Life Cycle Initiative

hosted by UN environment programme

Single-use plastic take-away food packaging and its alternatives

Recommendations from Life Cycle Assessments

Suggested Citation:

(UNEP 2020). United Nations Environment Programme (2020). Single-use plastic take-away food packaging and its alternatives - Recommendations from Life Cycle Assessments.

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ACKNOWLEDGEMENTS

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Recommended citation: United Nations Environment Programme (2020). Single-use plastic take-away food packaging and its alternatives - Recommendations from Life Cycle Assessments.

DESIGN AND LAYOUT: kmugridge.com

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EXECUTIVE SUMMARY

This report summarises knowledge about the environmental impact of single-use plastic packaging for take-away food and alternatives that could potentially replace it. Take-away food is interpreted as food that is sold for immediate consumption after purchase and is consumed away from the food outlet (e.g., home, work, street). Different types of food take-away packaging are used today, for example:

- food boxes,
- containers,
- clamshells,
- trays,
- crates and food savers.

Though packagings might be different in design, form and volume, their names are sometimes used interchangeably (for instance, containers and food savers). However all the alternatives considered in this study should provide the same function for storage and transportation of take-away food that is sold for immediate consumption after purchase and is consumed away from the food outlet.

The assessed packaging alternatives include mainly packaging made for single-use, with alternatives for re-use being considered as well. The materials used for the assessed packaging are different types of plastics (made of fossil and bio-based resources, virgin or recycled content) and other types of materials: aluminium, paper/cardboard/wood and glass (the latter only for reusable containers).

The report also discusses implications of this knowledge for policy makers and other actors aiming at reducing the environmental impact of single-use food packaging.

The report is based on a meta-analysis of six life cycle assessment (LCA) studies as well as reflections on five additional studies, all of them found in the table below.

Type of material / Publication	Plastic (single-use)	Aluminium (single-use)	Paper/ Wood (single-use)	Plastic (reusable)	Glass (reusable)	Geographic scope	Life Cycle stages	Functional unit
LCA studies comparing single-use plastic take-away food packaging								
Single use thermoform boxes made from PS*, PLA (corn) and PLA (cassava starch) (Suwanmanee et al. 2013)						Thailand	Cradle to consumer gate	10,000 units of 8.0×10.0×2.5 cm of PS, PLA, and PLSA/starch boxes. with the carrying capacity of 100 g.
PLA, PET and PS thermoformed clamshell containers, used for packaging of strawberries (Madival et al. 2009)						USA	Cradle-to-cradle	1000 containers of capacity 0.4536 kg (1 lb) each for the packaging of strawberries.
Four types of clam shells: multilayer film from PLA and TPS, PP, PET, and PLA (Benetto et al., 2015).						Italy	Cradle-to-grave	film is used to produce a 500 ml clam shell (including the cover).
LCA studies comparing single-use plastic take-away food packaging vs single-use packaging of other materials								
Laminated bio-based thermoformable paper food trays against existing plastic packaging solutions: APET/PE and EPS (Johansson et al. 2020)						Belgium	Cradle-to-grave	1000 trays of product successfully delivered to the final customer and disposed of after use.
Packaging used for fruit and vegetables: six different types of plastics (XPS, OPS, PET, RPET, PLA (corn), PP) and one type made of recycled moulded pulp (Belley 2011)						Canada	Cradle-to-grave	one tray (52 cubic inches).
Foam polystyrene, paper-based, and PLA foodservice products (Franklin Associates, 2011)						USA	Cradle-to-grave	10,000 items of sandwich-size clamshells.
LCA studies comparing single-use plastic take-away food packaging vs reusable packaging								
Takeaway food containers: single-use and reusable plastic containers and single-use aluminium (Gallego-Schmid et al. 2019)						Europe	Cradle-to-grave	container storing a meal for one person.
Reusable containers made of plastics and glass (Gallego-Schmid et al. 2018)						Europe	Cradle-to-grave	50 uses of plastic (polypropylene) and glass food savers over their lifetime.
Single-use and reusable food containers for takeaway food (Baumann et al. 2018)						Australia	Cradle-to-grave	360 uses of reusable food containers.
Reusable plastic crate or recyclable cardboard box (Koskela et al. 2014)						Finland	Cradle-to-grave	8 loaves of bread delivered in one crate/box.
Single-use wooden boxes, plastic crates, cardboard boxes and reusable plastic crates (Accorsi et al. 2013)						Italy	Cradle-to-grave	transportation of 1200 t of fruits and vegetables.

Publications included in meta-analysis

Publications that are discussed but not included in meta-analysis

*Abbreviations: PS= polystyrene, PLA= Polyactic acid, PET= Polyethylene terephthalate, TPS= Thermoplastic starch, APET= Amorphous polyethylene terephthalate; EPS= Expanded polystyrene, XPS= extruded polystyrene, OPS= oriented polystyrene, RPET= recycled PET

EXECUTIVE SUMMARY

The table below summarises the analysis' findings, including some of the environmental benefits and drawbacks of single-use compared to alternative take-away food packaging. The three impact categories included in the table are some of the most frequently includedin the studied LCAs. Other impacts were also covered by the analysed studies, as described and discussed in the main body of the report.

Environmental impacts of the products studied: Summary Table

Impact indicator	Climate change		Acidification		Eutrophication	
Publication	**Best**	**Worst**	**Best**	**Worst**	**Best**	**Worst**
Comparison between single-use plastic take-away food packaging						
Single use thermoform boxes made from PS*, PLA (corn) and PLA (cassava starch) (Suwanmanee et al. 2013)**	PS	PLA (cassava starch)	PS	PLA (corn)	N/A	N/A
PLA, PET and PS thermoformed clamshell containers, used for packaging of strawberries (Madival et al. 2009)	PLA (corn), PS	PET	PET, PS	PLA (corn)	PLA (corn), PS	PET
Four types of clam shells: multilayer film from PLA and TPS, PP, PET, and PLA (Benetto et al., 2015).	Excluded from meta-analysis. The study indicates that PET performs worst in terms of human health, climate change and resource use, where PLA has the lowest impact for those impact categories.					
LCA studies comparing single-use plastic take-away food packaging vs single-use packaging of other materials						
Laminated bio-based thermoformable paper food trays against existing plastic packaging solutions: APET/PE and EPS (Johansson et al. 2020)***	Laminated bio-based thermoformable paper with multilayer lidding film	APET/PE with multilayer lidding film	Laminated bio-based thermoformable paper with multilayer lidding film	APET/PE with multilayer lidding film	Laminated bio-based thermoformable paper with multilayer lidding film	APET/PE with multilayer lidding film
Packaging used for fruit and vegetables: six different types of plastics (XPS, OPS, PET, RPET, PLA (corn), PP) and one type made of recycled moulded pulp (Belley 2011)	XPS and recycled moulded pulp	OPS, PET, PLA, PP	XPS and recycled moulded pulp	PLA, PP	XPS, recycled moulded pulp, OPS, PET	PLA
Foam polystyrene, paper-based, and PLA (corn) foodservice products (Franklin Associates, 2011)	Excluded from meta-analysis. The study indicates that PLA clam shells have the highest impact on climate change, while fluted paperboard- the lowest (providing the assumption that no decomposition at landfill is performed. When the maximum decomposition at landfill of fluted paperboard is assumed, then the impact on climate change is still lower than PLA, but slighly higher than foam polystyrene.					
LCA studies comparing single-use plastic take-away food packaging vs reusable packaging						
Takeaway food containers: single-use and reusable plastic containers and single-use aluminium (Gallego-Schmid et al. 2019)	XPS, reusable PP (if reused more than 18 times)	single-use PP	XPS, reusable PP (if reused more than 29 times)	single-use PP	XPS, reusable PP (if reused more than 18 times)	single-use PP
Reusable containers made of plastics and glass (Gallego-Schmid et al. 2018)	reusable PP	reusable glass	reusable PP	reusable glass	reusable PP	reusable glass
Single-use and reusable food containers for takeaway food (Baumann et al. 2018)	Only included in discussion and conclusions (section 3). The study indicates that reusable PP containers leads to 93% lower GHG emissions in comparison with single use polystyrene container. The study compared one reusable PP container to 360 units of single-use polystyrene container. Different scenarios for reuse systems have been analysed in this study. Other aspects were also considered (costs, social etc.). It was shown that centralised and semi-centralised were the best in terms of environment but the worst in terms of other aspects.					
Reusable plastic crate or recyclable cardboard box (Koskela et al. 2014)	Only included in discussion and conclusions (section 3). Comparing two bread delivery systems the study indicates that recyclable cardboard box is a more environmentally friendly option than the reusable plastic crate system in all studied impact categories. The study concluded that assumptions regarding delivery system and transportation affect significantly the results.					
Single-use wooden boxes, plastic crates, cardboard boxes and reusable plastic crates (Accorsi et al. 2013)	Only included in discussion and conclusions (section 3). The study indicates that adoption the system for reusable plastic crades leads to lower environmental impact in terms of CO2eq emissions. Modelling of transportation and end-of-life scenarios affects significantly the results.					

*Abbreviations: PS= polystyrene, PLA= Polyactic acid, PET= Polyethylene terephthalate, TPS= Thermoplastic starch, APET= Amorphous polyethylene terephthalate; PE= Polyethylene, EPS= Expanded polystyrene, XPS= Extruded polystyrene, OPS= Oriented polystyrene, RPET= recycled PET
**Results for climate change are shown here including direct GHG and indirect LUC emissions. PLA scores better when idirect LUC emissions are not accounted for.
***The results are presented for baseline scenario. Alternative scenarios were tested in sensitivity analysis.

CRITICAL PARAMETERS INFLUENCING THE ENVIRONMENTAL IMPACT OF TAKE-AWAY FOOD PACKAGING:

- **Single or multi-use**. The analysed studies show that reusable plastic packaging has a better overall environmental performance compared to single-use plastic packaging, if used a sufficient number of times. Besides the number of reuses, also the delivery system set up and the use-phase transportation modes as well as transportation distances are important factors influencing whether, and to what extent, reusable packaging is environmentally preferable.
- **Functional differences,** such as food volume that can be held, transportability, capacity to handle warm and/or liquid food, prevention of food waste, assurance of food safety, etc., influence which packaging type can be used for which food item in which contexts. For example, paper and cardboard boxes without appropriate barrier coating can be less suitable for food with liquid sauces, a parameter that is unrelated to environmental impact. Another important parameter is the extent to which a certain packaging prevents food waste, as this may be a more decisive factor for its environmental performance, than what material it is made of or how it is disposed at end of life. This is because the food inside the packaging has most often higher environmental impact than the packaging itself. This cannot be concluded based on the above analysed studies, but has ample support in the literature.
- **Weight of packaging**. Generally, the lighter the packaging per unit of serving, the better its environmental performance (as long as it is functionally equivalent to a heavier alternative). For example, several studies show clear environmental benefits of lighter PS packaging compared to its alternatives, emphasizing its low weight as a main reason for its favourable environmental performance. Note also that in reusable packaging the unit weight of the packaging is divided by the number of reuses (units of serving).
- **Packaging material**. Comparing single-use take-away packaging of different materials, several studies indicate that packaging made of polystyrene (PS), XPS and paper have often a better environmental performance than packaging alternatives of other materials (i.e., single-use take-away food packaging made of PET, PLA, PP, aluminium). Also, compared to single-use take-away food packaging made of PET and PP, packaging made of PLA shows a lower environmental impact for most of the environmental impact categories. Moreover, one study indicates that a reusable polypropylene (PP) container has a lower environmental impact than a similar reusable container made of glass.
- **Production route and resources used**. Seemingly identical take-away food packaging may be made by different production routes and from different resources. These differences are important for the environmental impact of the packaging. For example, plastic packaging may be made from fossil or bio-based (corn, cassava starch, forest residues, etc.) resources, and from primary or secondary (i.e., recycled) resources. Also, the maturity of the production route influences its environmental impact – with less mature and small-scale production generally showing higher impact due to the non-existent economies of scale; this may be a disadvantage for some bio-based plastic packaging compared to more established fossil-based plastic packaging. However, production routes for bio-based plastics have a high evolution potential, which will positively influence their environmental impact in the future.

- **End-of-life treatment**. For example, whether single-use paper-based or other types of biodegradable packaging is recycled, incinerated or landfilled at end-of-life can influence the preferability of the packaging when compared to single-use plastic packaging. There are studies that indicate that paper-based and other types of biodegradable packaging biodegrade in landfills generating methane. This results in a higher global warming potential, especially in case of landfills with low methane capture efficiency. However, this might not be a problem for state-of-the-art landfills with high methane capture efficiency. Moreover, food leftovers in single-use plastic packaging might impede its recyclability, potentially making reusability or compostability environmentally preferable design options.

  None of the reviewed studies assessed the potential environmental impact of littering. However, it is an important issue for non-degradable packaging materials and should be considered in LCA studies and decision making.

- **Geographical context** is an important factor influencing several of the above aspects, for example, with regard to access to a low-carbon power generation and end-of-life processes, availability of various feedstock for producing bio-based plastics, and the feasibility of reuse, recycling or composting of certain packaging due to differences in consumer behaviour and availability of infrastructure. Thus, the environmentally preferred container in one country or region may not be the best container in another country or region.

RECOMMENDATIONS FOR POLICY MAKERS:

- An overarching conclusion spanning several of the points following this one, is that **policies must have a systems perspective**. This includes considering the entire life cycle of packaging, from production to end-of-life handling and considering direct, as well as indirect environmental impacts (e.g., through packaging's influence on food waste). Also, the fact that production systems in use, consumer behaviour, end-of-life infrastructure, policies already in place, and other environmentally decisive factors, vary with geography and over time must be accounted for.

  The need for a systems perspective means that one must decide which policy instruments are needed to influence each of the necessary elements in the system. For example, if one has identified reusable packaging as a suitable solution for take-away food in a certain city or country, one may ban single-use options, or charge them to disincentivise them. Yet one may also need to promote innovation for the preferred solutions and generate consumer awareness concerning reuse practices.

- **Policies must consider functional differences between packaging**. Firstly, policies should not only consider the environmental impact of the packaging itself (its production, possible chemical contamination of the food inside by packaging material during its use phase, its end-of-life stage, etc.) but also, for example, how well the packaging prevents food waste (directly due to its technical performance, but also indirectly through its influence on consumer behaviour). There is limited coverage of this in the 11 publications analysed in the present study, but other literature supports that this is decisive for the environmental consequences of food packaging. Secondly, policy makers must ensure that they interpret studies in a fair way with regards to functionality, and acknowledge that, for example, different materials may be preferable for different types of packaging and for different types of food.

- **Policies must consider differences in environmental impact between and within material categories**. For example, differences between single-use plastic packaging and single-use paper-based packaging should be considered, with the latter often found to be preferable, but a lack of recycling or composting infrastructure can change the conclusion. Similarly, policies should acknowledge that in producing single-use plastic packaging, there are different production routes and feedstocks – virgin or recycled, fossil or bio-based, different types of bio-based – resulting in considerably different environmental impact.

- **Policies must account for future changes of packaging solutions and surrounding systems**. Novel production technologies may, compared to established large-scale technologies, be environmentally inferior at their current scale, but have a great potential for improving their environmental performance. Moreover, recycling technologies for certain types of packaging are developing rapidly, which must be considered when interpreting assessments of their current feasibility and environmental performance. Similarly, power generation systems, transportation and recycling processes may change over time, influencing the relative environmental performance of different packaging options for take-away food.
- **The complete reuse system must be considered when adopting policies regarding reusable packaging**, including their transportation from the customer back to the retailer (modes and distances), washing technologies and practices, and other factors influencing the system's environmental performance. The system also needs to ensure that reusable packaging is indeed reused a sufficient number of times.
- **Policies must consider differences in end-of-life practices**. For instance, single-use paper-based packaging appears to have environmental benefits compared to single-use plastic packaging in countries where incineration with energy recovery is prevalent and recycling systems are available, whereas in countries with widespread use of landfilling it appears to be a less suitable alternative. Another example is the use of biodegradable packaging, which shows environmental benefits when industrial composting or anaerobic digestion is in place.
- **Policies must be geographically adapted**, as many of the above listed environmentally decisive aspects are geographically dependent, such as available feedstocks for bio-based packaging, the available power generation systems, consumer behaviour with regard to reuse and recycling, and available waste management systems and end-of-life processes.
- **Policies must recognise and manage trade-offs and risks of burden-shifting between environmental impacts**. For instance, one study shows that a single-use aluminium container is the worst among the studied option in terms of depletion of elements, ozone layer depletion, human toxicity, marine and terrestrial ecotoxicity, while a single-use PP container is the worst option in terms of abiotic depletion of fossil resources, acidification, eutrophication, freshwater aquatic ecotoxicity, climate change, photochemical ozone creation and primary energy demand.
- **Policies must be based on several sources for information on environmental impact**. LCA results, such as those available in the 11 studies analysed as part of this report, need to be considered together with other sources of relevant information on environmental aspects. Aspects seldom covered by LCAs are food safety (e.g., chemical leaching to food), possible health impacts of certain packaging materials, terrestrial and marine littering and the subsequence effects on ecosystems, and environmental impact associated with land use and land use change (including extraction of fossil and mineral resources through mining, as well as extraction of bio-based feedstock through agri and silviculture).

Apart from the above bullet points, the report sheds light on the benefits and challenges of LCA as a method to assess the environmental impact of take-away food packaging, and provides guidance that can improve the comprehensiveness, consistency and accuracy of future LCA studies. This meta-analysis cannot be used as the sole source for environmentally related advice on specific policy making, such as specific prohibition of specific containers, taxes and fees, or labelling. However the meta-analysis can give recommendations of aspects that policy making should consider. Policymakers should not pick and choose from these recommendations but take all the elements into account.

Abbreviations

TERM	DEFINITION
APET	Amorphous polyethylene terephthalate
EPS	Expanded polystyrene
EVA	Ethylene-Vinyl Acetate
EVOH	Ethylene vinyl alcohol copolymer
HDPE	High-density polyethylene
LCA	Life cycle assessment
LDPE	Low-density polyethylene
LUC	Land use change
MP	Moulded pulp
OPS	Oriented polystyrene
PA	Polyamide
PE	Polyethylene
PET	Polyethylene terephthalate
PLA	Polyactic acid
PP	Polypropylene
PS	Polystyrene (used to refer also to OPS and XPS)
TPS	Thermoplastic starch
XPS	Extruded polystyrene

01 Introduction

01 INTRODUCTION

1.1 BACKGROUND

Single use plastic products have become an important attribute of modern society. They include a "diverse range of commonly used fast-moving consumer products that are discarded after having been used once for the purpose for which they were provided, are rarely recycled, and are prone to becoming litter" (Directive (EU) 2019/904, 2009). Examples of these products include: food packaging, bottles, straws, containers, cups, cutlery and shopping bags (UNEP 2018a, 2018b). It has been estimated that about 100-150 million tonnes of plastics are produced for single use purposes and about 8 million tonnes of plastics are dumped into the oceans every year (Plastics Oceans 2019, UNEP 2018a).

There is an increasing trend of consuming food in disposable take-away food packages and one of the most critical environmental aspects related to this type of packaging is waste generation (Gallego-Schmid et al. 2019, Youhanan et al. 2019). This is mainly caused by poor consumer behaviour, poor waste management in certain countries (including waste handling, collection and treatment), as well as poor design and lack of clear instructions to the consumers about suitable ways of disposal leading to low recyclability potential of certain types of packaging (UNEP & Consumers International 2020, Gallego-Schmid et al. 2019).

There is a need to consider alternative solutions to single-use plastic take-away food packaging. Resolution 9 of the fourth edition of the United Nations Environment Assembly (UNEA4) in March 2019, on "Addressing single-use plastic products pollution" (UNEP/EA.4/R.9), "encourages member states to take actions, as appropriate, to promote the identification and development of environmentally friendly alternatives to single-use plastic products, taking into account the full life cycle implications of those alternatives" (UNEP 2019). UN Environment Programme was requested by UNEP/EA.4/R.9 to make available existing information on the full life cycle environmental impacts of plastic products compared to products of alternative materials.

Life cycle assessment (LCA) is the tool mainly used for comparing the environmental impact of products. LCA is a standardised method (ISO 2006a, 2006b) quantifying the potential environmental impacts during the whole life cycle of a product: from raw material extraction through production, use, and waste treatment to final disposal. LCA has certain challenges, such as consideration of the complexity of environmental issues and systems perspectives and the lack of standardised assessment methods for e.g. littering of marine and terrestrial ecosystems. Moreover, there is sometimes a lack of harmonisation between LCA studies, which sometimes leads to seemingly contradicting results. Due to these complexities, it is essential – with expert guidance on the interpretation of LCA studies – to understand the environmental impacts of single-use plastic products. There is a need to summarise what LCAs say about different alternatives and their environmental impact, and what this can say in terms of developing policies and improving LCAs (i.e., insights to LCA practitioners and those interpreting LCA results).

Guided by the UNEA4 resolution on "Addressing single-use plastic products pollution" (UNEP/EA.4/R.9), this study aims to provide an insight into how LCA can be used to make informed decisions on single-use plastic products and their alternatives. This study, a part of a series of reports on single use plastic products[1], addresses single-use plastic take-away food packaging and its alternatives.

Other products analysed to date are single-use plastic bags (UNEP 2020a) and single-use plastic bottles and their alternatives (UNEP 2020b).

1 *https://www.lifecycleinitiative.org/activities/key-programme-areas/technical-policy-advice/single-use-plastic-products-studies/*

1.2 PURPOSE, SCOPE AND METHOD

This report presents how LCA can inform decisions on single-use plastic packaging for take-away food and its alternatives, that could potentially replace it. Take-away food considered in this study is defined as type of food that is sold for immediate consumption after purchase and is consumed away from the food outlet (e.g., home, work, street) (Gallego-Schmid et al, 2019). Different types of food take-away packaging are used today, for example:

- food boxes,
- containers,
- clamshells,
- trays,
- crates and food savers.

Though packagings might be different in design, form and volume, their names are sometimes used interchangeably (for instance, containers and food savers). However all the alternatives considered in this study should provide the same function for storage and transportation of take-away food that is sold for immediate consumption after purchase and is consumed away from the food outlet.

The assessed packaging alternatives include mainly packaging made for single-use, with alternatives for re-use being considered as well. The materials used for the assessed packaging are different types of plastics (made of fossil and bio-based resources, virgin or recycled content) and other types of materials: aluminium, paper/cardboard/wood and glass (the latter only for reusable containers).

The report is based on a review and analysis (meta-analysis) of previously published LCA studies comparing different types of single-use plastic packaging for take-away food or comparing single-use plastic packaging and other packaging solutions for take-away food. Studies in line with the scope of the report were iteratively identified and selected by the authors together with UNEP and the Technical Advisory Committee (TAC). Studies were selected for the meta-analysis based on the following criteria:

- **Types of packaging:** Common types of packaging for take-away food were included, with a focus on packaging for solid food. Packaging made for the sole purpose of containing soups were thus excluded. Also, food packaging not made for transporting food were excluded, such as cups.
- **Publication date of the study:** Production technologies and processes evolve over time, including a potential change in their environmental impact. This factor was taken into account by considering studies published from the year 2009 and later.
- **Transparency:** Studies of sufficient transparency were selected. Transparency was here defined as the possibility to access the underlying data and the detailed methodology used in the analysis, as this is needed for interpreting the robustness of results.
- **Geographical coverage:** The selection of studies should have a global coverage, as the report is intended to be used globally. Not each study needs to have a global scope, but as a group they should have a broad geographical coverage, meaning that studies from different countries should be analysed.
- **Language:** The report mainly focused on studies published in English.
- **Peer reviewed:** Peer review ensures a certain extent of quality, as studies are scrutinised by fellow experts before being published. For this reason, peer-reviewed studies were given priority.

Compliance to international standards, such as ISO 14044:2006, was not used as a selection criterion as the project does not aim at assessing the compliance of studies but rather at explaining their results and extracting the knowledge that can be obtained from them.

Based on the above criteria, six studies were selected for the meta-analysis: three from Europe, two from North America and one from Asia. To enhance the coverage of the report, five additional studies were considered for further discussion and conclusions, though they were not included in the actual meta-analysis. These studies were excluded as they did not meet some selection criteria; e.g., they might not have been peer- reviewed or might not have covered packaging material primarily intended for take-away food packaging (such as crates for fruit and bread delivery). Three out of the five additional studies were conducted in Europe, one in North America and one in Australia.

TABLE 1 summarises the eleven selected publications, which covered food boxes, deli containers, salad containers, clamshells, wedges, pizza boxes, trays, and burger boxes. Note that these publications, as well as the present report, focus on packaging providing take-away food to the consumer, while the impact of food production is not considered.

Type of material	Plastic (single-use)	Aluminium (single-use)	Paper/ Wood (single-use)	Plastic (reusable)	Glass (reusable)	Geographic scope	Life Cycle stages	Functional unit
Publication								
Comparison between single-use plastic take-away food packaging								
Single use thermoform boxes made from PS*, PLA (corn) and PLA (cassava starch) (Suwanmanee et al. 2013)	□					Thailand	Cradle to consumer gate	10,000 units of 8.0×10.0×2.5 cm of PS, PLA, and PLSA/starch boxes. with the carrying capacity of 100 g.
PLA, PET and PS thermoformed clamshell containers, used for packaging of strawberries (Madival et al. 2009)	□					USA	Cradle-to-cradle	1000 containers of capacity 0.4536 kg (1 lb) each for the packaging of strawberries.
Four types of clam shells: multilayer film from PLA and TPS, PP, PET, and PLA (Benetto et al., 2015).	■					Italy	Cradle-to-grave	film is used to produce a 500 ml clam shell (including the cover).
LCA studies comparing single-use plastic take-away food packaging vs single-use packaging of other materials								
Laminated bio-based thermoformable paper food trays against existing plastic packaging solutions: APET/PE and EPS (Johansson et al. 2020)	□		□			Belgium	Cradle-to-grave	1000 trays of product successfully delivered to the final customer and disposed of after use.
Packaging used for fruit and vegetables: six different types of plastics (XPS, OPS, PET, RPET, PLA (corn), PP) and one type made of recycled moulded pulp (Belley 2011)	□		□			Canada	Cradle-to-grave	one tray (52 cubic inches).
Foam polystyrene, paper-based, and PLA foodservice products (Franklin Associates, 2011)	■		■			USA	Cradle-to-grave	10,000 items of sandwich-size clamshells.
LCA studies comparing single-use plastic take-away food packaging vs reusable packaging								
Takeaway food containers: single-use and reusable plastic containers and single-use aluminium (Gallego-Schmid et al. 2019)	□	□		□		Europe	Cradle-to-grave	container storing a meal for one person.
Reusable containers made of plastics and glass (Gallego-Schmid et al. 2018)				□	□	Europe	Cradle-to-grave	50 uses of plastic (polypropylene) and glass food savers over their lifetime.
Single-use and reusable food containers for takeaway food (Baumann et al. 2018)	■			■		Australia	Cradle-to-grave	360 uses of reusable food containers.
Reusable plastic crate or recyclable cardboard box (Koskela et al. 2014)			■	■		Finland	Cradle-to-grave	8 loaves of bread delivered in one crate/ box.
Single-use wooden boxes, plastic crates, cardboard boxes and reusable plastic crates (Accorsi et al. 2013)	■		■	■		Italy	Cradle-to-grave	transportation of 1200 t of fruits and vegetables.

□ Publications included in meta-analysis

■ Publications that are discussed but not included in meta-analysis

*Abbreviations: PS= polystyrene, PLA= Polyactic acid, PET= Polyethylene terephthalate, TPS= Thermoplastic starch, APET= Amorphous polyethylene terephthalate; EPS= Expanded polystyrene, XPS= extruded polystyrene, OPS= oriented polystyrene, RPET= recycled PET

1.3 THE BASICS OF LCA

LCA is the calculation and evaluation of the environmentally relevant inputs and outputs and the potential environmental impacts of the life cycle of a product, material or service (ISO, 2006a, 2006b). Environmental inputs and outputs refer to the demand for natural resources, to emissions and to solid waste. The life cycle consists of the technical system of processes and transports used for raw materials extraction, production, use and after use (waste management or recycling).

LCA is well adapted to quantify potential impacts of global or regional scale (e.g., climate, acidification, eutrophication and resource use) and represents a powerful tool for environmental comparison of different products, services or technological systems. In addition, LCA brings a holistic perspective into decision-making and has gained acceptance as a decision-making tool in industry, procurement and policy making.

An LCA is divided into four phases: goal and scope definition, inventory analysis, impact assessment, and interpretation.

Goal and scope definition

The first phase consists of defining the LCA's purpose, intended audience, application, scope and functional unit – the reference unit reflecting the function of the studied product, to which the calculated environmental impact is related. Also the impact categories to consider (e.g., climate change, acidification, eutrophication), key limitations and assumptions of the studies, allocation procedures and system boundaries are also defined and set in accordance with the purpose of the study.

Inventory analysis

The next phase of an LCA is the inventory analysis. It starts with the construction of the life cycle flow chart and the collection of data for all relevant inputs (energy and material) and outputs (emissions and wastes) along the life cycle. These data are then set in relation to the functional unit defined in the goal and scope definition.

Impact assessment

The third phase of an LCA is the impact assessment, which is divided into classification and characterisation. During the classification, the inventory results are assigned to their respective impact categories. This is followed by the two-step characterisation, i.e., the inventory results are first multiplied with the equivalence factors of the different impacts and then summed up into the various impacts.

An LCA is generally an iterative process and the impact assessment helps increase the knowledge regarding the environmental importance of inputs and outputs. This knowledge can then be used to collect better data and consequently, improve the inventory analysis.

Interpretation

In the final phase the results are analysed in relation to the goal and scope definition. Conclusions and recommendations with respect to the aim of the assessment are given and the limitations of the results are presented. The conclusions of the LCA should be compatible with the goals and quality of the study.

02 Meta-analysis of the LCA studies

This chapter presents the main findings and results of the six LCA studies covered by the meta-analysis. The studies are grouped in three clusters:

- LCA studies comparing different types of single-use plastic packaging (Section 2.1),
- LCA studies comparing single-use plastic packaging and single-use packaging of other materials (Section 2.2),
- LCA studies comparing single-use and reusable packaging (Section 2.3).

Apart from a short description and summary of the results, most information for each study is presented in tables, where the main methodological choices are described.

A standardised color-coding is used in the tables to visualise the comparative impact/performance of each packaging product analysed (Figure 1). These are indicative and to fully understand the results, the reader is recommended to read the original reference.

Figure 1. Color-coding for the impact indicators.

(green)	**Best**
(blue)	**In-between**
(orange)	**Worst**

It should be noted that each study has a different scope and level of detail. For example, results may be displayed in terms of absolute numbers, percentages or illustrated in figures. Thus, the descriptions of the studies vary: some descriptions contain more detailed information about the results (e.g., specific percentages), while others more general observations (e.g., ranking of compared alternatives).

02 META-ANALYSIS OF THE LCA STUDIES

2.1 LCA STUDIES COMPARING DIFFERENT TYPES OF SINGLE-USE PLASTIC PACKAGING

2.1.1 Food boxes made of three different materials: Polystyrene, PLA (corn), PLA (cassava starch) (Suwanmanee et al. 2013)

This study compares the environmental impact of bio-based and petroleum-based (i.e., fossil-based) plastics for single-use **boxes**, which can be used for serving pastry deserts (or similar) and are also called “tray with a lid” in the study. The three different packaging materials studied are:

- polystyrene (PS) from crude oil,
- polylactic acid (PLA) derived from corn, and
- polylactic acid (PLA) derived from cassava starch blend.

The study analyses different energy sources: Thai electricity grid mix (TEGM), Thai coal electricity (TCE), Thai natural gas combine cycle (TNGCC), and Thai coal integrated gasification combine cycle (TIGCC).

Life cycle stages from cradle to consumer gate were analysed, thus waste management stages were excluded from the study. This is the limitation of the study that should be taken into account when interpreting its results and conclusions.

Short summary of results and conclusions:

- When land use change (LUC) emissions are accounted for in PLA production, the PS boxes have lower environmental impact from cradle to consumer gate than PLA boxes regardless of the energy source used for their production.
- When LUC emissions are not considered, the environmental impact of PLA boxes produced with TIGCC as energy source are equal to the environmental impact of PS.
- Thai coal integrated gasification combine cycle (TIGCC) was found to be the most appropriate energy source for PLA box production.
- In case of PLA boxes (made from corn or cassava starch blend), LUC emissions of renewable feedstocks, such as corn and cassava, are the main contributors to the climate impact.

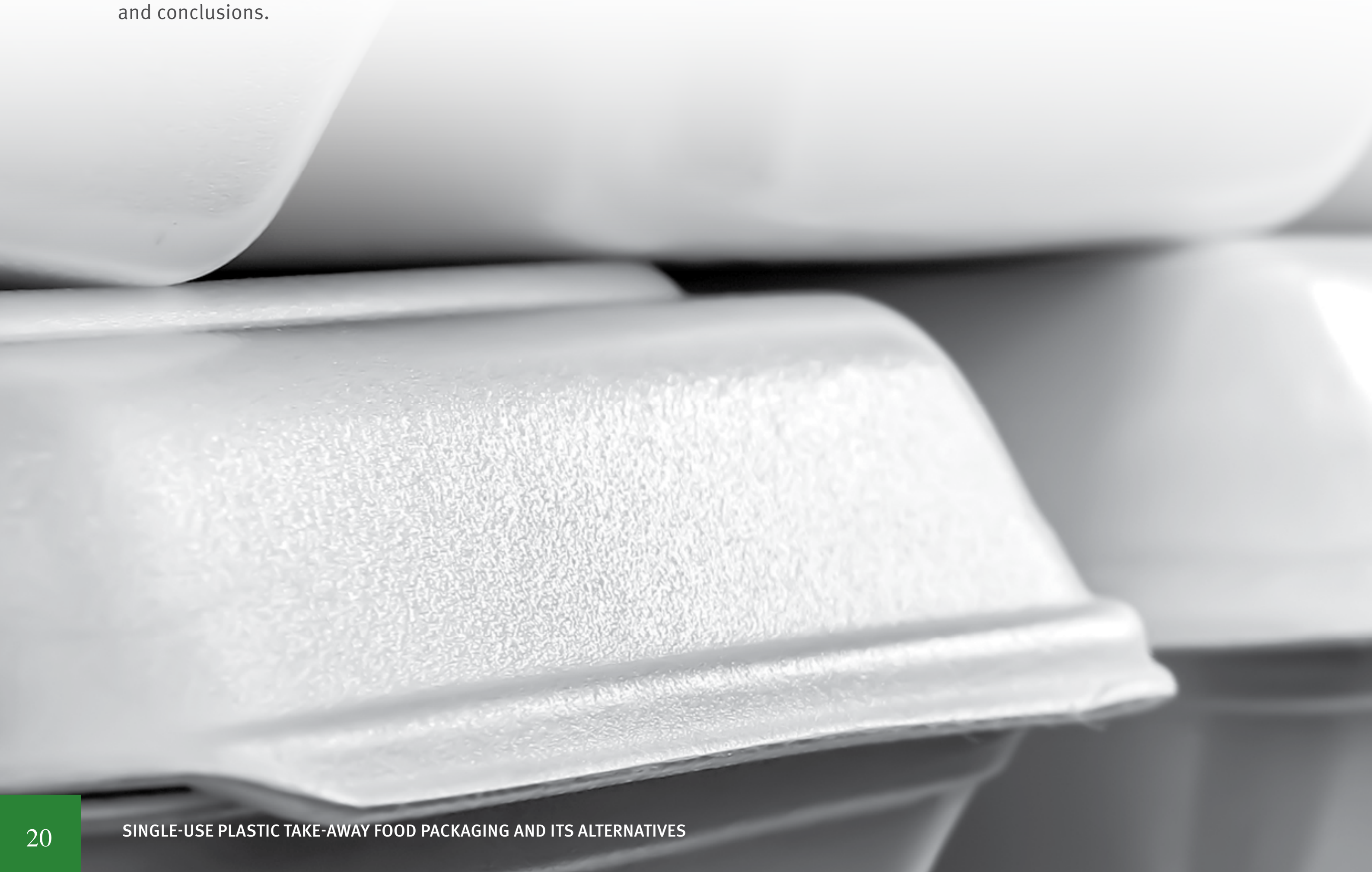

TABLE 2. Summary table for products considered in the study: food boxes made of Polystyrene, PLA (corn), PLA (cassava starch) (Suwanmanee et al. 2013).

		PRODUCTS CONSIDERED IN STUDY		
		Polystyrene	PLA (corn)	PLA (cassava starch blend)
STUDY SCOPE	Material	Polystyrene derived from petroleum	Polyactic acid (PLA) derived from corn	Polyactic acid (PLA) derived from cassava starch blend
	Functional unit	10,000 units of 8.0×10.0×2.5 cm of PS, PLA, and PLSA/starch boxes. It has been assumed that all boxes have the carriing capacity of 100 g		
	Capacity (ml)	200	200	200
	Number of uses	1		
	Weight per container (g)	45	60	55
	Geographic region	Thailand		
	Life cycle stages	Production, use stage (cradle to consumer gate)		
	End of life assumptions	Not included		
INDICATORS	GWP, including direct GHG and indirect LUC emissions			
	Acidification			
	Photochemical ozone formation			
Other comments		Different energy scenarios were assumed for production of boxes: Thai electricity grid mix, Thai coal electricity, Thai natural gas combine cycle and Thai integrated gasification combine cycle.		
		Polystyrene has lower GWP (when LUC emissions are accounted for PLA boxes) regardless the energy scenario assumed. LUC emissions from corn and cassava are the main contributors to GWP of PLA.		
		PLA and PLA (starch) boxes are more environmentally friendly when LUC emissions are not accounted for and Thai integrated gasification combine cycle is used as energy source.		

2.1.2 Containers used for packaging strawberries: PLA, PET, PS (Madival et al. 2009)

This study compares the environmental impact of **clamshell containers** made of three different materials and used for packaging of strawberries,[2] with emphasis on different end-of-life scenarios. These materials are:

- polylactic acid (PLA) from corn-based starch,
- polyethylene terephthalate (PET) from crude oil, and
- polystyrene (PS) thermoformed from crude oil.

Short summary of results and conclusions:

- PET clamshells rank worst in most of the impact categories – except aquatic acidification and respiratory organics and inorganics; mainly due to their higher weight.
- The transportation stage of the packaging (i.e., transportation from resin supplier to container manufacturer and transportation of containers from strawberry filler to distributors) is an important contributor to the environmental impact of the packaging systems during the life cycle of the three types of the studied clamshell containers. Thus, the results are sensitive to the assumptions regarding distance and type of transportation system used to distribute the packaging systems.

2 *Although this study is on a packaging product not primarily used for take-away food, it might be assumed that similar materials and packaging types are used for take-away food and thus it was deemed relevant to include in the meta-analysis.*

TABLE 3. Summary table for products considered in the study: clamshells containers used for packaging strawberries: PLA, PET, PS (Madival et al. 2009)

		PRODUCTS CONSIDERED IN STUDY		
		PLA	PET	PS
STUDY SCOPE	Material	polyactic acid (PLA) from corn-based starch	polyethylene terephthalate (PET) from crude oil	Polystyrene (PS) from crude oil
	Functional unit	1000 containers of capacity 0.4536 kg (1 lb) each for the packaging of strawberries.		
	Capacity (kg)	0.4536	0.4536	0.4536
	Number of uses	1	1	1
	Weight per container (g)	29.6	N/A	24.2
	Geographic region	Europe, North America and the Middle East.		
	Life cycle stages	cradle-to-cradle		
	End of life assumptions	Current– 23.5% incineration and 76.5% landfill (which was assumed to be the same of all the studied types of packaging). Other scenarios were tested in sensitivity analysis: • Scenario I – 40% recycling/30% incineration/30% landfill; • Scenario II – 100% landfill; • Scenario III – 100% recycling; • Scenario IV – 50% incineration/50% landfill		
INDICATORS	Climate change			
	Aquatic acidification			
	Ozone layer depletion			
	Aquatic eutrophication			
	Respiratory organics			
	Respiratory inorganics			
	Auatic ecotoxicity, water			
	Energy			
	Land occupation			
Other comments		Weight for PLA and PS containers are based on real values, but not for PET (where the weight was calculated based on the formula). The weight for PET clamshells is heavier than for PLA and PS.		
		The study showed that transportation stage is the major contributor to most of the impact categories.		
		The results are sensitive to the distances assumed.		
		No data for landfilling, incineration or recycling was available for PLA. Data for mixed plastics were used. It was considered that PLA, PET and PS do not degrade in landfill. Authors assume that specific data on recycling and composting of PLA could change the results.		

2.2 LCA STUDIES COMPARING SINGLE-USE PLASTIC PACKAGING AND SINGLE-USE PACKAGING OF OTHER MATERIALS

2.2.1 Food trays made of three different materials: FibreForm®, APET/PE, EPS (Johansson et al. 2019)

This study compares the environmental impact of three types of single-use sealed **shallow food trays** that can, for example, be used for cold meats, and have multilayer lidding films, made of different materials:

- Two layers of a novel bio-based thermoformable bio-based paper (FibreForm®) laminated with multilayer films of PE (polyethylene), PA (polyamide), EVOH (ethylene vinyl alcohol copolymer) and adhesives.
- Multilayer substrate of APET (amorphous polyethylene terephthalate), PE, EVOH (ethylene vinyl alcohol copolymer), polybutelene and adhesives.
- Expanded PS (EPS).

In addition to the tray, the compared options have a lid made of PET, PE, EVOH and adhesives, and for the FibreForm® tray also PA and polybutylene. Differences in lidding materials are to achieve the necessary ceiling and physical properties.

The FibreForm® tray (without lid) is 85% bio-based, and the full product (with lid) is 71% bio-based. The materials of the other trays are primarily of fossil origin.

Summary of results and conclusions:

- The FibreForm® tray has lower environmental impact than the other trays in all evaluated impact categories, in the baseline scenario and in all except one of the alternative scenarios tested in a sensitivity analysis (the scenarios are outlined in Table 4, where results are given for the baseline scenario). Only in comparison with a lighter EPS tray the FibreForm® tray does not outperform the alternative – in this scenario the eutrophication impact of the FibreForm® and EPS trays are similar.
- The lower environmental impact of the FibreForm® tray is mainly because the considerably lower impact of the production of the FibreForm® material compared to the production of the polymer layers of the other trays. For the impact category of climate change, also lower greenhouse gas emissions at end-of-life for the FibreForm® tray makes a noticeable difference.
- The environmental impact of production of lid material is higher for the FibreForm® tray than for the other trays – but this does not offset the other lower impact in other life-cycle processes.

TABLE 4. Summary table for products considered in the study: bio-based thermoformable bio-based paper (FibreForm®) laminated food trays against existing plastic packaging solutions (Johansson et al. 2020)

		PRODUCTS CONSIDERED IN STUDY		
		Shallow tray will multilayer lidding film		
STUDY SCOPE	Material (tray)	FibreForm® (bio-based thermoformable paper) + multilayer films of PE, PA, EVOH, adhesives	APET, PE, EVOH, polybutelene, EVA and adhesives	EPS (expanded PS)
	Material (lid)	PET, PE, PA, EVOH, polybutylene, adhesives	PET, PE, EVOH, adhesives	PET, PE, EVOH, adhesives
	Functional unit	1000 trays of product successfully delivered to the final customer and disposed of after use		
	Size	120 mm X 180 mm with a depth of ~15 mm		
	Number of uses	1		
	Weight per product (g)	9.1 g (7.6 g tray, 1.5 g lid)	10.1 g (8.7 g tray, 1.4 g lid)	6.4 g (5 g tray, 1.4 g lid) (3 g tray assessed in sensitivity analysis)
	Geographic region	Belgium		
	Life cycle stages	Cradle-to-grave (but excluding, e.g., transportation to retailers and consumers)		
	End of life assumptions (tray)	89.4% recycling, 10.6% energy recovery	99% energy recovery, 1% landfill	99% energy recovery, 1% landfill
	End of life assumptions (lid)	99% energy recovery, 1% landfill		
IMPACT INDICATORS	Climate change			
	Acidification			
	Eutrophication			
	Photochemical ozone creation			
Other comments		Above geographic region concerns where the trays were assumed to be filled, consumed and desposed of at end-of-life. Parts of production were assumed to take place in other countries, namely Germany and Sweden.		
		Choices of allocation methods were not consistently made. For allocation at end-of-life, the cut-off method was used for recycling (i.e., no credit is given for substituting material production) and system expansion with substitution was used for energy recovery (i.e., a credit is given for substituting energy production).		
		The above presented results are based on the baseline scenario. Alternative scenarios were tested in a sensitivity analysis, with regard to material specifications, weight of the EPS tray, end-of-life assumptions (e.g., no recycling of the FibreForm® tray), databases assumed, and climate impact characterisation (above results include uptake and emissions of biogenic CO2).		

2.2.2 Packaging used for fruit and vegetables: six different types of plastics and one type made of recycled molded pulp (Belley 2011)

This study compares the environmental profiles of **trays used for fruits and vegetables**[3] transportation made of seven different types of materials, of which one is made of recycled molded pulp:

- 100% virgin extruded polystyrene foam (XPS),
- 90% virgin 10% recycled[4] oriented polystyrene (OPS),
- 90% virgin and 10% recycled polyethylene terephthalate (PET),
- 100% recycled PET,
- 90% virgin and 10% recycled polylactic acid (PLA),
- 90% virgin and 10% recycled polypropylene (PP),
- 100% recycled molded pulp (MP).

Short summary of results and conclusions:

- Trays made of PLA show the worst environmental performance, while trays made of XPS and MP the best.
- Production processes (raw materials and energy consumption during manufacturing) are the main contributors to the environmental footprint of the trays throughout their entire life cycles.
- The main advantage of XPS in terms of lower environmental impact is its low mass.
- Sensitivity analysis shows that the results are very sensitive to the type of electricity mix used in manufacturing of the trays, showing the environmental advantages of manufacturing the trays in Quebec, Canada, with 95% hydroelectricity (rather than using the North American electricity grid mix, which is powered 45% by coal, 19% by nuclear and 17% by natural gas).

3 *Although this study is on a packaging product not primarily used for take-away food, it might be assumed that similar materials and packaging types are used for take-away food and thus it was deemed relevant to include in the meta-analysis.*

4 *Modelling of the recycled plastic (OPS, PET, PLA, PP) manufacturing considers only the electric energy estimated to manufacture new granules, since no other information on this process was available.*

TABLE 5. Summary table for products considered in the study: single-use food trays used for fruit and vegetables: six different types of plastics and one type made of recycled molded pulp (Belley 2011)

		PRODUCTS CONSIDERED IN STUDY Single-use food trays for fruit and vegetables						
STUDY SCOPE	Material	100% virgin extruded polystyrene foam XPS	90% virgin 10% recycled oriented polystyrene (OPS)	90% virgin and 10% recycled PET	100% recycled PET	90% virgin and 10% recycled PLA	90% virgin and 10% recycled PP	100% recycled moulded pulp (MP)
	Functional unit	contain and permit the stacking and retailing of an amount of fruits or vegetables that can be contained in a tray volume of 52 cubic inches to consumers in Quebec in 2010						
	Size	8.38 in. long X 5.88 in. wide X 1.06 in. high						
	Number of uses	1						
	Weight per product (g)	10.45 g	20.85	27.15	27.15	25.2	19.8	20
	Geographic region	Canada						
	Life cycle stages	cradle-to-grave						
	End of life assumptions (tray)	100% landfill	15% recycling, 85% landfill	38% recycling, 62% landfill	38% recycling, 62% landfill	100% landfill	17% recycling, 83% landfill	41% recycling, 59% landfill
IMPACT INDICATORS	Potential human health damages							
	Ecosystem quality							
	Climate change							
	Resource use							
	Aquatic acidification							
	Aquatic eutrophication							
Other comments		The results are obtained using Impact2002+ method. Two impact categories (aquatic acidification and eutrophication) and four damage categories were calculated: Human health (representing combination of several impact categories, such as Human toxicity, Respiratory effects, Ionizing radiations, ozone layer depletion); Ecosystem quality (representing Aquatic ecotoxicity. Land ecotoxicity, soil acidification. land occupation), Climate change (representing Global warming); Resource use (representing Non-renewable primary energy, Ore mining).						
		Global warming indicator results are calculated considering 500 years time horizon (unlike 100 years that is used in most of the studies.)						
		The study performed sensitivity analysis on the main parameters (tray weight, PET recycling, allocation approach, electricity grid mix, impact method, tray distribution to retailers) and concluded the the results are very sensitivity to electricity mix used to form the tray.						

2.3 LCA STUDIES COMPARING SINGLE-USE AND REUSABLE TAKE-AWAY FOOD PACKAGING

2.3.1 Take-away food packaging: single-use plastic, reusable plastic and single-use aluminium (Gallego-Schmid et al. 2019)

This study performs comparative LCA for four types of food take-away **containers used for storing a meal** for one person:

- Aluminium take-away container
- Extruded polystyrene (XPS) container
- Single-use polypropylene (PP) container
- Polypropylene reusable food saver (Tupperware)

Different scenarios for end-of-life treatment were tested.

Short summary of results and conclusions:

- The best option among the three single-use take-away food packaging is the XPS container with the lowest impacts across the 12 studied impact categories.
- Reusable PP Tupperware food savers need to be reused from 16 to 208 times (depending on the impact category) to have an equal impact as the XPS container.
- The use of aluminium containers leads to the highest depletion of elements, ozone layer impacts as well as human toxicity, marine and terrestrial ecotoxicity potentials.
- Single-use PP container is the worst alternative for the other seven impact categories considered: abiotic depletion of fossil resources, acidification, eutrophication, freshwater aquatic ecotoxicity, climate change, photochemical ozone creation and primary energy demand.
- The study also discusses that XPS containers cause other environmental impacts (including littering and negative effects on marine organisms), which usually is not included in LCA. Due to their lightness, XPS containers can easily be blown away contributing to litter. However these impacts could be decreased by development of XPS recycling system which is technically possible but is associated with high costs and, consequently, its development is not proiritised.

TABLE 6. Summary table for products considered in the study: takeaway food containers: plastic (single-use and reusable) and single-use aluminium (Gallego-Schmid et al. 2019)

		PRODUCTS CONSIDERED IN STUDY			
		Aluminium takeaway container	Extruded polystyrene takeaway container	Polypropylene takeaway container	Polypropylene food saver- reusable (tupperware)
STUDY SCOPE	Material	**Aluminium, paper, polyethylene (lid),** Packaging: cardboard, polyethylene	**Polystyrene,** Packaging: cardboard, polyethylene (for all types of containers)	**Polypropylene,** Packaging: cardboard, polyethylene (for all types of containers)	**Polypropylene, silicone,** Packaging: cardboard, polyethylene (for all types of containers)
	Functional unit	production, use and disposal of a container storing a meal for one person			
	Capacity (ml)	670	670	670	670
	Number of uses	1	1	1	"transition point" (different numbers of uses were tested)
	Weight per product (g)	14.5	7.8	31.5	141.3
	Geographic region	Europe			
	Life cycle stages	Cradle to grave			
	End of life assumptions	Aluminium (54% recycled and 46% landfilled); XPS (50% landfilling and 50%incineration with energy recovery); paper lids in the aluminium container (54% is incinerated and 46% landfilled), the cardboard packaging of the containers (85% recycling, 8% incineration with energy recovery and 7% landfilling), the silicone (in Tupperware) and polyethylene (in packaging) (100% landfilling).			
INDICATORS	Abiotic depletion potential of elements				208 times*
	Abiotic depletion potential of fossil resources				18 times
	Acidification potential				29 times
	Eutrophication potential				18 times
	Freshwater aquatic ecotoxicity potential				39 times
	Global warming potential				18 times
	Human toxicity potential				37 times
	Marine aquatic ecotoxicity potential				24 times
	Ozone layer depletion potential				27 times
	Photochemical ozone creation potential				16 times
	Terrestrial ecotoxicity potential				
	Primary energy demand				19 times
Other comments		The system has been credited only for the percentage of recycled material that exceeds the recycled content in the original raw materials.			
		Credits during end-of-life are shown separately.			
		Different scenarios have been tested for EOL.			
		Number of times that the PP food saver (Tupperware) should be reused to have lower impacts than XPS varies from 16 times (for Photochemical ozone creation potential) to 208 times (Abiotic Depletion Potential of elements).			
		Takeaway polypropylene containers should be reused 3 to 39 times to have lower impacts than XPS.			

* This column shows how many times the reusable foodsaver should be used to equal the impacts of extruded polysterene take away container

2.3.2 Reusable containers made of plastics and glass (Gallego-Schmidt et al. 2018)

The study compares two types of **reusable food savers (made of plastic and glass)**, focusing on European conditions, and evaluates different options for improvement.

Short summary of results and conclusions:

- Glass food savers have 12%-64% higher impacts than the plastic reusable alternative and requires up to 3.5 times greater lifespan to match the environmental footprint of reusable plastic containers.
- The use stage of the reusable containers (washing them after each use) – whether it is plastic or glass – is the main contributor to their environmental impact (>40%).
- The greatest potential for reducing the environmental impacts of reusable containers is improved technology for washing the containers to reduce the amount of water, energy and detergents used.

TABLE 7. Summary table for products considered in the study: takeaway food containers: reusable containers made of plastics and glass (Gallego-Schmid et al. 2018)

		PRODUCTS CONSIDERED IN STUDY	
		Glass food saver-reusable	Polypropylene food saver-reusable (tupperware)
STUDY SCOPE	Material	Glass, polypropylene, silicone	Polypropylene, silicone
	Functional unit	50 uses of plastic (polypropylene) and glass food savers over their lifetime	
	Capacity (ml)	1100	1100
	Number of uses	50	50
	Weight per container (g)	672	182
	Geographic region	Europe	
	Life cycle stages	Cradle to grave	
	End of life assumptions	Glass waste: 73%recycled and 27% landfilled, Silicone- 100% landfill	PP waste: 11% recycling, 44% incineration with energy recovery and 45% landfilling Silicone- 100% landfill
INDICATORS	Abiotic depletion potential of elements		
	Abiotic depletion potential of fossil resources		
	Acidification potential		
	Eutrophication potential		
	Freshwater aquatic ecotoxicity potential		
	Global warming potential		
	Human toxicity potential		
	marine aquatic ecotoxicity potential		
	Ozone layer depletion potential		
	Photochemical oxidants creation potential		
	Terrestrial ecotoxicity potential		
	Primary energy demand		
Other comments		Glass food savers have 12%-64% higher impacts than the plastic and should be used up to 3.5 more to match the environmental footprint of plastic containers.	
		The use stage is the main contributor to the impacts related to the washing of two types of containers.	

03 Conclusions

03 CONCLUSIONS

The below sections are tailored for different audiences. Section 3.1, intended for all readers, presents a summary of the knowledge on the environmental impact of single-use plastic food packaging and alternative packaging solutions for take-away food. Section 3.2 lists key recommendations to be considered in policy responses to take-away food packaging. Section 3.3 summarises main recommendations for LCA practitioners interested in advancing the knowledge of environmental impacts of take-away food packaging.

3.1 ENVIRONMENTAL IMPACTS OF TAKE-AWAY FOOD PACKAGING

General observations regarding the environmental impacts of single-use plastic packaging and other packaging solutions for take-away food are provided in this section, based on the six studies analysed in Chapter 2 and the five additional studies listed in Table 1. Further details of the three types of comparisons are then presented in three consecutive subsections.

General conclusions:

- The analysed studies show that reusable plastic take-away food packaging has a better overall environmental performance than single-use packaging, if reused a sufficient number of times (Gallego-Schmidt et al. 2019). However, the set up of the delivery system, as well as the mode of transport and transportation distance during the use phase, are important factors influencing this finding.
- Comparing single-use plastic take-away food packaging and its single-use alternatives, a general trend is that single-use plastic take-away food packaging made of PS/XPS and paper-based packaging has a better environmental performance than other alternatives. In other words, the environmental impact of packaging for take-away food seems to be strongly linked to the main material of the packaging – further examples are given below (sections 3.1.1- 3.1.3). However, there are also other highly decisive factors for the environmental impact of the packaging. The material shall therefore not be used as the only factor for selecting or promoting a certain packaging solutions, and the environmental impact of packaging for take-away food should be assessed on a case-by-case basis.
- Geographical context is an important factor influencing the environmental impact of packaging for take-away food. For example, geography influences access to a low-carbon power generation and end-of-life processes, availability of various feedstock for producing bio-based plastics, and the feasibility of reuse and recycling of certain packaging due to differences in consumer behaviour and availability of infrastructure.
- It must be emphasised that the food inside the packaging has, in most cases, a higher environmental impact than the packaging itself. This cannot be concluded based on the studies analysed in the present report, as they explicitly or implicitly assume that the compared packaging alternatives have the same performance in terms of protecting the food and preventing food waste. Nevertheless, there is ample support in literature showing that the production of food has a much higher environmental impact than the food packaging (see, e.g., Notarnicola et al. 2017, Butler 2012, Verghese et al. 2012). This means that the technical performance of a certain type of packaging, and the extent to which it prevents food spoilage (i.e., preventing the generation of food waste), is a very important aspect for determining a packaging's environmental impact.
- Two additional aspects not covered by the analysed studies, which however, can be potentially important for the environmental impact of various types of take-away packaging, are: (1) the extent to which packaging recycling is compromised by food waste found in/on the packaging and (2) whether contamination with food waste makes compostability or reusability preferable design strategies. Fieschi and Pretato (2017) also

emphasise that biodegradable packaging can provide climate benefits since biodegradable materials can be collected together with food waste and sent directly to industrial composting. This conclusion is also supported by Dilkes-Hoffman et al. (2018). Related to this, Dilkes-Hoffman et al. (2018) also conclude that food packaging design needs to focus on the reduction of food waste, even if a biodegradable material is used.

3.1.1 Comparisons of different types of single-use plastic packaging.

- Comparing different types of single-use plastic packaging used for take-away food, XPS take-away food packaging shows a lower environmental impact. The low weight of XPS packaging is one of the reasons for this (Belley 2011). However, several challenges have been observed for the waste management of XPS packaging. For instance, current recycling technology for XPS packaging is associated with high costs and is, for the time being, not very common. As a result, this type of packaging is mostly landfilled or incinerated (Gallego-Schmid et al. 2019, Belley 2011). Lightness of material can also be associated to higher chances of the product being blown by wind and ending up as litter.

- Compared to PET take-away food packaging, PLA packaging shows a lower environmental impact for most of the studied environmental impact categories, except for acidification (as in the study by Madival et al. 2009 on clamshell containers) and eutrophication (as in the study by Belley (2011) on food trays). Madival et al. (2009) conclude that inventory data specific to waste management of PLA would change the impact results for PLA packaging and its potential ranking for certain impacts, where composting could be a preferable solution for PLA. However, there is a lack of commercially available technology for recycling or composting of PLA (Madival et al. 2009). The major challenge is that PLA is difficult to distinguish from PET in sorting facilities using conventional techniques (Benetto et al. 2015, Belley 2011). As a result, PLA packaging is likely to end up in landfills or being incinerated without the important benefits of recycling or composting (Benetto et al. 2015, Madival et al. 2009).

- Suwanmanee et al. (2013) show that the environmental impact of different types of single-use take-away food packaging made of bio-based plastics differ considerably, depending on the feedstock used (cassava starch or corn). This is consistent with a meta-analysis of plastic beverage bottles and their alternatives, which revealed considerable differences in the environmental impact of different types of bio-based plastics, due to different feedstocks, but also due to different production routes (and, e.g., their maturity) (UNEP 2020).

3.1.2 Comparisons of single-use plastic and non-plastic packaging

- Johansson et al. (2019), in a study assessing trays, indicate considerable benefits for paper single-use food packaging compared to fossil-based alternatives for several impact categories: climate change, acidification, eutrophication, and photochemical ozone creation. These benefits are robust in terms of various uncertainties of product system parameters (e.g., whether the paper alternative is recycled or not) and modelling choices.

- Comparing paper-based packaging with PS and PLA packaging, Franklin Associates (2011) conclude that paper-based packaging shows the lowest climate impact, assuming no decomposition of the paper-based packaging at a landfill.[5] However, if emissions due to paper decomposition at landfill are included, paper-based packaging shows a slightly higher impact than PS (though still lower than PLA packaging).

- Single-use take-away food packaging made from aluminum is covered in only one of the analysed studies (Gallego-Schmid et al. 2019). This study shows that, in comparison with single-use XPS packaging, aluminium packaging has a worse environmental performance for all studied environmental impact categories. The results also show that, in a comparison of single-use take-away food packaging made from aluminium, XPS and PP, aluminium packaging is the worst alternative in terms of five environmental impact categories: abiotic depletion potential of elements, human toxicity potential, marine aquatic ecotoxicity potential, ozone layer depletion potential and terrestrial ecotoxicity potential. However, Gallego-Schmid et al. (2019) point out that the higher recycling rate of aluminium might change these conclusions.

5 *The authors show that there are large uncertainties regarding data on landfill decomposition of paper-based packaging (since no landfill simulation studies have been performed). The coating on paper-based packaging might inhibit or prevent decomposition rate. Thus, the study assumed two scenarios: no decomposition and maximum decomposition rate (Franklin Associates, 2011).*

3.1.3 Comparisons of single-use and reusable packaging

- The analysed studies show that reusable take-away food packaging, if reused enough times, has a better overall environmental performance than single-use packaging. For instance, Gallego-Schmid et al. (2019) conclude that reusable PP take-away containers when reused more than 18 times have better environmental performance in terms of climate change than single-use extruded polysterene take away containers.
- The earlier study of the same authors (Gallego-Schmid et al. 2018) shows that a reusable PP take-away container has a better environmental performance than the same container made of glass.
- The studies by Baumann et al. (2018) and Accorsi et al. (2013) show similar conclusions in terms of comparing reusable and single-use packaging, where reusable plastic packaging shows a better environmental performance than single use PS containers (Baumann et al. 2018) or single-use wood, plastic and cardboard boxes (when different types of packaging is compared for fruit and vegetable transportation in Accorsi et al. (2013)). On the other hand, comparing packaging used for bread delivery systems, Koskela et al. (2014) conclude that single-use recyclable cardboard boxes are more environmentally friendly than reusable plastic crates. Koskela et al. (2014) emphasise the importance of a well established delivery system and of efficient ways of transportation on the environmental performance of delivery systems.

3.2 Important aspects in policy making

This meta-analysis cannot be used as the sole source for environmentally related advice on specific policy making, such as prohibition of specific packaging materials, taxes or fees, or labelling. But the meta-analysis can give recommendations on aspects that policy making should consider. In other words, it can be used as a starting point of, and complementing, studies designed to assess specific policies. Below is a non-exhaustive list of such aspects, to some extent mirroring the aspects listed in Section 3.3 for consideration in LCAs.

- An overall theme of the subsequent bullet points is the **need for policies to have a systems perspective**, in terms of considering the entire life cycle of packaging, from production to end-of-life handling; including its direct and indirect environmental impact (e.g., through its influence on food waste). Additionally, factors such as production systems in use, consumer behaviour, end-of-life infrastructure, policies already in place, and other environmentally decisive factors vary with geography and over time, and must therefore be accounted for.

  The need for a systems perspective means that one must decide which policy instruments are needed to influence each of the necessary elements in the system. For example, to move to a reusability scheme identified as a positive solution in a certain country, one may ban single-use options, or charge them to disincentivise them. But one may also need to promote innovation for the preferred solutions and generate consumer awareness concerning reuse practices – to name a few examples. Similarly, if biodegradable options are identified as preferable in a certain context, adequate waste collection and treatment (composting) must be delivered at the necessary scale, with the adequate policies in place to ensure their successful functioning. Thus investments in waste infrastructure and education can play a significant role in managing waste in an environmentally sound manner. Policy makers should consider how to improve the existing infrastructure instead of taking it as a given and focusing only on regulating products.
- **Policies must consider functional differences between take-away food packaging**. Firstly, policies should not just consider the environmental impact of the packaging itself (its production, possible chemical contamination in its use phase, its end-of-life stage, etc.) but also, for example, how well the packaging prevents food waste (directly due to its technical performance, but also indirectly through its influence on consumer behaviour). There is limited coverage on this in the 11 publications analysed in the present study, but there is other literature indicating that this is decisive for the environmental consequences of food packaging (Dilkes-Hoffmann et al. 2018, Molina-Besch et al. 2018). Secondly, policy makers must ensure that they interpret studies in a fair way with regards to functionality, and acknowledge that, for

example, different materials may be suitable for different types of packaging and for different types of food.

- **Policies must consider differences in environmental impact between and within material categories**. For example, differences between single-use plastic packaging and single-use paper-based packaging should be considered, with the later often found to be preferable (Johansson et al. 2019, Franklin Associates 2011) but a lack of recycling or composting infrastructure can change the conclusion (Frankling Associates 2011). Similarly, policies should acknowledge that in producing single-use plastic packaging, there are different production routes and feedstocks – virgin or recycled, fossil or bio-based, different types of bio-based – resulting in considerably different environmental impact (Gallego-Schmid et al. 2019, Johansson et al. 2019, Suwanmanee et al. 2013, Belley 2011, Madival et al. 2009).

- **Policies must account for future changes of packaging solutions and surrounding systems**. Novel production technologies may, compared to established large-scale technologies, appear as environmentally inferior at their current scale, but have a great potential for improving their environmental performance. Moreover, recycling technologies for certain types of packaging (PLA and XPS, for instance) are developing very fast (Benetto et al. 2015, Belley 2011), which must be considered when interpreting assessments of their current feasibility and environmental performance. Similarly, power generation systems, transportation and recycling processes may change over time, influencing the relative environmental performance of different packaging solutions for take-away food.

- **Reuse systems must be considered when adopting policies regarding reusable containers**, including their transportation from the customer back to the retailer (modes and distances), washing technologies and practices, etc. (Baumann et al. 2018, Gallego-Schmid et al. 2018, Belley 2011). More specifically, Gallego-Schmid et al. (2018) suggest policy makers to develop strategies for raising awareness for resource efficient dish-washing. There may also be legal challenges for reusable containers, for instance, concerning the legal responsibility in case of food poisoning due to insufficient cleaning (Gallego-Schmid et al., 2019). It shall be acknowledged that single-use packaging may also be associated with similar legal concerns (although not mentioned in any of the analysed studies). Thus, when comparing reusable containers, it is important to analyse the whole reuse system and not just compare the containers and their types of materials, as also discussed in Belley (2011) and Koskela et al. (2014).

- **Policies must consider differences in end-of-life practices**. It is important that policy and decision-making is based on full cradle-to-grave assessments and each material is assessed considering the most feasible end-of-life option. For instance, single-use paper-based packaging appears to have environmental benefits compared to single-use plastic packaging in countries where incineration with energy recovery is prevalent and recycling systems are available (Johansson et al. 2019, Franklin Associates 2011), whereas in countries with widespread use of landfilling it appears to be a less suitable alternative (Franklin Associates 2011). Another example is the use of biodegradable packaging, which shows environmental benefits when industrial composting or anaerobic digestion is chosen as end-of-life option (Dilkes-Hoffmann et al. 2018, Fieschi and Pretato 2017).

  Aluminium recycling rate has been also identified as an important factor to consider for packaging made of aluminium. As identified by Gallego-Schmid et al. (2019), increasing the current EU aluminium recycling rate from 54% to 75%, as per the EU 2025 proposal, would reduce GWP from production of aluminium containers by 23% compared to the current situation.

- **Policies must be geographically adapted**. Many of the above listed environmentally decisive aspects are geographically dependent, such as available feedstocks for bio-based packaging, available power generation technology, consumer behaviour with regard to reuse and recycling, and available waste management systems and end-of-life practices (as shown in the bullet point above).

- **Policies must recognise and manage trade-offs and risks of burden-shifting between environmental impacts**. The analysed studies provide several examples of trade-offs. For example, in Gallego-Schmid et al. (2019), the studied single-use aluminium container is the worst option in terms of depletion of elements, ozone layer depletion, human toxicity, marine and terrestrial ecotoxicity, whereas the single-use PP container is worst in terms of abiotic depletion of fossil resources, acidification, eutrophication, freshwater aquatic ecotoxicity, climate change, photochemical ozone creation and primary energy demand.

- **Policies must be based on several sources of information for environmental impact.** LCA results, such as those available in the eleven studies analysed in this report, need to be considered together with other sources of relevant information on environmental aspects. Aspects seldom covered by LCAs are food safety (chemical leaching to food), possible health impacts of certain packaging materials, terrestrial and marine littering and the subsequence effects on ecosystems, and environmental impact associated with land use and land use change (including extraction of fossil and mineral resources through mining, as well as extraction of bio-based feedstock through agri- and silviculture).

3.3 Important aspects in life cycle assessments of take-away food packaging

Based on the analysed LCA studies, several aspects were identified that should be carefully considered when conducting and interpreting LCAs of single-use plastic packaging and alternative packaging solutions for take-away food. Below is a non-exhaustive list of such aspects.

- **Geographical context**. Examples of important parameters connected to geographical context are available power generation technology and end-of-life processes, and the available end-of-life options (Belley 2011). Consumer behaviour might also differ between geographical contexts. For instance, as pointed out by Baumann et al. (2018), who studied different systems for reusable take-away food packaging, there is a need to analyse real-world behavioural responses of customers and food outlet staff.

- **Functional equivalence**. Due to the many differences in functionality of different take-away food packaging – in terms of volume of food that can be transported, transportability, capacity to handle warm and/or liquid food, prevention of food waste, assurance of food safety, etc. – one must be careful in defining functional units and comparing alternatives. For example, paper and cardboard boxes without appropriate barrier coating can be less suitable for food with liquid sauces (Gallego-Schmid et al, 2019). And PS packaging has been controversial in relation to the ongoing debate about food safety risks due to potential migration of styrene into the food (Barnes et al 2011), however numerous studies confirm that PS is safe to use in contact with food (Gallego-Schmid et al. 2019).

  It should be also noted that packaging for take-away food (i.e., packaging used for transportation and immediate consumption of food) cannot directly be compared with packaging used for food in retail (where storage is more important). as Also, for take-away food packaging the litter/leakage aspect is very important for the overall environmental impact.

- **Lack of process-specific data** has been shown to hamper the robustness of some results of the analysed studies. For example, production and waste management for bioplastics were modelled without process-specific data (Suwanmanee et al. 2013, Madival et al. 2009). Madival et al (2009) conclude that impact results for PLA packaging are likely to change if more process-specific inventory data were to be used for modelling waste management of PLA (which were missing at the time of the study). Therefore, LCA practitioners should try to find more specific data, and manufacturers should help with providing it.

- **Different maturity and scale of technologies** must be considered by LCA practitioners. For instance, production of bio-based plastics is currently less mature and of smaller scale than production of fossil-based, as is the case of PLA studied by Madival et al. (2009) and Suwanmanee et al. (2013). This is consistent with a previous meta-analysis of plastic beverage bottles and their alternatives, in which analysed studies comparing fossil and bio-based plastics particularly emphasised differences in maturity and how this caused uncertainties in the comparisons (UNEP 2020b). However, production routes for bio-based plastics have a high evolution potential, which will positively influence their environmental impact. Moreover, there is more room for development for other types of solutions for take-away food packaging material.

  If an LCA study aims at giving advice to, for example, policy making influencing future product systems, the study must attempt to accurately and fairly portray the environmental impact of these future systems. This includes the analysis of how anticipated increases in maturity and scale are expected to influence the environmental performance of the assessed systems. Here it shall be acknowledged that also established packaging solutions, and background systems influencing novel as well as established packaging solutions (electricity grids, transportation modes, etc.), are likely to change in the future. Thus LCA practitioners attempting to guide decisions with bearing on future contexts and developments, should attempt to identify all environmentally significant factors of the studied product system that may change in the future, and capture how these may reasonably influence the environmental performance of the systems, for example, through scenario analysis.

- **Assumptions regarding transportation and distribution to retailer**. Modelling scenarios for transportation and distribution to retailers is usually associated with considerable uncertainties, as exact transport distances and types of vehicles are usually unknown. So results in comparisons between different types of packaging can sometimes vary depending on what transport distribution and use phase distances are assumed. As shown in Koskela et al. (2014) and Belley (2011), transportation plays an important role for the results. Lighter packaging is often environmentally preferable in case of longer transportation distances. It should be noted however that these results depend on how the impacts from transportation are modelled and what share of the impact from transportation is allocated to the packaging itself. For instance, the weight of the packaging is more important to consider if the packages can be packed so efficiently that the load per vehicle is limited by the weight of the load. However it can be argued that when transporting the lighter packaging the load is rather limited by its volume, then the light weight of the packaging might be less relevant.

- Assumptions **regarding reuse scenario** (when reusable packaging is compared) should be carefully made, considering their importance towards the end results. Gallego-Schmid et al. (2018) show that electricity and use of resources during the washing of reusable containers contribute a high share to their total life-cycle impact.

- **Decomposition of biobased products at** landfill should be carefully modelled by LCA practitioners. As Frankling Associates (2011) show, there is a high uncertainty concerning decomposition of paper-based packaging and this can have a great influence on the calculated climate impact. This is due to CO2-eq associated with potential emissions of methane into the atmosphere during paper decomposition. Comparing PLA, PS and paper-based clamshells, the study indicates that paper-based clamshells have the lowest climate impact under the assumption that there is no decomposition at landfill. However, when considering maximum decomposition at landfill, the climate impact of paper-based clamshells is higher than for PS clamshells. There are studies that indicate that paper-based and other types of biodegradable packaging degrade in landfills and generate methane (Franklin Associated 2011, Dilkes-Hoffmann et al. 2018). This results in a higher global warming potential, especially in case of landfills with low methane capture efficiency. However, this might not be a problem for state-of-the-art landfills with high methane capture efficiency (Dilkes-Hoffmann et al. 2018).

- **Choice of environmental impact indicators** is important for avoiding shifting burdens, for example reducing climate impact while increasing other types of impact. If the study is to explore the consequences of a certain policy, for example, the study must reflect the intended environmental benefits of said policy, as well as its likely unintended and relevant environmental drawbacks.

  Relatedly, some environmental aspects are less well-covered by LCA of food packaging in comparison to others – as shown by the present report, which is consistent with a previous meta-analysis of beverage packaging (UNEP 2020b). For example, impacts from littering on marine and terrestrial ecosystems, biodiversity impact of land use, or toxic effects of microplastics released to the marine environment are seldom included in LCAs, mainly due to a lack of sufficiently robust and established characterisation methods. None of the reviewed studies assessed the potential environmental impact of littering. However, it is an important issue for non-degradable packaging materials and should be considered in LCA studies and decision

making (UNEP 2020a, Gallego-Schmid et al. 2019). There are several ongoing projects that develop methodology for including the impacts of litter in LCA. For instance, the project MariLCA aims to integrate potential environmental impacts of marine litter in LCA results, which will lead to a more comprehensive picture of potential environmental impacts in order to identify trade-offs associated with the use of plastic and other materials (MariLCA, 2020). Another example is the Plastic Leak Project (PLP) that aims to develop methodology to map, measure and forecast plastic leakage along their value chain (Quantis, 2020).

Thus another type of study may therefore have to complement the LCA study, to provide a sufficiently complete picture of the environmental impact of the studied product system. Relatedly, impact results may be associated with considerably different uncertainties – a 10% difference in climate impact results between two compared products can be a significant and meaningful difference, whereas a 10% difference in toxicity impact results is probably not.

- **Consistent modelling choices** is recommended to ensure robust studies, and if deviations are made they should be clearly justified. For instance, Johansson et al. (2019) applied an inconsistent set of allocation methods: the cut-off method was used for the parts of the studied products being recycled at end-of-life, while system expansion with substitution was used for fractions being incinerated at end-of-life. This inconsistency was not justified in the report, but when contacted, the authors explained it to be based on the different underlying purposes of the incineration and recycling operations, respectively. Thus, if different modelling choices are made for different parts of the product system, it is recommended that the justification behind these choices is clearly stated in the report.[6] Critical review of data quality and methodological choices is especially important for comparative LCAs. Standard ISO 14040-44 is one of the possible ways that can ensure this.

6 *In this specific case, we do not deem that this modelling inconsistency influences the overall conclusions of the study as reported in the present report.*

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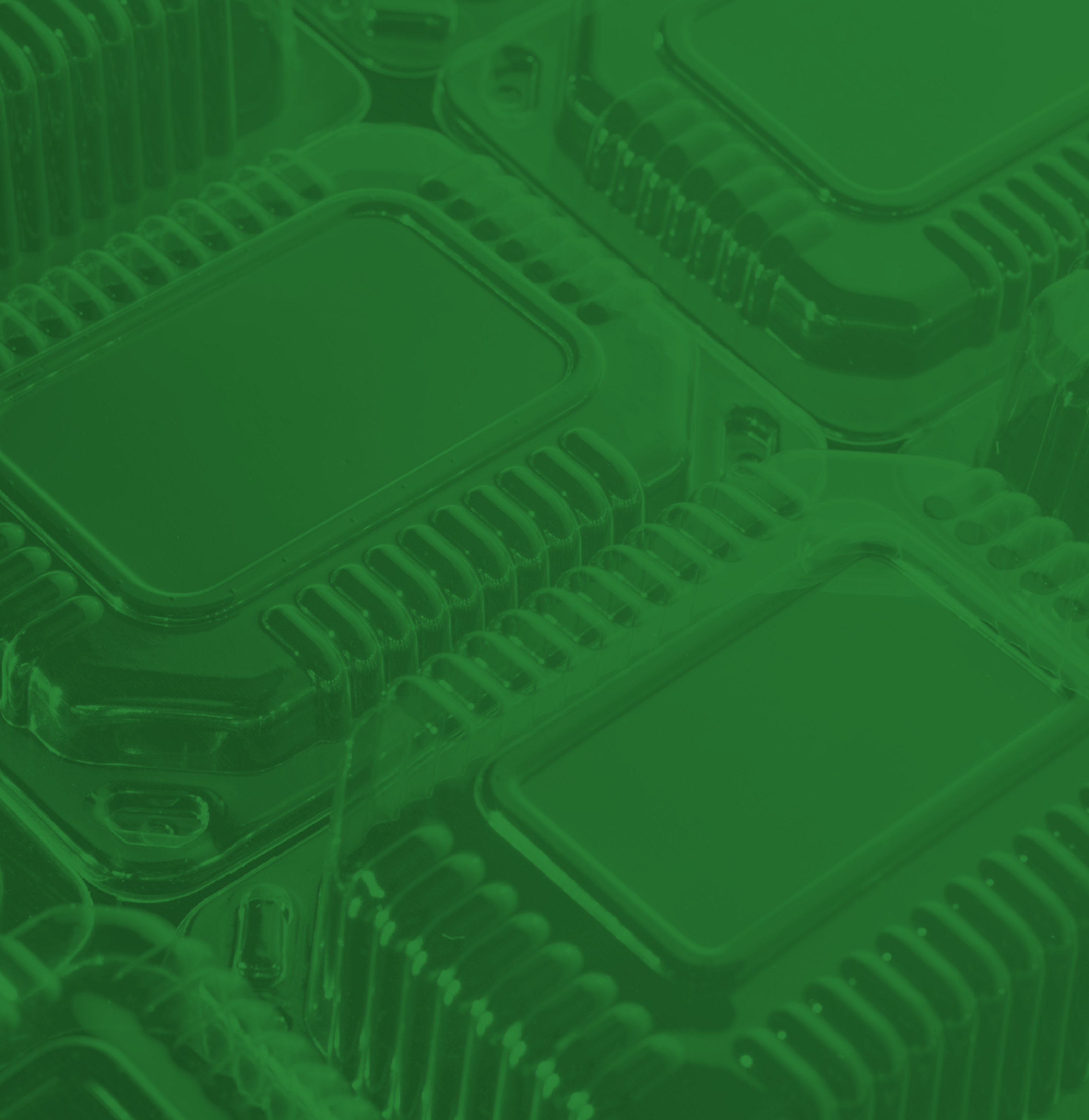

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