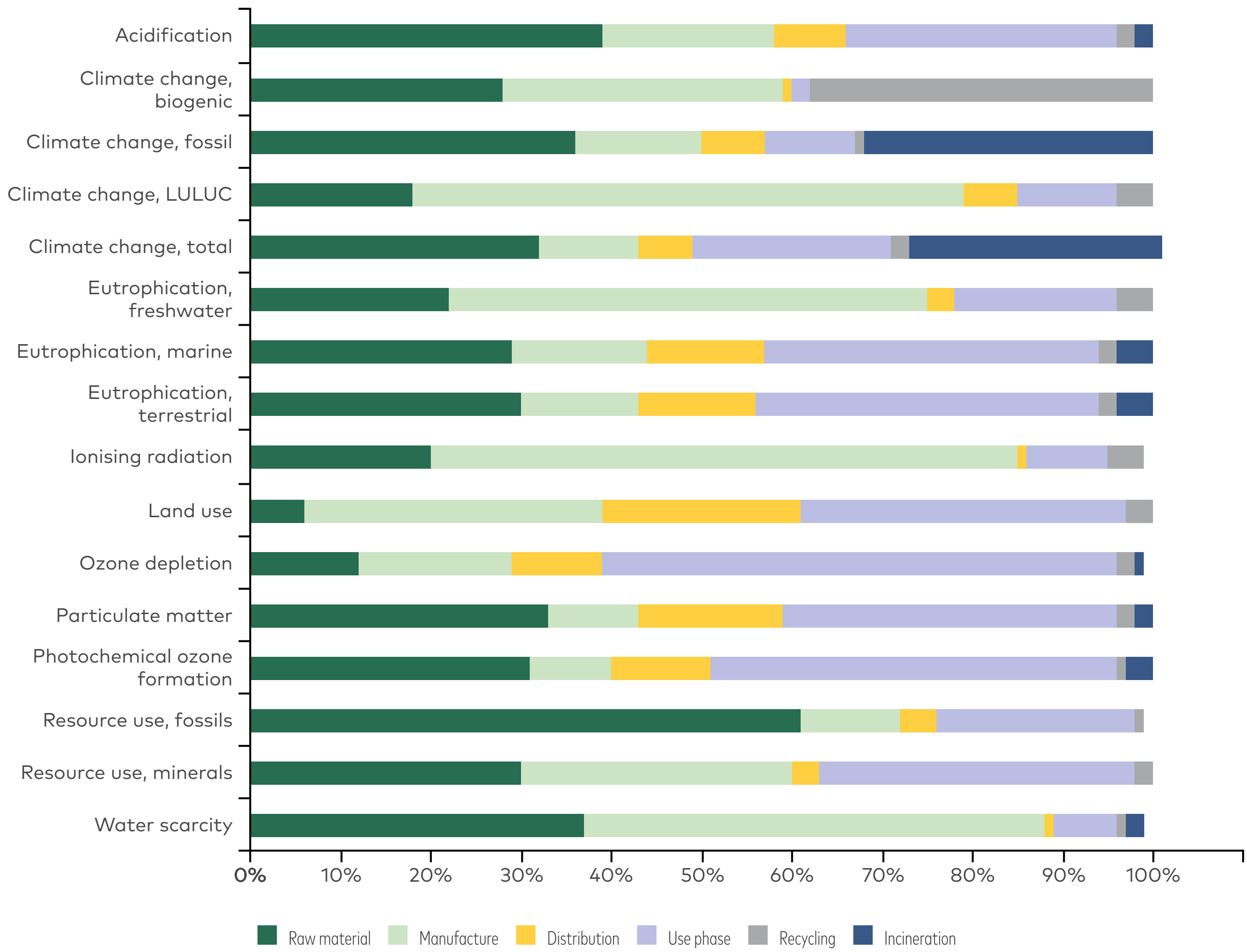

Figure 31 Contribution analysis reuse (only environmental burden, i.e., excluding credits).

Appendix K. LCIA tables sensitivity analyses Takeaway

Table 39 LCIA tables of sensitivity analysis for takeaway container.

			Manufacturing				CFF									
	Baseline scenario		-10% weight (TA1a)	10% weight (TA2a)	-10% weight (TA1b)	10% weight (TA2b)	A=0 (avoided burdens)		A=1 (cut-off) (SA1h)		R2=0 (SA1i)		R2=1 (SA1k)		B=1 (cut-off)	
Case study Take Away	Single-use	Re usable	Re-usable	Re-usable	Single-use	Single-use	Single-use	Re-usable	Single-use	Re-usable	Single-use	Re-usable	Single-use	Re-usable	Single-use	Re-usable
EF-Acidification [mol H+ equivalents]	6,20E-04	3,77E-04	3,45E-04	4,09E-04	5,60E-04	6,79E-04	5,88E-04	3,58E-04	6,51E-04	3,96E-04	6,35E-04	3,88E-04	5,81E-04	3,47E-04	6,64E-04	3,97E-04
EF-Climate change, biogenic [kg CO2-Equivalents]	3,86E-04	2,34E-04	2,12E-04	2,55E-04	3,48E-04	4,24E-04	5,61E-04	3,10E-04	2,11E-04	1,58E-04	1,64E-04	1,37E-04	9,68E-04	4,88E-04	5,09E-04	2,90E-04
EF-Climate change, fossil [kg CO2-Equivalents]	2,63E-01	1,46E-01	1,34E-01	1,59E-01	2,37E-01	2,89E-01	2,54E-01	1,41E-01	2,72E-01	1,52E-01	3,06E-01	1,67E-01	1,52E-01	9,25E-02	1,75E-01	1,07E-01
EF-Climate change, land use and land use change [kg CO2-Equivalents]	8,73E-05	1,23E-04	1,15E-04	1,30E-04	7,88E-05	9,57E-05	8,94E-05	1,24E-04	8,51E-05	1,22E-04	6,93E-05	1,15E-04	1,34E-04	1,45E-04	1,29E-04	1,42E-04
EF-Climate change, total [kg CO2-Equivalents]	2,63E-01	1,47E-01	1,34E-01	1,60E-01	2,38E-01	2,89E-01	2,55E-01	1,41E-01	2,72E-01	1,52E-01	3,06E-01	1,67E-01	1,53E-01	9,32E-02	1,76E-01	1,07E-01
EF-Eutrophication, freshwater [kg N equivalents]	4,04E-05	2,14E-05	1,96E-05	2,33E-05	3,64E-05	4,43E-05	4,06E-05	2,15E-05	4,02E-05	2,14E-05	3,84E-05	2,05E-05	4,56E-05	2,37E-05	4,51E-05	2,35E-05

EF-Eutrophication, marine [kg P equivalents]	1,37E-04	8,13E-05	7,47E-05	8,80E-05	1,24E-04	1,50E-04	1,33E-04	7,90E-05	1,40E-04	8,36E-05	1,38E-04	8,25E-05	1,34E-04	7,82E-05	1,43E-04	8,42E-05
EF-Eutrophication, terrestrial [mol N equivalents]	1,33E-03	8,10E-04	7,45E-04	8,75E-04	1,20E-03	1,45E-03	1,28E-03	7,80E-04	1,38E-03	8,40E-04	1,34E-03	8,23E-04	1,29E-03	7,74E-04	1,42E-03	8,52E-04
EF-Ionising radiation, human health [kBq U235 equivalents]	2,27E-02	1,89E-02	1,74E-02	2,03E-02	2,04E-02	2,49E-02	2,29E-02	1,90E-02	2,24E-02	1,87E-02	2,05E-02	1,79E-02	2,83E-02	2,16E-02	2,77E-02	2,12E-02
EF-Land use [pt]	2,76E-01	3,50E-01	3,26E-01	3,74E-01	2,52E-01	3,01E-01	3,00E-01	3,61E-01	2,52E-01	3,38E-01	1,30E-01	2,83E-01	6,59E-01	5,24E-01	5,96E-01	4,94E-01
EF-Ozone depletion [kg CFC11 equivalents]	1,63E-09	1,58E-09	1,46E-09	1,70E-09	1,49E-09	1,78E-09	1,63E-09	1,57E-09	1,63E-09	1,60E-09	1,42E-09	1,50E-09	2,19E-09	1,79E-09	2,19E-09	1,83E-09
EF-Particulate matter [disease incidence]	7,13E-09	4,52E-09	4,15E-09	4,89E-09	6,46E-09	7,81E-09	6,87E-09	4,32E-09	7,40E-09	4,72E-09	7,23E-09	4,64E-09	6,89E-09	4,21E-09	7,59E-09	4,73E-09
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	5,76E-04	3,58E-04	3,29E-04	3,87E-04	5,21E-04	6,30E-04	5,45E-04	3,40E-04	6,07E-04	3,75E-04	5,92E-04	3,68E-04	5,33E-04	3,30E-04	6,13E-04	3,75E-04
EF-Resource use, fossils [MJ]	5,04E+00	2,73E+00	2,48E+00	2,98E+00	4,55E+00	5,54E+00	4,57E+00	2,51E+00	5,51E+00	2,95E+00	5,43E+00	2,91E+00	4,04E+00	2,25E+00	5,27E+00	2,83E+00
EF-Resource use, minerals and metals [kg Sb equivalents]	6,87E-07	4,31E-07	4,03E-07	4,58E-07	6,25E-07	7,49E-07	6,57E-07	4,20E-07	7,17E-07	4,41E-07	7,10E-07	4,38E-07	6,26E-07	4,11E-07	7,04E-07	4,38E-07
Water scarcity	5,42E-02	5,73E-02	5,28E-02	6,20E-02	4,89E-02	5,96E-02	5,03E-02	5,46E-02	5,81E-02	6,00E-02	5,50E-02	5,84E-02	5,23E-02	5,45E-02	6,25E-02	6,16E-02

Appendix L. LCIA tables sensitivity analyses E-commerce

				Manufacturing weight						Manufacturing material			Use transport								
	Baseline scenarios			min weight (EC2)	max weight (EC1)	min weight (EC2)	max weight (EC1)	min weight (EC2)	max weight (EC1)	raw material recycle plastic (EC 3.1)	raw material only kraft paper (EC 3.2)	raw material recycle plastic (EC 3.1)	100% Car (EC10)	100% Van (EC11)	100% Walk (EC12)	100% Car (EC10)	100% Van (EC11)	100% Walk (EC12)	100% Car (EC10)	100% Van (EC11)	100% Walk (EC12)
E-commerce	Single Use Plastic	Single Use Paper	Reuse	Single Use Plastic	Single Use Plastic	Single Use Paper	Single Use Paper	Reuse	Reuse	Single Use Plastic	Single Use Paper	Reuse	Single Use Plastic	Single Use Plastic	Single Use Plastic	Single Use Paper	Single Use Paper	Single Use Paper	Reuse	Reuse	Reuse
EF-Acidification [mol H+ equivalents]	1,48E-04	4,42E-04	3,63E-04	1,36E-04	1,59E-04	4,00E-04	4,84E-04	3,29E-04	3,98E-04	8,74E-05	3,45E-04	2,55E-04	1,49E-04	1,46E-04	1,46E-04	4,47E-04	4,34E-04	4,33E-04	3,81E-04	3,37E-04	3,34E-04
EF-Climate change, total [kg CO2-Equivalents]	6,18E-02	1,00E-01	1,34E-01	5,66E-02	6,70E-02	9,10E-02	1,10E-01	1,21E-01	1,47E-01	4,61E-02	7,64E-02	1,05E-01	6,21E-02	6,13E-02	6,13E-02	1,02E-01	9,81E-02	9,79E-02	1,40E-01	1,27E-01	1,26E-01
EF-Eutrophication, freshwater [kg N equivalents]	6,90E-06	1,09E-04	2,11E-05	6,22E-06	7,57E-06	9,80E-05	1,20E-04	1,90E-05	2,31E-05	4,64E-06	1,07E-04	2,19E-05	6,94E-06	6,84E-06	6,83E-06	1,09E-04	1,09E-04	1,09E-04	2,17E-05	2,00E-05	1,99E-05
EF-Eutrophication, marine [kg P equivalents]	3,52E-05	5,58E-04	8,39E-05	3,25E-05	3,79E-05	5,03E-04	6,14E-04	7,59E-05	9,19E-05	2,78E-05	5,30E-04	7,69E-05	3,55E-05	3,49E-05	3,48E-05	5,60E-04	5,57E-04	5,56E-04	8,85E-05	7,76E-05	7,63E-05

EF-Eutrophication, terrestrial [mol N equivalents]	3,45E-04	1,61E-03	8,42E-04	3,18E-04	3,71E-04	1,46E-03	1,77E-03	7,61E-04	9,22E-04	2,51E-04	1,38E-03	7,00E-04	3,48E-04	3,41E-04	3,40E-04	1,63E-03	1,59E-03	1,59E-03	8,90E-04	7,76E-04	7,61E-04
EF-Ionising radiation, human health [kBq U235 equivalents]	3,39E-03	-1,86E-03	1,04E-02	3,04E-03	3,74E-03	-1,67E-03	-2,06E-03	9,42E-03	1,15E-02	1,95E-03	-4,62E-03	1,12E-02	3,40E-03	3,38E-03	3,38E-03	-1,83E-03	-1,91E-03	-1,92E-03	1,06E-02	1,03E-02	1,03E-02
EF-Land use [pt]	1,01E-01	1,12E+01	3,91E-01	9,09E-02	1,11E-01	1,00E+01	1,23E+01	3,52E-01	4,29E-01	1,33E-01	1,16E+01	5,18E-01	1,02E-01	9,87E-02	9,85E-02	1,12E+01	1,11E+01	1,11E+01	4,15E-01	3,54E-01	3,50E-01
EF-Ozone depletion [kg CFC11 equivalents]	2,08E-10	2,86E-09	1,08E-09	1,88E-10	2,29E-10	2,57E-09	3,14E-09	9,88E-10	1,16E-09	1,84E-10	1,11E-09	1,12E-09	2,15E-10	1,98E-10	1,97E-10	2,89E-09	2,80E-09	2,80E-09	1,19E-09	9,03E-10	8,90E-10
EF-Particulate matter [disease incidence]	1,79E-09	6,56E-09	4,55E-09	1,65E-09	1,92E-09	5,93E-09	7,19E-09	4,11E-09	4,99E-09	1,38E-09	5,48E-09	3,82E-09	1,80E-09	1,76E-09	1,76E-09	6,65E-09	6,44E-09	6,42E-09	4,83E-09	4,14E-09	4,09E-09
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	1,65E-04	5,39E-04	3,76E-04	1,51E-04	1,78E-04	4,87E-04	5,91E-04	3,43E-04	4,10E-04	8,31E-05	4,63E-04	2,77E-04	1,66E-04	1,63E-04	1,63E-04	5,45E-04	5,29E-04	5,28E-04	3,98E-04	3,45E-04	3,41E-04
EF-Resource use, fossils [MJ]	1,03E+00	1,16E+00	2,57E+00	9,37E-01	1,12E+00	1,05E+00	1,27E+00	2,32E+00	2,81E+00	2,32E-01	6,77E-01	8,10E-01	1,03E+00	1,02E+00	1,02E+00	1,18E+00	1,13E+00	1,12E+00	2,63E+00	2,46E+00	2,45E+00
EF-Resource use, minerals and metals [kg Sb equivalents]	1,89E-07	4,12E-07	6,19E-07	1,76E-07	2,02E-07	3,75E-07	4,50E-07	5,60E-07	6,77E-07	1,28E-07	3,02E-07	5,15E-07	1,92E-07	1,84E-07	1,84E-07	4,28E-07	3,88E-07	3,87E-07	6,70E-07	5,37E-07	5,35E-07
Water scarcity	2,42E-02	4,18E-02	4,65E-02	2,20E-02	2,64E-02	3,78E-02	4,59E-02	4,19E-02	5,10E-02	1,23E-02	2,34E-02	3,22E-02	2,42E-02	2,41E-02	2,41E-02	4,20E-02	4,16E-02	4,15E-02	4,70E-02	4,56E-02	4,56E-02

E-commerce	Baseline scenarios			CFF															Energy mix			Energy credit		
				A=0 (avoided burdens) (EC7)			A=1 (cut-off) (EC6)			100% incineration R3=1 (EC8)			100% recycling R2= 1 (EC9)			Different avoided energy grid mix (EC14)			B=1 (EC13)					
	Single Use Plastic	Single Use Paper	Reuse	Single Use Plastic	Single Use Paper	Reuse	Single Use Plastic	Single Use Paper	Reuse	Single Use Plastic	Single Use Paper	Reuse	Single Use Plastic	Single Use Paper	Reuse	Single Use Plastic	Single Use Paper	Reuse	Single Use Plastic	Single Use Paper	Reuse			
EF-Acidification [mol H+ equivalents]	1,48E-04	4,42E-04	3,63E-04	1,38E-04	4,13E-04	3,46E-04	1,58E-04	5,59E-04	3,80E-04	1,53E-04	5,50E-04	3,73E-04	1,37E-04	4,16E-04	3,41E-04	1,49E-04	4,43E-04	3,65E-04	1,59E-04	4,44E-04	3,79E-04			
EF-Climate change, total [kg CO2-Equivalents]	6,18E-02	1,00E-01	1,34E-01	5,94E-02	9,92E-02	1,30E-01	6,42E-02	1,06E-01	1,39E-01	7,37E-02	9,82E-02	1,57E-01	3,53E-02	1,01E-01	8,48E-02	6,21E-02	1,01E-01	1,35E-01	4,07E-02	1,02E-01	9,52E-02			
EF-Eutrophication, freshwater [kg N equivalents]	6,90E-06	1,09E-04	2,11E-05	6,79E-06	1,06E-04	2,12E-05	7,01E-06	1,21E-04	2,09E-05	6,43E-06	1,18E-04	2,00E-05	7,96E-06	1,07E-04	2,35E-05	7,06E-06	1,09E-04	2,13E-05	8,20E-06	1,10E-04	2,31E-05			
EF-Eutrophication, marine [kg P equivalents]	3,52E-05	5,58E-04	8,39E-05	3,38E-05	6,45E-04	8,21E-05	3,67E-05	2,14E-04	8,57E-05	3,62E-05	2,18E-04	8,53E-05	3,30E-05	6,39E-04	8,09E-05	3,56E-05	5,59E-04	8,44E-05	3,63E-05	5,57E-04	8,49E-05			
EF-Eutrophication, terrestrial [mol N equivalents]	3,45E-04	1,61E-03	8,42E-04	3,27E-04	1,57E-03	8,14E-04	3,63E-04	1,76E-03	8,69E-04	3,54E-04	1,78E-03	8,59E-04	3,23E-04	1,57E-03	8,03E-04	3,48E-04	1,61E-03	8,47E-04	3,64E-04	1,61E-03	8,64E-04			
EF-Ionising radiation, human health [kBq U235 equivalents]	3,39E-03	-1,86E-03	1,04E-02	3,32E-03	-5,47E-03	1,06E-02	3,46E-03	1,26E-02	1,03E-02	2,83E-03	9,54E-03	9,29E-03	4,63E-03	-4,58E-03	1,30E-02	4,76E-03	-1,15E-03	1,26E-02	4,78E-03	-1,14E-03	1,27E-02			
EF-Land use [pt]	1,01E-01	1,12E+01	3,91E-01	1,07E-01	1,09E+01	4,04E-01	9,47E-02	1,22E+01	3,77E-01	5,49E-02	1,20E+01	3,14E-01	2,04E-01	1,10E+01	5,62E-01	1,09E-01	1,12E+01	4,03E-01	1,90E-01	1,12E+01	5,32E-01			

EF-Ozone depletion [kg CFC11 equivalents]	2,08E-10	2,86E-09	1,08E-09	2,10E-10	2,64E-09	1,08E-09	2,07E-10	3,71E-09	1,07E-09	1,41E-10	3,47E-09	9,71E-10	3,58E-10	2,71E-09	1,31E-09	2,16E-10	2,86E-09	1,09E-09	3,55E-10	2,91E-09	1,31E-09
EF-Particulate matter [disease incidence]	1,79E-09	6,56E-09	4,55E-09	1,71E-09	6,52E-09	4,41E-09	1,86E-09	6,75E-09	4,69E-09	1,82E-09	6,82E-09	4,64E-09	1,71E-09	6,50E-09	4,34E-09	1,79E-09	6,57E-09	4,56E-09	1,87E-09	6,55E-09	4,66E-09
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	1,65E-04	5,39E-04	3,76E-04	1,53E-04	5,28E-04	3,60E-04	1,76E-04	5,83E-04	3,93E-04	1,73E-04	5,87E-04	3,89E-04	1,46E-04	5,27E-04	3,49E-04	1,66E-04	5,39E-04	3,78E-04	1,72E-04	5,38E-04	3,86E-04
EF-Resource use, fossils [MJ]	1,03E+00	1,16E+00	2,57E+00	9,31E-01	1,03E+00	2,32E+00	1,13E+00	1,67E+00	2,81E+00	1,10E+00	1,57E+00	2,77E+00	8,68E-01	1,06E+00	2,11E+00	1,05E+00	1,17E+00	2,60E+00	1,09E+00	1,18E+00	2,66E+00
EF-Resource use, minerals and metals [kg Sb equivalents]	1,89E-07	4,12E-07	6,19E-07	1,77E-07	4,02E-07	6,02E-07	2,01E-07	4,53E-07	6,35E-07	1,99E-07	4,46E-07	6,32E-07	1,68E-07	4,04E-07	5,89E-07	1,89E-07	4,12E-07	6,19E-07	1,94E-07	4,14E-07	6,26E-07
Water scarcity	2,42E-02	4,18E-02	4,65E-02	2,26E-02	3,71E-02	4,44E-02	2,57E-02	6,08E-02	4,85E-02	2,46E-02	5,77E-02	4,67E-02	2,34E-02	3,80E-02	4,60E-02	2,72E-02	4,34E-02	5,13E-02	2,68E-02	4,26E-02	5,06E-02

Appendix M. E-commerce with baseline RR = 90%

This Appendix presents the results for the e-commerce case with everything equal, just the reuse rate increased to 90%

Reusable plastic system

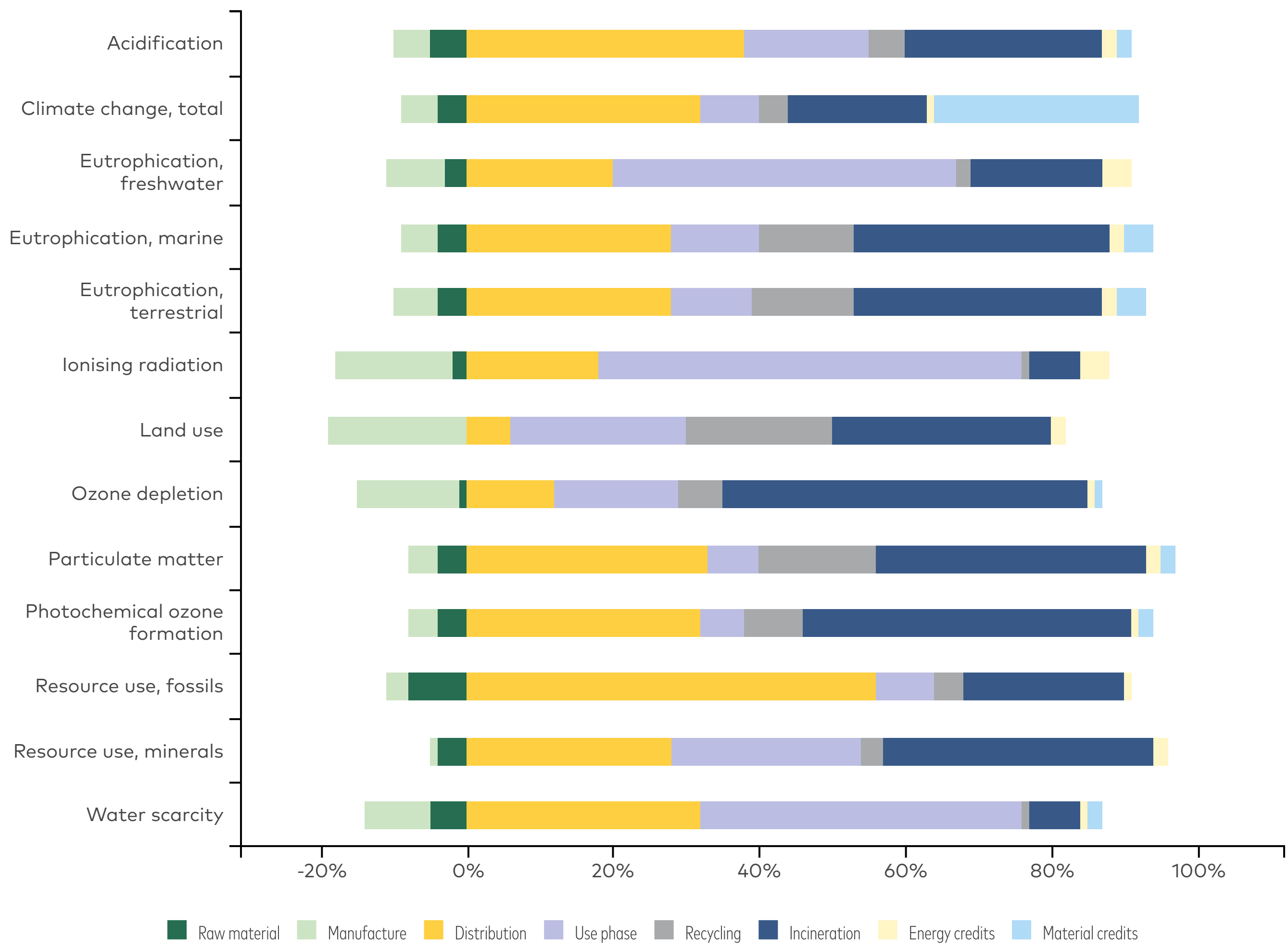

Figure 32 Reusable system contribution analysis by life cycle stage (total environmental impact) (RR=90%).

Single use plastic system

Table 40 Results from base case "Single use plastic bag system" and "Reusable bag system". The results are com-pared by the difference between base case results (subtracting the results of the Reusable system from the results of the Single use system) as percentage of the reusable system. The beneficial system per impact category is shaded in light green (RR=90%).

EF Impact category	Single use plastic bag system	Reusable bag system	Comparison and difference between base case results as percentage of the reusable
EF-Acidification [mol H+ equivalents]	1.48E-04	1.80E-04	The single use system shows noticable benefits. (-18%)
EF-Climate change, total [kg CO2-Equivalents]	6.18E-02	6.26E-02	The single use system shows marginal benefits. (-1%)
EF-Eutrophication, freshwater [kg N equivalents]	6.90E-06	9.57E-06	The single use system shows moderate benefits. (-28%)
EF-Eutrophication, marine [kg P equivalents]	3.52E-05	4.38E-05	The single use system shows noticable benefits. (-19%)
EF-Eutrophication, terrestrial [mol N equivalents]	3.45E-04	4.43E-04	The single use system shows moderate benefits. (-22%)
EF-Ionising radiation, human health [kBq U235 equivalents]	3.39E-03	4.49E-03	The single use system shows moderate benefits. (-24%)
EF-Land use [pt]	1.01E-01	2.12E-01	The single use system shows very significant benefits. (-52%)
EF-Ozone depletion [kg CFC11 equivalents]	2.08E-10	7.08E-10	The single use system shows very significant benefits. (-71%)
EF-Particulate matter [disease incidence]	1.78E-09	2.37E-09	The single use system shows moderate benefits. (-25%)
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	1.65E-04	2.11E-04	The single use system shows moderate benefits. (-22%)
EF-Resource use, fossils [MJ]	1.03E+00	1.20E+00	The single use system shows noticable benefits. (-14%)
EF-Resource use, minerals and metals [kg Sb equivalents]	1.89E-07	3.16E-07	The single use system shows significant benefits. (-40%)
EF-Water scarcity [m3 world-Eq deprived]	2.42E-02	1.95E-02	The reusable system shows moderate benefits. (24%)

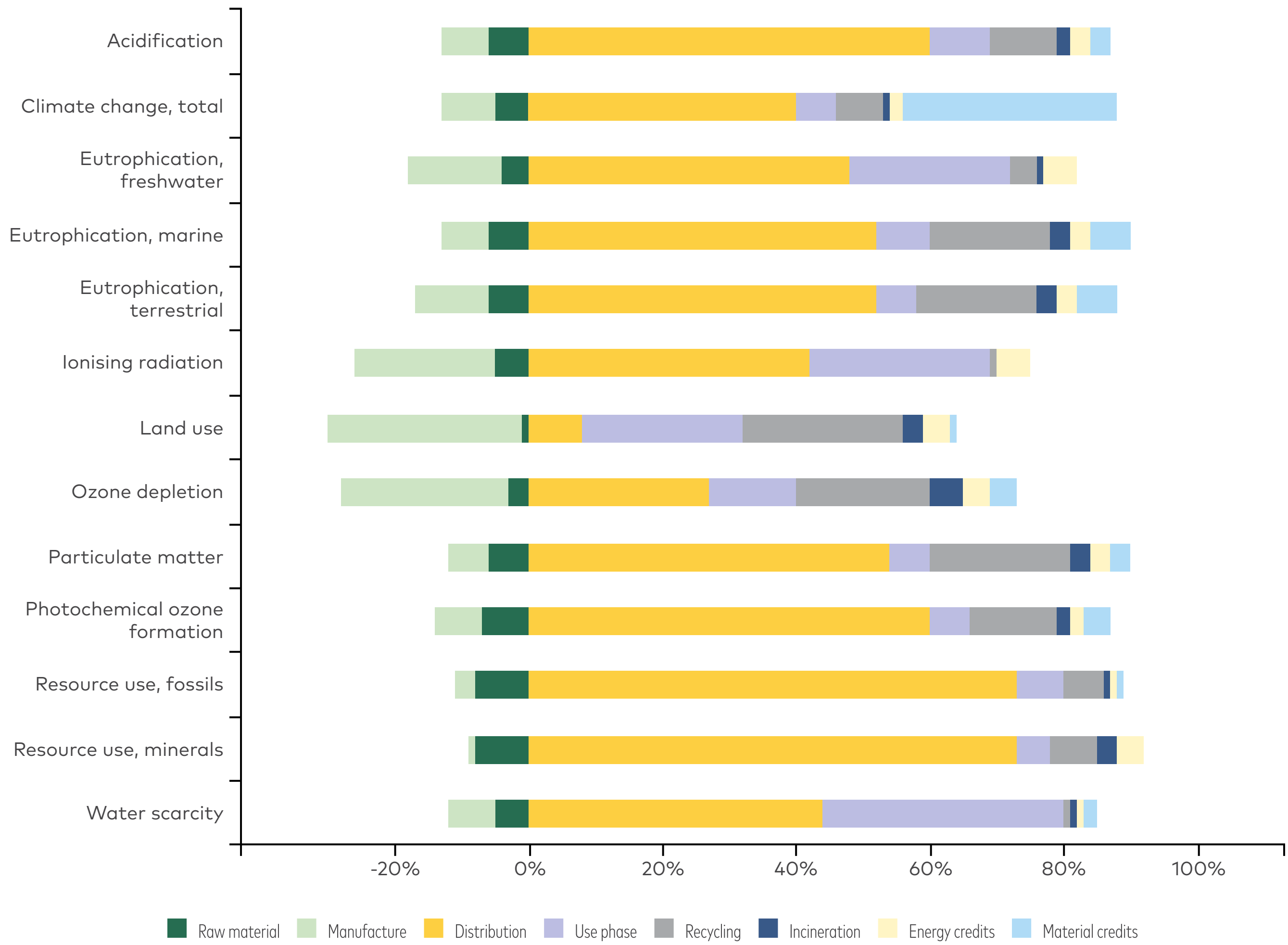

Figure 33 Single-use plastic system contribution analysis by life cycle stage (E-commerce) (total environmental impact) (RR=90%).

Table 41 Summary of the comparison "Single use plastic bag system" against "Reusable bag system". In case the reusable system shows benefits the comparison cell per impact category is shaded in light yellow (RR=90%).

EF Impact category	Comparison and difference between base case results as percentage of the reusable	Robustness of the results
EF-Acidification [mol H+ equivalents]	The single use system shows noticable benefits. (-18%)	medium robustness
EF-Climate change, total [kg CO2-Equivalents]	The single use system shows marginal benefits. (-1%)	medium robustness
EF-Eutrophication, freshwater [kg N equivalents]	The single use system shows moderate benefits. (-28%)	high robustness
EF-Eutrophication, marine [kg P equivalents]	The single use system shows noticable benefits. (-19%)	high robustness
EF-Eutrophication, terrestrial [mol N equivalents]	The single use system shows moderate benefits. (-22%)	high robustness
EF-Ionising radiation, human health [kBq U235 equivalents]	The single use system shows moderate benefits. (-24%)	high robustness
EF-Land use [pt]	The single use system shows very significant benefits. (-52%)	high robustness
EF-Ozone depletion [kg CFC11 equivalents]	The single use system shows very significant benefits. (-71%)	high robustness
EF-Particulate matter [disease incidence]	The single use system shows moderate benefits. (-25%)	high robustness
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	The single use system shows moderate benefits. (-22%)	high robustness
EF-Resource use, fossils [MJ]	The single use system shows noticable benefits. (-14%)	medium robustness
EF-Resource use, minerals and metals [kg Sb equivalents]	The single use system shows significant benefits. (-40%)	high robustness
EF-Water scarcity [m3 world-Eq deprived]	The reusable system shows moderate benefits. (24%)	low robustness

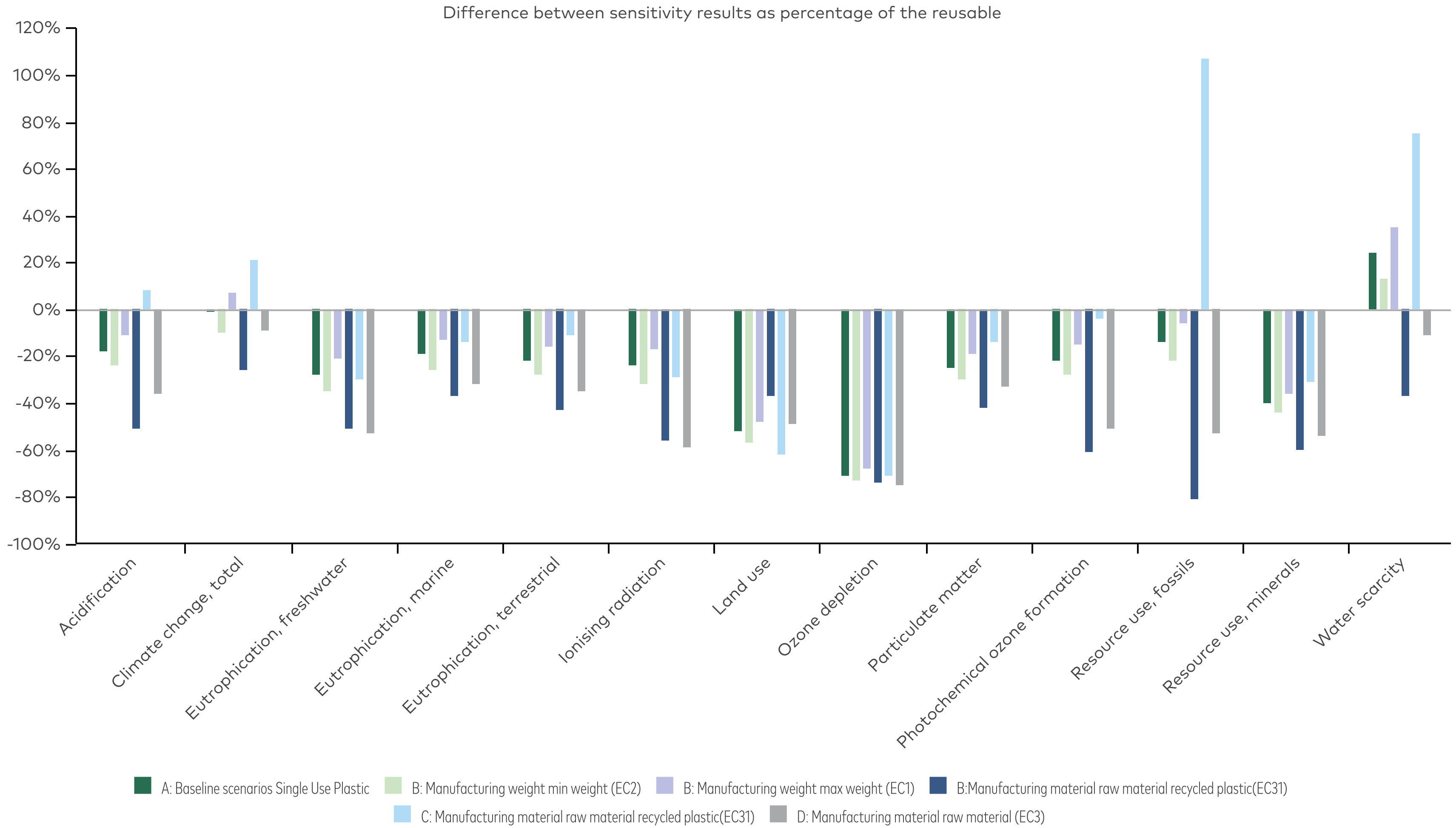

Figure 34 Production related sensitivity analyses for the e-commerce case (RR=90%).

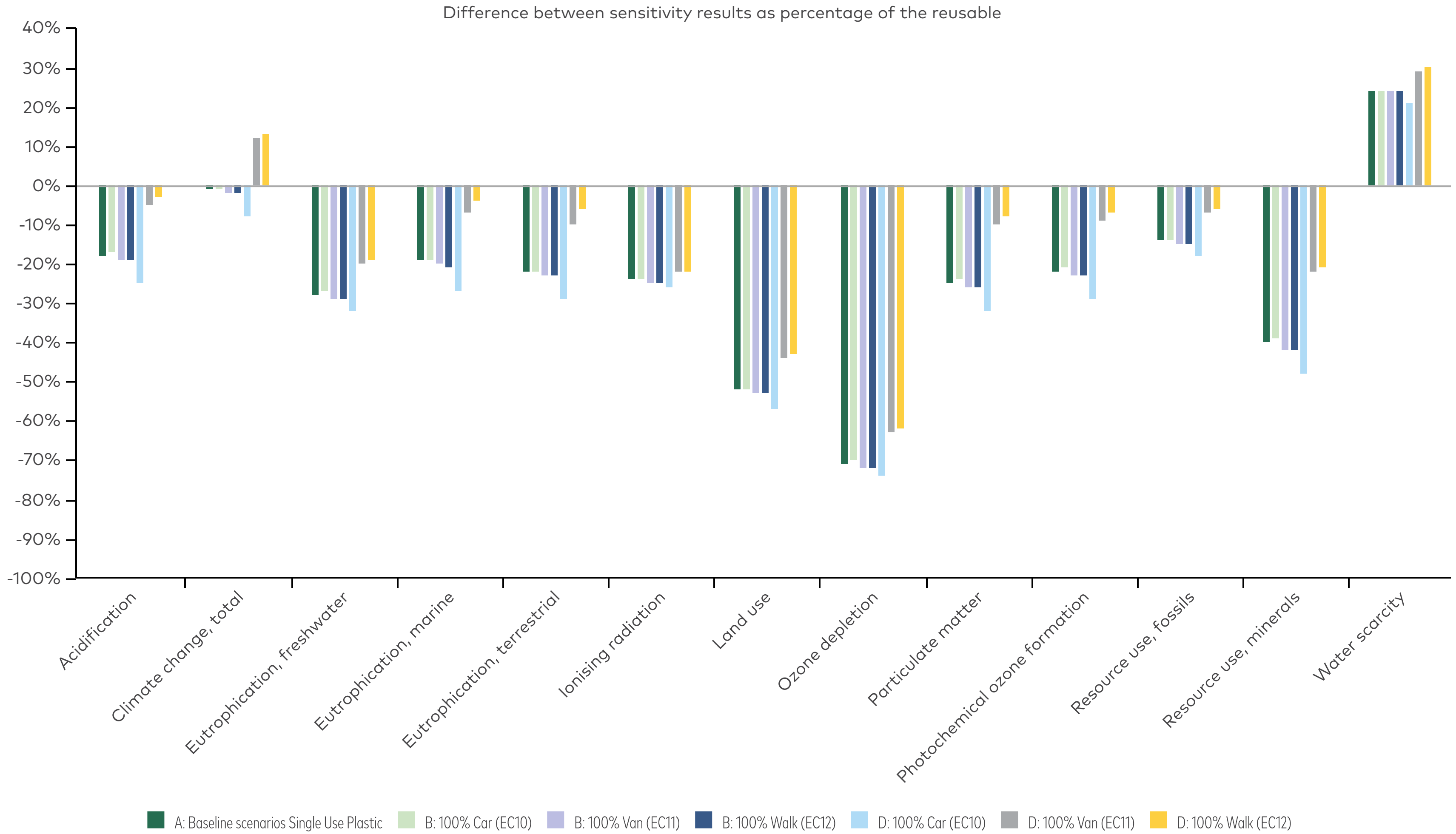

Figure 35 Use phase related sensitivity analyses for the e-commerce case (RR=90%).

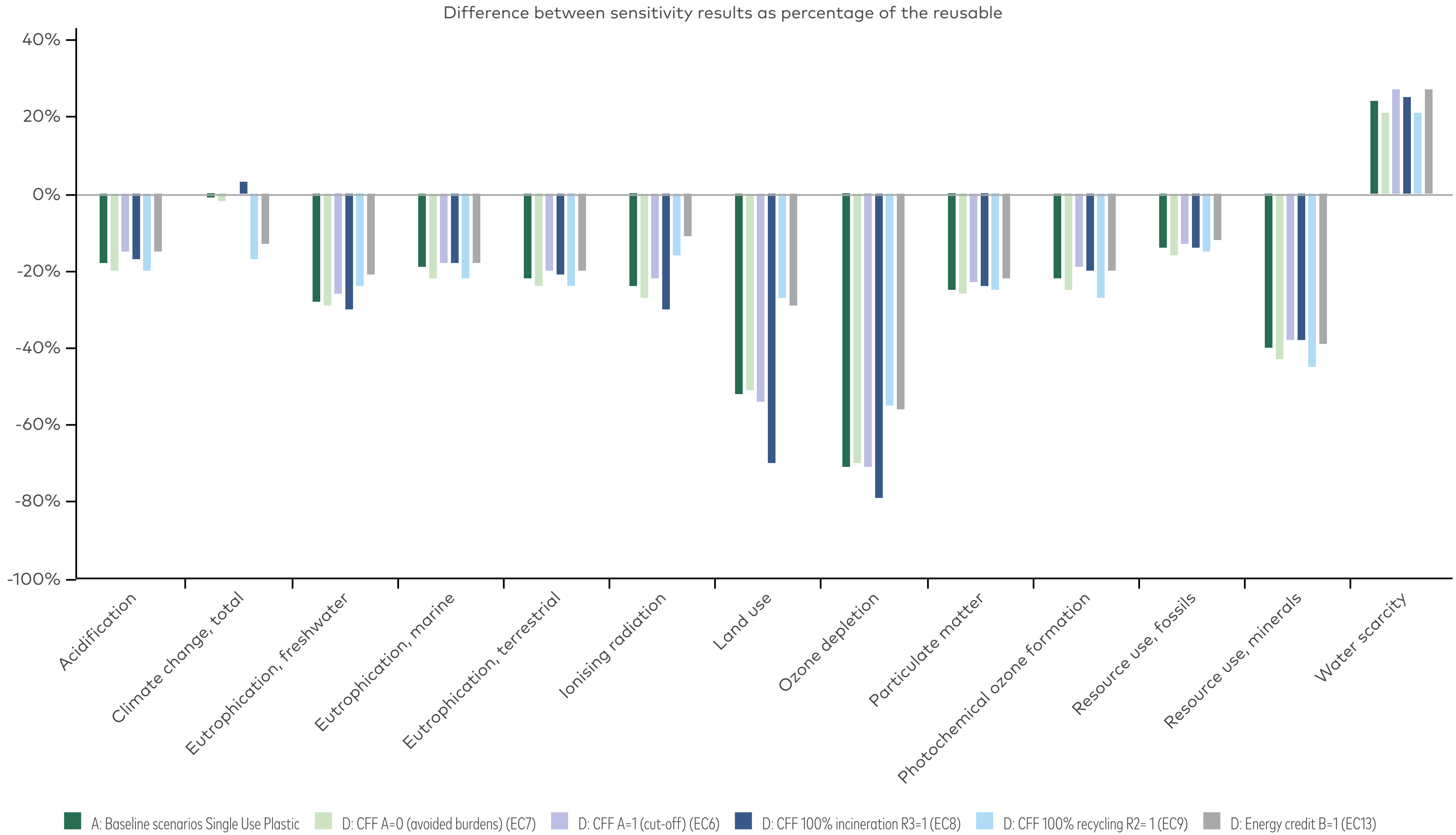

Figure 36 CFF implementation related sensitivity analyses for the e-commerce case (RR=90%).

Single use paper system

Table 42 Results from base case "Single use paper bag system" and "Reusable bag system". The results are com-pared by the difference between base case results (subtracting the results of the Reusable system from the results of the Single use system) as percentage of the reusable system. The beneficial system per impact category is shaded in light green (RR=90%).

EF Impact category	Single use paper bag system - Base case	Reusable bag system – Base case	Comparison and difference between base case results as percentage of the reusable
EF-Acidification [mol H+ equivalents]	4.42E-04	1.80E-04	The reusable system shows very significant benefits. (146%)
EF-Climate change, total [kg CO2-Equivalents]	1.00E-01	6.26E-02	The reusable system shows very significant benefits. (60%)
EF-Eutrophication, freshwater [kg N equivalents]	1.09E-04	9.57E-06	The reusable system shows very significant benefits. (1038%)
EF-Eutrophication, marine [kg P equivalents]	5.58E-04	4.38E-05	The reusable system shows very significant benefits. (1176%)
EF-Eutrophication, terrestrial [mol N equivalents]	1.61E-03	4.43E-04	The reusable system shows very significant benefits. (264%)
EF-Ionising radiation, human health [kBq U235 equivalents]	-1.86E-03	4.49E-03	The single use system shows very significant benefits. (-142%)
EF-Land use [pt]	1.12E+01	2.12E-01	The reusable system shows very significant benefits. (5169%)
EF-Ozone depletion [kg CFC11 equivalents]	2.86E-09	7.08E-10	The reusable system shows very significant benefits. (303%)
EF-Particulate matter [disease incidence]	6.56E-09	2.37E-09	The reusable system shows very significant benefits. (177%)
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	5.39E-04	2.11E-04	The reusable system shows very significant benefits. (155%)
EF-Resource use, fossils [MJ]	1.16E+00	1.20E+00	The single use system shows marginal benefits. (-3%)
EF-Resource use, minerals and metals [kg Sb equivalents]	4.12E-07	3.16E-07	The reusable system shows significant benefits. (30%)
EF-Water scarcity [m3 world-Eq deprived]	4.18E-02	1.95E-02	The reusable system shows very significant benefits. (114%)

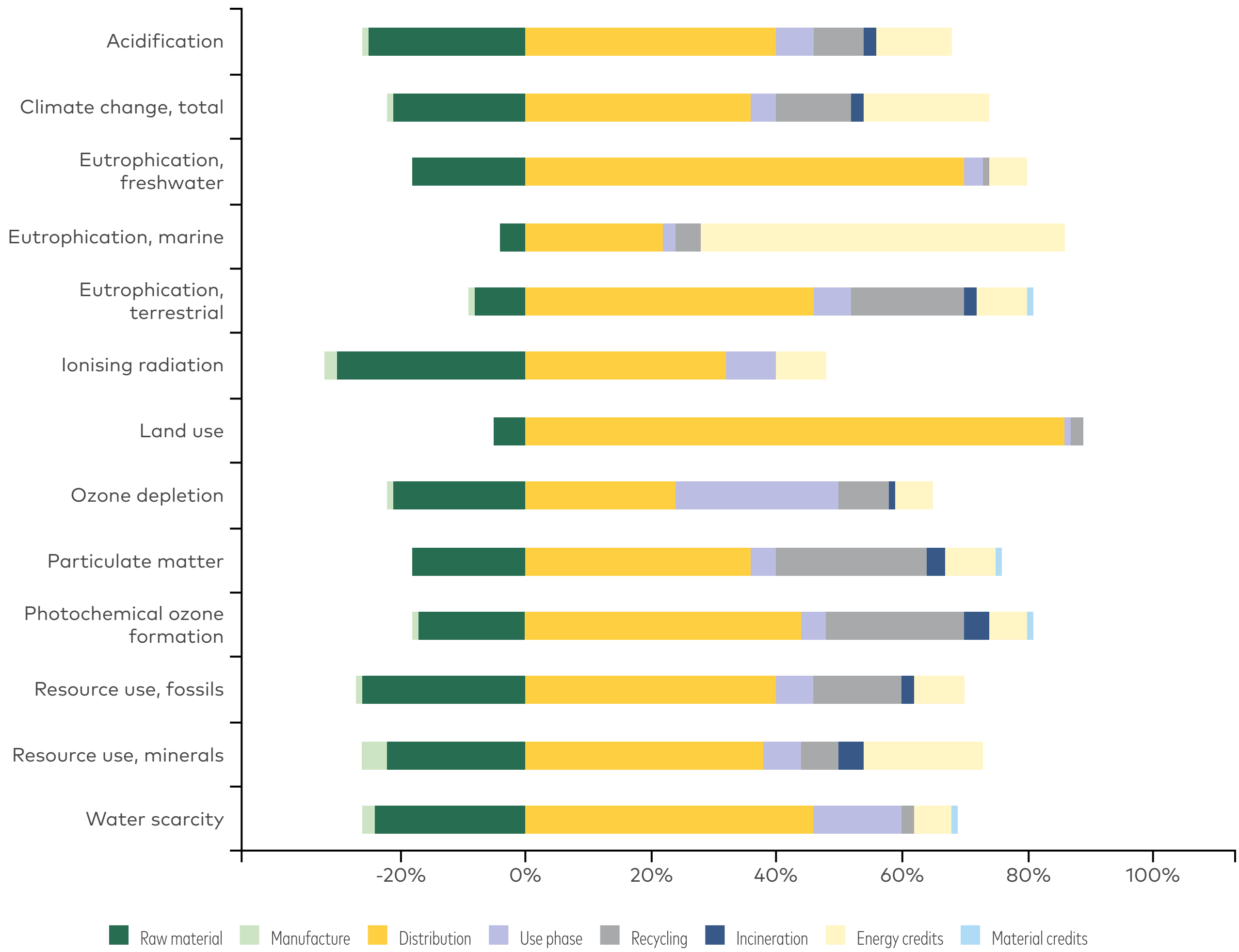

Figure 37 Single-use paper system contribution analysis by life cycle stage (E-commerce) (total environmental impact) (RR=90%).

Table 43 Summary of the comparison "Single use paper bag system" against "Reusable bag system". In case the reusable system shows benefits the comparison cell per impact category is shaded in light green (RR=90%).

EF Impact category	Comparison and difference between base case results as percentage of the reusable	Robustness of the results
EF-Acidification [mol H+ equivalents]	The reusable system shows very significant benefits. (146%)	high robustness
EF-Climate change, total [kg CO2-Equivalents]	The reusable system shows very significant benefits. (60%)	high robustness
EF-Eutrophication, freshwater [kg N equivalents]	The reusable system shows very significant benefits. (1038%)	high robustness
EF-Eutrophication, marine [kg P equivalents]	The reusable system shows very significant benefits. (1176%)	high robustness
EF-Eutrophication, terrestrial [mol N equivalents]	The reusable system shows very significant benefits. (264%)	high robustness
EF-Ionising radiation, human health [kBq U235 equivalents]	The single use system shows very significant benefits. (-142%)	medium robustness
EF-Land use [pt]	The reusable system shows very significant benefits. (5169%)	high robustness
EF-Ozone depletion [kg CFC11 equivalents]	The reusable system shows very significant benefits. (303%)	high robustness
EF-Particulate matter [disease incidence]	The reusable system shows very significant benefits. (177%)	high robustness
EF-Photochemical ozone formation - human health [kg NMVOC equivalents]	The reusable system shows very significant benefits. (155%)	high robustness
EF-Resource use, fossils [MJ]	The single use system shows marginal benefits. (-3%)	low robustness
EF-Resource use, minerals and metals [kg Sb equivalents]	The reusable system shows significant benefits. (30%)	medium robustness
EF-Water scarcity [m3 world-Eq deprived]	The reusable system shows very significant benefits. (114%)	high robustness

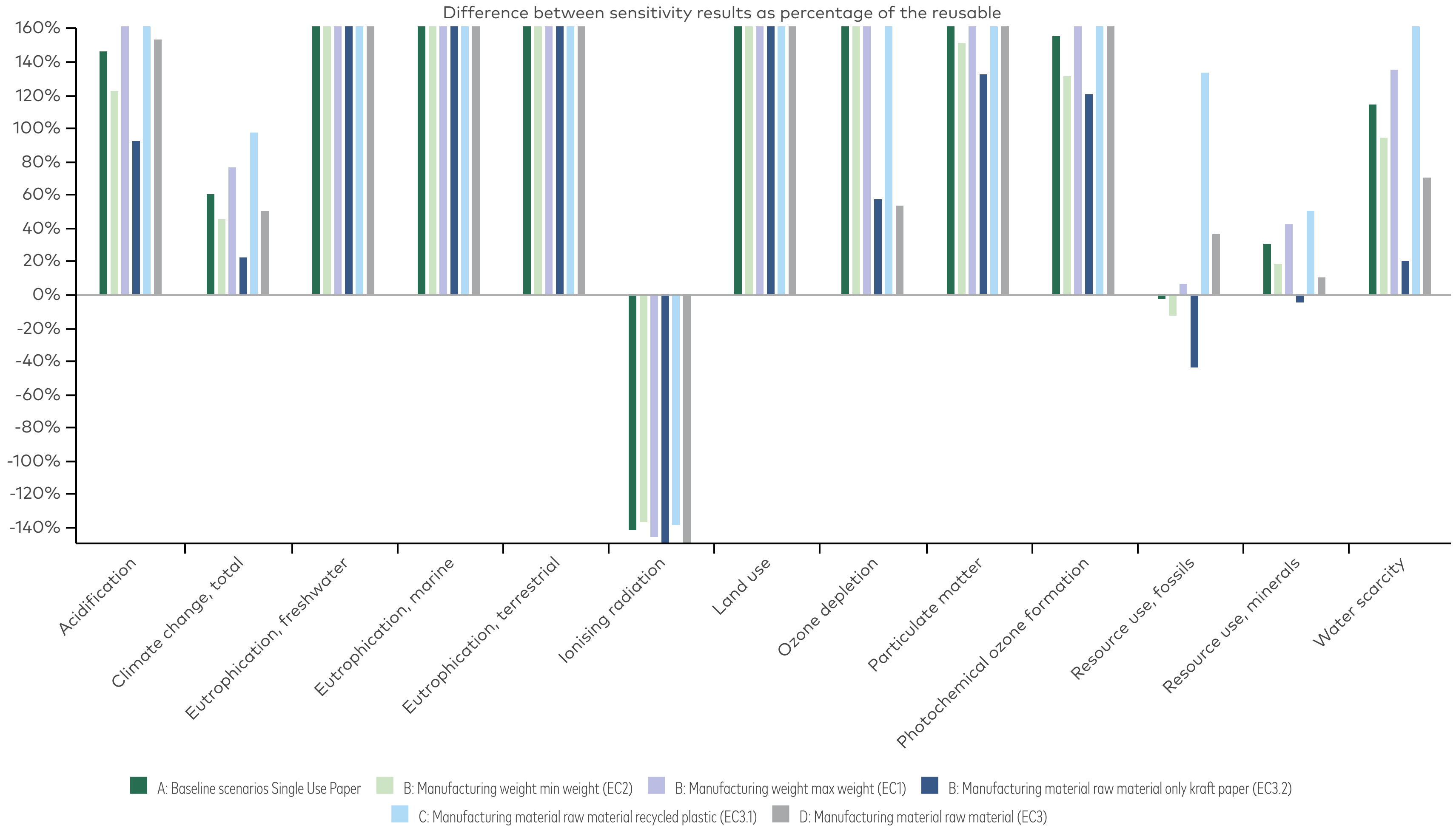

Figure 38 Production related sensitivity analyses for the e-commerce case (RR=90%).

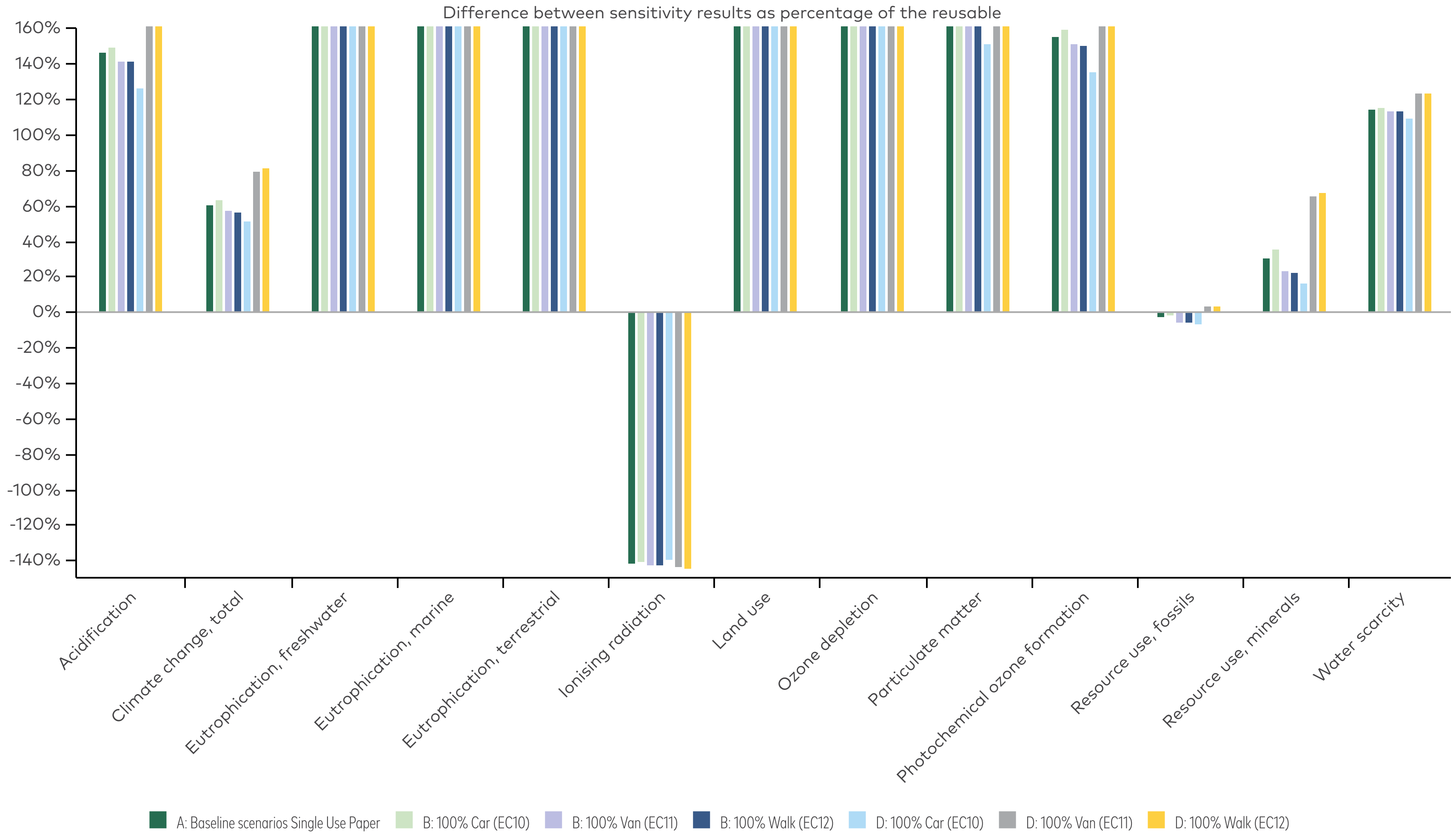

Figure 39 Use phase related sensitivity analyses for the e-commerce case (RR=90%).

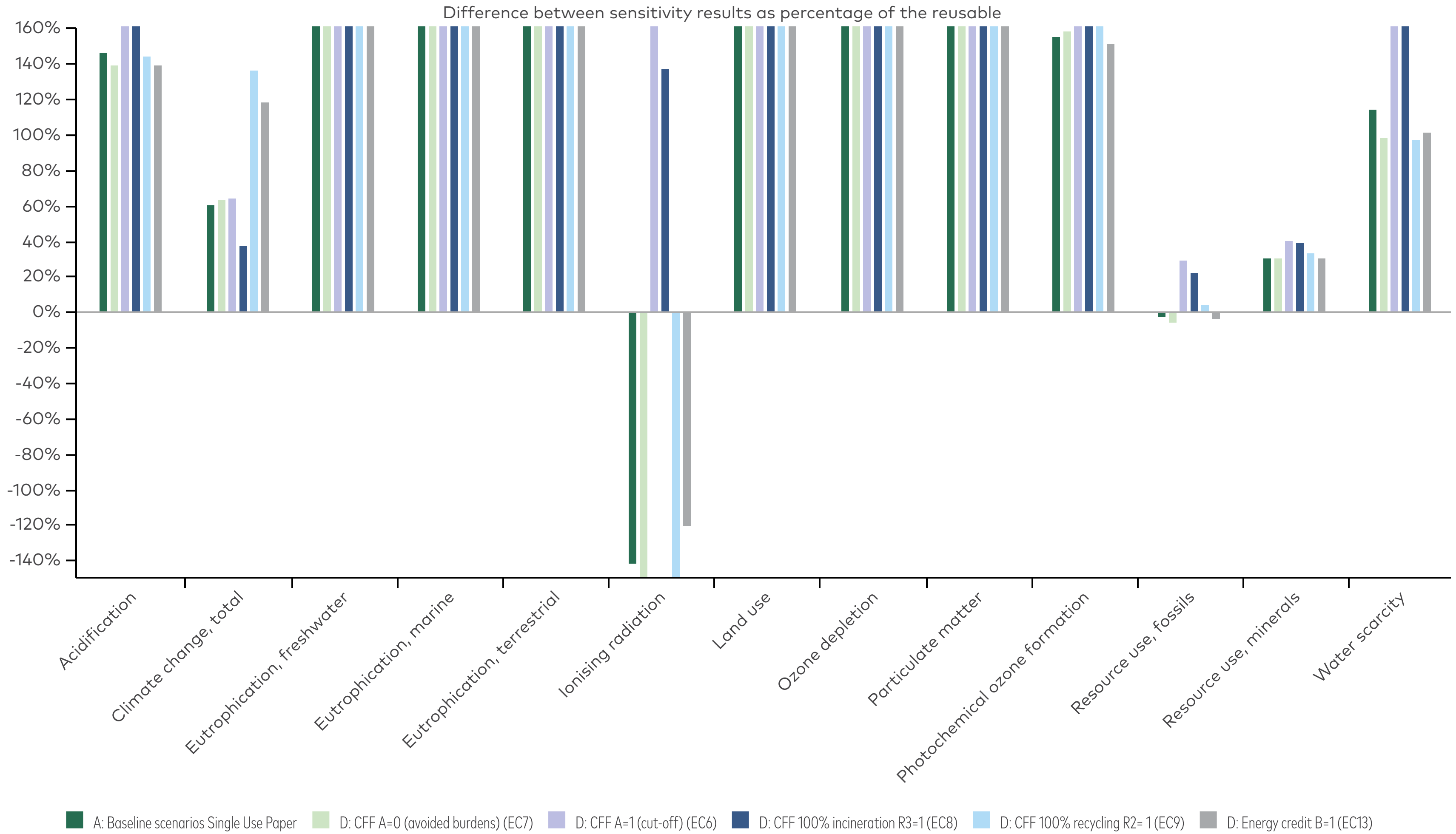

Figure 40 CFF implementation related sensitivity analyses for the e-commerce case (RR=90%).

Appendix N. Critical Review statement

Review of life cycle assessment of single-use and reuse packaging

Tomas Ekvall, adjunct professor in Environmental Systems Analysis at Chalmers University of Technology, and consultant in Tomas Ekvall Research Review & Assessment
20-12-2023

Summary review statement

This study is a mainly attributional comparative environmental assessment of single-use and reuse packaging for take-away food and for e-commerce. An external expert reviewed the study based on the international standards for LCA. Overall, the reviewer finds that the methodological choices in the study are adequate and justified in the report. The findings and conclusions are sound.

The LCA report complies with the majority of the many reporting requirements posed by ISO 14044 on a comparative assertion disclosed to the public. It includes an adequate assessment of key uncertainties and a full-bodied discussion of the results. However, while the study is transparent in theory, the effective transparency is low, making it difficult to understand how the results are produced.

The numerical results should be used with care because, as stated in the report, other results would have been obtained with a different set of input data or calculation methods.

Introduction

The study

This study compares single-use and reuse packaging for take-away food and for shipping clothes bought on the internet. It was conducted by a team of consultants at Ramboll with 2-3 years each of experience from life cycle assessment (LCA). The work was checked internally by Katja Gradin and coordinated by Janus Kirkeby, both with extensive experience from LCA research.

The study is intended to provide decision support to authorities as well as companies. The funding for the project was provided by the Nordic Working Group for Circular Economy (NCE) under the Nordic Council of Ministers. A steering group with representatives from the national environmental authorities in Denmark, Finland, Norway, and Sweden oversaw the project.

The report states in Chapter 2 that the study is made in accordance with the international standards for LCA: ISO 14040 and ISO 14044. ISO 14040 specifies the structure of the analysis. ISO 14044 gives some guidance on the methods used in the study, but primarily includes requirements on the reporting and review of the

LCA. These requirements are more comprehensive in studies, such as this, when the results are used as basis for assertions disclosed to the public about what product or system is environmentally superior.

The review

For LCAs that makes comparative assertions to the public, ISO 14044 requires that a review be conducted by a panel of interested parties and experts. This review deviates from ISO 14044 here, because NCE decided a review by an external expert was sufficient. The reviewer appointed by NCE is Tomas Ekvall, adjunct professor in Environmental Systems Analysis at Chalmers University of Technology, and consultant in Tomas Ekvall Research Review & Assessment. Professor Ekvall has over 30 years of experience from life cycle assessment and is a frequently cited scientific expert on modelling in life cycle inventory analysis (LCI).

The scope of the review is consistent with ISO 14044. The main aim of the review was to ensure that the methods used in the study are scientifically and technically valid, that the input data are appropriate, that the interpretations reflect the goal and limitations of the study, and that the report is transparent, clear, and consistent. In addition, the reviewer investigated to what extent the methods and report are consistent with the international LCA standard ISO 14044.

The reviewer was involved all through the project and gratefully acknowledges a good and constructive collaboration with the authors of the study. The project team at Ramboll hosted five meetings where they presented results and got feedback from the reviewer and the Nordic steering group. The review also included an early scoping report, with the literature review and the goal and scope definition of the LCA, and a preliminary version of the complete report. This meant several of the perspectives and insights of the reviewer could be integrated in the study, and that most of the initial review comments are addressed in the final version of the report.

Comments

The remaining review comments are listed below. Note that these comments are valid for the manuscript version on which the review report is based. Some or all of them might be amended before the LCA report is published.

General

The report includes a thorough background study to collect information about the systems and give a basis for the choice of cases studied in the LCA. The LCA, in turn, is ambitious in terms of environmental impacts (13 impact categories) and sensitivity analyses. This means it generates many numerical results.

The study is mostly based on generic input data rather than site-specific data. This is justified because the aim is not to investigate a very specific case but to increase the knowledge on the environmental performance of single-use and reusable packaging overall in the Nordic countries.

The report adequately describes the systems investigated and the methodological choices made in the LCA. However, it does not present sufficient input data and calculations to make it clear how the results from the life cycle impact assessment (LCIA) and sensitivity analyses are produced (see also Transparency below).

Numerical results from an LCA depend heavily on subjective methodological choices and uncertain input data. The sensitivity analyses in this study illustrate only part of the range of possible results. For this reason, readers of the report should focus on the qualitative findings rather than the numerical results.

The executive summary is comprehensive, clear, and reflects the content of the study.

Transparency

The report includes sources with references to the input data and the characterization factors. It also presents the methods used in the calculations and outlines the calculation procedure. This makes the study transparent in theory. It also meets most of the many requirements posed by ISO 14044 on a comparative assertion disclosed to the public. An important exception is that input data on important processes, such as material production, are not included in the report. These data are from the Ecoinvent database, which prohibits publication of the data.

Important partial results, such as the LCI results, are missing in the report. Characterization factors and end-pointy conversion factors are also absent. The contribution and sensitivity analyses make it possible for the reader to understand what is important for the results, but the effective transparency of the calculations is low. This makes it difficult for readers to assess the study and its results.

Clarity of the report

The text in the report is in most parts clear but would benefit from editing and a language check.

The results are mainly presented in bar diagrams. Bar diagrams are good in that they show the relationships between different results without indicating that the numerical results are precise. However, the dominance analysis (Figures 11-12 and 14-16) is presented with shades rather than clear colors. However, in the presentation of the sensitivity analysis, the colored square for each analysis is very small. This makes it hard for the reader to grasp what results relate to what sensitivity analysis.

LCI modelling approaches

Many LCA experts distinguish between attributional and consequential LCA. Attributional LCA can be said to assign part of the total human impact on the environment to the product investigated. A consequential LCA, on the other hand, estimates how the production and use of the product affect the total human impact on the environment; this can include increases as well as reductions in emissions and resource use.

This study is presented as a an attributional LCA; however, waste management and recycling are modelled with the Circular Footprint Formula (CFF) from the Environmental Footprint methodology, the EU framework for LCA. The CFF includes aspects that are often associated with consequential LCA. Credits are given to the product investigated for the energy and part of the primary-material production that are avoided when the product is incinerated or recycled after use. The use of recycled material in the product investigated is also burdened with part of the primary-material production that the recycled material substitutes. Hence, the study is not attributional in a strict sense.

When an LCA includes a mix of attributional and consequential methods, the results do not respond to a clear question. This can be considered a weakness in the study. However, the methodological choice was approved by the steering group, which considered the method adequate and relevant.

A purely attributional assessment can probably be obtained by combining variations that are separately tested in the sensitivity analysis: setting both CFF Factors A and B to 1. However, in this particular attributional approach no emissions from waste incineration are assigned to the packaging. The steering group would be likely to object to such an approach.

Functions and functional units

The single-use and reusable packaging solutions are compared based on their primary function: containing takeaway food and transporting clothes bought on the internet to their customer. The packaging might have secondary uses, such as storing food leftovers at home and containing clothes returned to the seller. These secondary functions are not considered in the study.

The packaging solutions can also vary in additional functionality such as printing/advertising and safekeeping of the goods. Any such differences in functionality are not accounted for in this study.

This means the packaging solutions cannot be expected to have identical functionality. The authors are clear about this limitation in the study. This should also be remembered when using the results as basis for policy decisions, as stated in the discussion of the results.

Modelling of recycling

Paper and plastic packaging materials are assumed to be 100% primary materials. This is a conservative assumption, since recycled material might be used at least for shipping clothes. Hence, the assumption might contribute to net results overestimating environmental impacts where primary production is worse than the recycling process.

Modelling of electricity

The electricity supply is modelled using average data for the country or region where the electricity is used. This is a common approach in attributional LCA. Electricity used in the Nordic countries is modelled using Nordic average data rather than national average data. This makes the electricity use reasonably significant in the LCA results. However, the use of average data does not reflect the foreseeable consequences of using electricity, because the electricity system is affected on the margin. This is one of the reasons why attributional LCA does not reflect how the choice of packaging solutions affects the affect the human impacts on the environment.

Life cycle impact assessment methods

The choice of impact categories is ambitious and well justified. The choice of calculation methods in the LCIA is not clearly justified but reasonable.

Calculations and results

Most of the calculations could not be checked, since important input data, LCI results, characterization factors, etc. are not included in the report. The climate impact associated to production and waste incineration of plastics could be compared to other sources to check if they are reasonable: they are reasonable. Other results depend heavily on case-specific factors or on input data with great variability between sites and over time. This makes it difficult to assess them without checking the calculations.

Interpretation

The study includes a dominance analysis and a good number of sensitivity analyses. Besides the significance of CFF Factor B, the sensitivity analyses illustrate how the results are affected by a small change (10%) in the weight of the packaging, but also by extreme assumptions on, for example, consumer behavior (the mode of transportation and the prewashing of used takeaway packaging), and on the market for recycled material – represented by Factor A in the CFF.

The results from the baseline calculations and sensitivity analysis are discussed under the statement or assumption that a 30% difference is significant. This is in line with the general language, where a "significant difference" is understood to mean "large difference". However, in an LCA, "significant difference" should be used to denote differences that are larger than the uncertainty. The uncertainty varies greatly between, for example, impact categories, as indicated in Section 4.2.4. Hence, a 30% difference might be significant for the climate-change impact, but it will often not be significant for acidification or eutrophication, and rarely for the impact categories ionizing radiation, land use, water use, etc.

The discussion of the results is clear and accounts for the limitations of the study.

Conclusions and recommendations in the report

The report includes several conclusions and recommendations that are both valid and relevant to the broad intended audience: the public, private companies, and authorities.

About this publication

LCA on reuse of packaging in the Nordics

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