# JUSTIFYING PLASTIC POLLUTION

## THE SHORTCOMINGS OF LIFE CYCLE ASSESSMENTS IN FOOD PACKAGING POLICY

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In a study for Friends of the Earth Europe and Zero Waste Europe, on behalf of the Rethink Plastic Alliance, 'Unwrapped: how throwaway plastic is failing to solve Europe's food waste problem (and what we need to do instead)', the Institute for European Environmental Policy was commissioned to examine the interactions between food waste and plastic packaging. The study team noted the use of life cycle assessment (LCA) studies as a decision-supporting tool in food packaging design and the increasing frequency with which results from these studies were referenced in plastic packaging industry-led communications with policy-makers.

A non-exhaustive review of 21 LCA studies on food and beverage packaging, both with and without food waste considerations, was conducted in order to analyse the potential limitations in using LCA to assess the environmental impact of packaging approaches.

## KEY CONCLUSIONS AND RECOMMENDATIONS

- LCAs are increasingly used to inform policy discussions on food packaging. In the context of food and packaging waste. As a methodology, LCA has both strengths and weaknesses.
- LCA emphasis on greenhouse gas (GHG) emissions (particularly during the production of food and during transport) has resulted in decisions in food packaging design made at the expense of material efficiency, with too much focus on carbon emissions and too little on end-of-life impacts. The result is complex packaging design, such as pouches, which are impossible to recycle and lead to 'mixed residues destined for landfill' or incineration [37].
- Existing LCAs consider waste management scenarios which often ignore environmental leakage of packaging. Assessments could better consider the waste treatment realities of specific markets in order to develop measures to reduce marine litter and other forms of pollution.
- As the knowledge base on chemical migration from food contact materials grows, these considerations should be better integrated into the assessment of packaging design and material choice. In the absence of such strong evidence, the precautionary principle should be adopted.
- LCAs should be better combined with knowledge on food waste drivers in order to understand the extent to which packaging can reduce waste of the product itself. Most food waste drivers (e.g. over-purchasing and preparation techniques) are not linked to packaging, and some packaging practices (e.g. trimming and multipacks) can increase food waste.
- Where LCA is applied, greater attention should be paid to investigating systemic solutions, such as short food supply chains, package-free retail and reusable packaging.

This document aims to provide a scoping assessment of the effectiveness of LCAs as a tool for assessing packaging options to reduce food waste. Particular attention is paid to the extent to which LCAs can inform packaging policy intended to reduce both food and packaging waste as part of a circular economy paradigm. The study examined the potential strengths and limitations of the current reliance on LCAs to assess the environmental impact of packaging approaches. Rather than carrying out an exhaustive or peer-reviewed meta-analysis, this study aims to inform the conclusions and policy recommendations of the report 'Unwrapped: how throwaway plastic is failing to solve Europe's food waste problem (and what we need to do instead)' (Schweitzer et al., 2018). Beverage packaging is also reviewed here.

# LCA, EU POLICY AND FOOD PACKAGING

Life Cycle Assessment (LCA) provides, in principle, the most comprehensive framework for analysing and assessing the environmental impact of goods and services at each stage in the supply chain (European Commission, 2016). An LCA can quantify the attributes of a product in terms of human health, resource consumption and environmental considerations, and account (at least partly) for its full life cycle from the raw materials used in its production to end-of-life waste management (European Commission, 2014).

The European Commission's Better Regulation Guidelines (SWD(2015) 111 final) list LCA as a tool which can be used to assess the impacts of different policy options. LCA already features in a number of European environmental policies, many of which refer to product policies either directly or indirectly relevant to packaging (see Table 1). The Joint Research Centre (JRC) has published a number of reports providing guidelines for the application of LCAs to policy-making, including a detailed methodological handbook (JRC and IES, 2010) and review of the use of LCA in impact assessments (Sala et al., 2016).

**TABLE 1 – INTEGRATION OF LCA IN EUROPEAN POLICIES WITH POTENTIAL RELEVANCE TO PACKAGING**

| POLICY TYPE | POLICY DOCUMENT | INTEGRATION OF LCA |
|---|---|---|
| Regulations | REACH Regulation on Chemicals (Regulation No 1907/2006) | Not explicitly mentioned but states that the assessment of chemicals shall consider all stages of the life cycle of the substance resulting from the manufacture and identified uses |
| | EMAS - Community eco-management and audit scheme (Regulation No 1221/2009) | Non-industrial organisations should consider the environmental aspects associated with their core business, including product life cycle related issues (design, development, packaging, transportation, use and waste recovery/disposal) |
| | EU Ecolabel (Regulation No 66/2010) | Aims to establish a voluntary ecolabel award scheme intended to promote products with a reduced environmental impact during their entire life cycle and to provide consumers with accurate, non-deceptive, scientific information on the environmental impact of products |
| Directives | Waste and repealing certain Directives (Waste framework Directive - WFD) (2008/98/EC) | Article 4(2) opens the possibility of deviations from the waste hierarchy for specific waste streams 'where this is justified by life cycle thinking on the overall impacts of the generation and management of such waste' |
| | Public procurement and repealing Directive 2004/18/EC (2014/24/EC) | Life Cycle Costing (LCC) is mentioned as a methodology by which contracting authorities can identify the most economically advantageous tender |
| Communications | Integrated Product Policy (COM(2003)302) | IPP seeks to minimise environmental impacts across the life cycle of different products |
| | Taking sustainable use of resources forward: A Thematic Strategy on the prevention and recycling of waste (COM(2005)666) | Introduce life cycle analysis in policy-making and clarify, simplify and streamline EU waste law |
| | Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan (COM(2008)397/3) | Improving the overall environmental performance of products throughout their life cycle |
| | Public procurement for a better environment (COM(2008)400) | Public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle |
| | Roadmap to a resource efficient Europe (COM(2011)571) | Life cycle approach should support the protection of natural capital and should be applicable to different sectors, especially in the key sectors envisaged by the roadmap (food, buildings and mobility) |
| | Building the single market for green products (COM(2013)196) | Invites Member States (MS) to use the harmonised LCA methodology (PEF and OEF, as defined in Recommendation 2013/179/EU) in national policies/initiatives on the assessment and communication of the environmental performances of products |
| | Closing the loop – An EU Action Plan for the Circular Economy (COM(2015)614) | LCA (in particular the PEF, currently under testing) is mentioned as a methodology whose use will be explored for the measurement/communication of environmental information |
| | A European Strategy for Plastics in a Circular Economy (COM(2018)28 final) | Objectives for a 'truly circular lifecycle for plastics'. Life cycle impacts of alternative feedstocks of plastics to be assessed. LCA will also be used to assess whether or not the use of biodegradable or compostable plastic is beneficial |

The ability of LCAs to give a rigorous assessment of every component and process resulting in a final product has led to their extensive use in evaluating the environmental performance of food and beverage packaging. In such cases, LCAs are often used to compare alternative packaging made from various materials or designs, in a bid to identify the option with the least impact on the environment, resources and health. Impact categories and indicators are defined, weighted or omitted based on the study objectives.

In many cases, LCAs for food and beverage packaging include the packaged product itself in their examination, e.g. assessing the environmental impact of the meat that is packaged, as well as the packaging itself. The inclusion of the packaged product in a packaging LCA is a logical inclusion, as the environmental impact of food production and product losses through the supply chain can be significant (Flanigan, Frischknecht and Trisha, 2013).

Most studies integrating the packaged product into their examination conclude that a given packaging design is desirable if this would lead to less food waste. Such conclusions are based on the argument that the production of one more unit of food product causes greater environmental damage than the production and waste management of one more unit of packaging to (potentially) protect the food product. However, growing awareness of the problematic aspects of packaging waste and pollution, alongside persistently high levels of food waste, brings this argument into question (Schweitzer et al., 2018).

In the context of policy developments on both food waste and packaging waste, analysis suggesting that packaging can significantly reduce the impact of food waste has the potential to be both politically and industrially valuable. Indeed, media and public communications linked to the food packaging industry commonly focus on the value of plastic packaging in reducing food waste. There is thus a need to better understand how LCA data is used to develop policies on packaging and food waste.

This study summarises a non-exhaustive review of 21 LCAs on food and beverage packaging, both with and without food waste considerations (nine studies consider food waste). Key findings are extracted from each of these studies to identify the methodologies employed and to reflect on the conclusions and recommendations of the authors.

The methodology used here first defined the objective of this study (as described above), which then enabled the collection of relevant LCAs (i.e. those published in the last two decades, and those which compared food and beverage packaging options). Through the course of the literature review carried out for the purpose of the main report, papers were identified in grey literature and peer review journals. Additional papers were also identified using the following keywords in Science Direct: 'food waste'; 'packaging design'; 'life cycle assessment'; 'plastic packaging'; 'reusable packaging'; and 'single-use packaging'. The aim was not be exhaustive but, rather, to better understand how LCA is applied in the sector. The literature collected was then reviewed and the key findings were documented (see Table 2 below). These findings allowed for a number of key observations and conclusions to be drawn, and these are discussed after Table 2.

## TABLE 2 - LCA STUDIES ON FOOD AND BEVERAGE PACKAGING

| AUTHOR(S) AND TITLE | METHODOLOGY | FOOD/ DRINK EXAMINED | ENVIRONMENTAL VARIABLES | MAIN FINDINGS | SPONSOR | FOOD WASTE INCLUDED |
|---|---|---|---|---|---|---|
| Accorsi et al (2014). Economic and environmental assessment of reusable plastic containers - A food catering supply chain case study | LCA study that compares a multi-use system to traditional single-use packaging (e.g. wooden boxes, disposable plastic crates and cardboard boxes) | Fresh fruit and vegetables | Climate change | The adoption of a reusable plastic container system will lead to a reduced environmental impact in terms of carbon emissions | | NO |
| Accorsi, Versari and Manzini (2015). Glass vs. Plastic - Life Cycle Assessment of extra-virgin olive oil bottles across global supply chains | LCA study that compares a glass bottle to a plastic bottle | Extra-virgin olive oil | Climate change, ozone layer depletion, non-renewable energy use, acidification, eutrophication and photochemical smog | Glass bottle had a lower impact than the PET bottle. However, the best scenario is when PET bottles are mixed with reusable PET bottles | | NO |
| Banar and Cokaygil (2009). A Life Cycle Comparison of alternative cheese packages | LCA study that compares three different cheese packages: completely polypropylene, tin and polyethylene, and carton and polyethylene | Cheese | Fossil fuels, minerals, land use, acidification/ eutrophication, ecotoxicity, global warming potential, ozone layer, carcinogens, radiation, respiratory organics and respiratory inorganics | According to the environmental variables chosen, the best packaging is carton and polyethylene option, followed by entirely polypropylene, and, finally, tin and polyethylene | Anadolu University, Turkey | NO |
| Bertoluci, Leroy and Olsson (2014). Exploring the environmental impact of olive packaging solutions for the European food market | Two series' of five LCAs corresponding to five EU countries were conducted on three olive packaging solutions: Doypacks (sealed plastic bags that are designed to stand upright), glass jars and steel cans | Olives | Climate change, human toxicity, particulate matter formation, fossil depletion and ionising radiation | The environmental performance of each packaging type differs from one country to another. The plastic packaging (non-renewable and non-recyclable) has the lowest environmental impact, while glass has the greatest. Packaging should satisfy consumer preference, and in order to improve packaging sustainability, better waste collection and recycling is necessary | | Partially – food waste is discussed but not included as part of the LCA analysis |

| AUTHOR(S) AND TITLE | METHODOLOGY | FOOD/ DRINK EXAMINED | ENVIRONMENTAL VARIABLES | MAIN FINDINGS | SPONSOR | FOOD WASTE INCLUDED |
|---|---|---|---|---|---|---|
| Bø, Hammervoll and Tvedt (2013). Environmental impact of refillable vs. non-refillable plastic bottles | LCA study that compares refillable to non-refillable PET bottles | Soft drink and carbonated water | Climate change | Non-refillable PET bottles generate 18% less CO2 emissions than refillable PET bottles. This was based on increased transportation and cleaning costs. However, the study identifies a number of limitations in the methodology, including uncertainty about the number of times a bottle is reused and the assumption of highly efficient recycling processes | | NO |
| De Monte, Padoano and Pozzetto (2005). Alternative coffee packaging: an analysis from a life cycle point of view | LCA study that examines packaging alternatives of 3kg white latten can, 250g white latten can, 125g white latten can, 250g serving white latten can, and 280g serving polylaminate bag. | Coffee | Climate change, ozone depletion, acidification, heavy metals, winter and summer smog, eutrophication and carcinogenics | Polylaminate bags with a capacity of 40 single-use coffee servings are a better solution than metallic cans, according to the environmental variables of the LCA | | NO |
| Gironi and Piemonte (2011). Life Cycle Assessment of polylactic acid and PET bottles for drinking water | LCA study that compares polylactic acid (PLA) to PET bottles | Water | Carcinogens, respiratory organics, respiratory inorganics, climate change, radiation, ozone layer, ecotoxicity, acidification/ eutrophication, land use, minerals, and fossil fuels | PLA bottles have a greater impact on ecosystem and human health than PET bottles. PLA bottles are favoured only where recycling is the final destination | | NO |
| Hanssen et al (2017). Environmental profile, packaging intensity and food waste generation | LCA study that compares three different types of dinner meals: a ready meal, a semi-prepared meal, and a homemade meal from fresh ingredients | Complete meals with meat, potatoes, vegetables and sauce | Climate change, energy use and waste generation | Ready meals were ranked last on all environmental variables except food waste, where they ranked first. The semi-prepared meals were ranked best for all environmental variables except for food waste | Grants from the Norwegian Packaging Optimisation Committee and from the Norwegian Research Council | YES |

| AUTHOR(S) AND TITLE | METHODOLOGY | FOOD/ DRINK EXAMINED | ENVIRONMENTAL VARIABLES | MAIN FINDINGS | SPONSOR | FOOD WASTE INCLUDED |
|---|---|---|---|---|---|---|
| Humbert et al (2009). Life cycle assessment of two baby food packaging alternatives - glass jars vs. plastic pots | LCA study that compares glass jars to plastic pots | Baby food | Carcinogens, non-carcinogens, respiratory inorganics, ionising radiation, ozone layer depletion, photochemical oxidation, aquatic/ terrestrial ecotoxicity, terrestrial acidification/ nutrification, land occupation, aquatic acidification, aquatic eutrophication, climate change, non-renewable energy, mineral extraction | Plastic pots showed advantages for non-renewable primary energy, global warming, respiratory inorganics and terrestrial acidification/ nutrification | | NO |
| Manfredi and Vignali (2015). Comparative life cycle assessment of hot filling and aseptic packaging systems used for beverages | LCA study that compares the hot filling and aseptic packaging systems | Beverages | Climate change, ozone depletion, terrestrial acidification, fresh water eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial/ freshwater/ marine ecotoxicity, ionising radiation, water depletion, metal depletion, fossil depletion | Results indicated that aseptic packaging systems had lower impacts, on the whole, in all impact categories | | NO |
| Meneses, Pasqualino and Castells (2012). Environmental assessment of the milk life cycle: the effect of packaging selection and the variability of milk production data | LCA study that assesses the impact of the most common packaging options for milk in the Spanish market (aseptic carton, PET, and HDPE) | Milk | Climate change, acidification | Larger aseptic carton packages have the best environmental performance. However, this is solely due to the recycling of the carton layer | | NO |
| OVAM (2015). Food loss and packaging | LCA study on five different products and how their packaging affects food waste | Meat and meat products, fruit and vegetables, cheese, bread, and soft drinks | Climate change | All products need more packaging to protect them from spoilage | Experts from Pack4Food formed part of the project team. This is a Flemish consortium of companies involved in food packaging | YES |
| Poovarodom, Ponnak and Manatphrom (2012). Comparative carbon footprint of packaging systems for tuna products | LCA study comparing retort pouches (made from a laminate of flexible plastic and metal foil) and cups to metal cans | Tuna products | Climate change | Retort cup system possesses a significant advantage over metal cans and retort pouch systems in terms of overall GHG emissions | Study funded by the European Union under the Thailand-EC Cooperation Facility Programme | NO |

| AUTHOR(S) AND TITLE | METHODOLOGY | FOOD/ DRINK EXAMINED | ENVIRONMENTAL VARIABLES | MAIN FINDINGS | SPONSOR | FOOD WASTE INCLUDED |
|---|---|---|---|---|---|---|
| Quantis (2015). Comparative LCA on four capsule systems | LCA study between single-serve capsule system coffee and bulk coffee | Coffee | Human toxicity, respiratory effects, Ionising radiation, ozone layer depletion, photochemical oxidation, aquatic and terrestrial eco-toxicity, aquatic acidification, eutrophication, acidification, land use, climate change, non-renewable energy, mineral extraction, water withdrawal | Single-serve coffee systems have significant benefits for the environment | PAC, a Canadian packaging consortium | YES |
| Schmidt Rivera, Espinoza Orias and Azapagic (2014). Life cycle environmental impacts of convenience food - comparison of ready meals and homemade meals | LCA study that compares ready meals and homemade meals | Complete meals with roast chicken, vegetables and sauce | Climate change, abiotic depletion, acidification, eutrophication, marine and freshwater aquatic ecotoxicity, human toxicity, ozone layer depletion, photochemical ozone creation, terrestrial ecotoxicity | Homemade meals have a lower impact than ready meals | | NO |
| Saraiva et al. (2016). Comparative lifecycle assessment of mango packaging | LCA study of a reusable polystyrene packaging, identical packaging without natural fibres, and commercial cardboard packaging | Mango | Climate change, ozone depletion, photochemical ozone formation, acidification, eutrophication (marine water and fresh water), ecotoxicity and human toxicity | 'Mangobox' (the reusable plastic container) had a smaller impact than cardboard if used more than 29-35 times | | YES |
| Silvenius et al (2011). Role of packaging in LCA of food products | This study presents the result of three LCA case studies to show the total environmental impact of three packaged food items | Sliced dark rye bread, whole meat cold cuts (ham) and Soygurt-drink | Climate change, eutrophication and acidification | Producing half a slice of rye bread and one slice of ham causes more GHGs than the production chain of packaging. The polypropylene package case of Soygurt and its waste management were more significant than producing the surplus food | 12 Finnish companies and associations representing the food and ICT-industry, packaging and packaging material manufacturers were involved in the project | YES |
| von Falkenstein, Wellenreuther and Detzel (2010). LCA studies comparing beverage cartons and alternative packaging - cln overall conclusions be drawn? | A meta-analysis of LCA studies on beverage cartons and other packaging | Beverage | Energy resource consumption (13), land use (8), water consumption (3), abiotic resource consumption (2), climate change (22), acidification (18), eutrophication (18), summer smog (14), ecotoxicity (5), human toxicity (5), ozone depletion (4), winter smog (2), odour (2) | For climate change, cumulative energy demand/ fossil resource consumption and acidification, beverage cartons chiefly had the most favourable results. For forestry, they clearly require the largest area | The Alliance for Beverage Cartons and the Environment, together with the World Wide Fund for Nature, ordered this study | NO |

| AUTHOR(S) AND TITLE | METHODOLOGY | FOOD/ DRINK EXAMINED | ENVIRONMENTAL VARIABLES | MAIN FINDINGS | SPONSOR | FOOD WASTE INCLUDED |
|---|---|---|---|---|---|---|
| Wikström, Williams and Venkatesh (2016). The influence of packaging attributes on recycling and food waste | LCA comparison between a lightweight tube and a tray packaging | Minced meat | Climate change, acidification<br><br>and ozone depletion | Key finding was that consumer behaviour regarding food waste and recycling should be included in LCA studies because it can completely change the results of the study | | YES |
| Wikstrom et al (2014). The influence of packaging attributes on consumer behaviour in LCAs | LCA study comparing three different packages for rice and three other packages for yogurt | Rice and yogurt | Climate change | Food waste has a higher environmental impact than packaging, thus, when it is included it dramatically alters the results | | YES |
| Williams and Wikström (2011). Environmental impact of packaging and food losses in a life cycle perspective: a comparative analysis of five food items | LCA study examining the environmental impact of the packaging of five different products | Beef, bread, cheese, ketchup, milk | Climate change, energy, eutrophication | Reducing beef waste by 10% would permit an increase in beef packaging up to three times. If the amount of bread loss is decreased by 5%, the new packaging solution may increase by up to 2.5 times. If the amount of cheese loss is reduced by 5%, the new packaging solution can increase more than 10 times. For ketchup, finding low-impact packaging is more important than reducing waste | | YES |
| UNEP/SETAC (2013) An analysis of life cycle assessment in packaging for food and beverage applications | 'Knowledge mining' of 69 LCA studies from Europe and North America, focusing on food and beverage packaging | Food and beverage | Meta-analysis | LCA is useful for developing holistic assessments of packaging options from a life cycle perspective, and can inform environmentally preferable packaging. Conclusions from LCA studies cannot be generalised across materials or products. There are limitations in the waste hierarchy for packaging applications | Pepsico, SIG International, Plastics Europe, Tetra Pak, World Steel Association, Flexible Packaging Association, European Aluminum Foil Association, American Chemical Council, ARECO, Amcor, Dutch Federation of Rubber and Plastics, Flexible Packaging Association, World Steel Association | YES |

## UNEP/SETAC STUDY ON THE USE OF LCA FOR FOOD AND BEVERAGE PACKAGING

A study on LCA for food and beverage packaging was carried out by the United Nations Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) (Flanigan, Frischknecht and Trisha, 2013). The study reviewed 69 existing LCAs of food and beverage products in order to illustrate the value of applying LCAs to inform packaging design in the sector. Based on its analysis, the UNEP/SETAC study explains the benefits of LCAs for assessing the impacts of packaging:

- Inclusion of multiple environmental impacts and indicators
- Inclusion of all product life cycle stages
- Inclusion of the packaged product in the analysis

The report refers to some potentially problematic issues in respect of LCA results and the waste hierarchy (p.24), the transferability of LCA results to developing countries (p.18) and the links between packaging and marine debris (p.22) but these issues are not explored in detail. For example, the analysis rightly questions the potential relevance of LCA for packaging for developed countries, noting the heterogeneity in environmental impacts and losses in the food supply chain between developed and developing economies (Flanigan, Frischknecht and Trisha, 2013). The report argues that packaging can help to reduce food loss in developing economies, in view of the inadequate infrastructure. In the same vein, however, it fails to acknowledge that inadequate infrastructure, such as waste management, will also likely increase the risk of environmental leakage of packaging, as confirmed by research into global marine litter sources (Jambeck et al, 2015). Although the UNEP/SETAC report provides useful insights into the relevance of LCA for packaging, it does not address some of the key sustainability challenges facing the packaging sector, nor does it examine how these can be tackled via LCA methodologies.

## KEY INSIGHTS FROM THE LCA REVIEW

The review above, together with the research linked to the main report, demonstrates the complexities inherent in capturing all of the environmental impacts of food packaging in a single methodology. The LCAs reviewed were not intended to capture all of the relevant aspects necessary to develop comprehensive policies on packaging and food waste but they nevertheless provide insights into the adaptation of studies for policy discussions in the future. The following sections identify some relevant gaps in the studies, concluding with a summary of opportunities for future research.

### NARROW RANGE OF ENVIRONMENTAL IMPACTS

Twelve of the 21 studies reviewed here focused on only one or very few environmental indicators, usually climate change (greenhouse gas emissions). The choice of environmental impact categories is important when analysing different types of materials, as some can be more resource-intensive or polluting during their production. The exclusion of specific indicators may therefore impact the results. For example, the OVAM (2015) report was conducted by an expert group which included experts from the Pack4Food[1] consortium. It found that all of the food products examined in the report needed to be covered with additional packaging to better protect them from spoilage. However, the only impact category considered in the LCA was 'climate change'. While GHG emissions are highly relevant for food waste discussions, other environmental impacts should also be considered. Indeed, one US report argues that existing studies have focused too much on carbon emissions and too little on end-of-life impacts. The result is complex packaging design, such as pouches, which are impossible to reuse and recycle and lead to 'mixed residues destined for landfill', incineration or litter (MacKerron, 2015).

## TYPES OF PACKAGING SELECTED FOR ASSESSMENT

When LCAs are designed, a choice is made about the packaging options to include. Typically, a limited range of packaging applications and types of distribution are considered, creating the impression of a choice between the 'least bad' of two (or several) options. For example, a plastic Doypack could have a lower environmental impact than a glass jar, as was the case in Bertoluci, Leroy and Olsson (2014) study on olive packaging, and carton is probably better than tin, which was the conclusion in the Banar and Cokaygil (2009) study on cheese packaging. However, re-useable packaging alternatives were not considered in most of the LCA studies reviewed. The possible impact of changing the length of the supply chain was similarly ignored.

Additional studies have since been identified which consider these aspects in more detail (WRAP, 2010a; WRAP, 2010b). These studies identify key determinants of the environmental performance of reusable packaging systems (i.e. materials used, return rates for reuse, transportation distance, time delay between reuse, transport mode, and waste management). One example examines different types of milk packaging, looking at plastic (HDPE) containers, returnable glass bottles, cartons with screwcaps, and gable top cartons (mixed materials). It concludes that combining lightweighting and recycling of packaging is the best approach. However, it is important to note that focus was on large retailers, and assumes travel distances for milk (including packaging and end of life) in excess of 800km by motorised transport (WRAP, 2010a).

None of the studies reviewed considered zero-packaging scenarios.[2] Although many studies are underpinned by the assumption that the food sector would have an even higher environmental footprint without packaging, this has never been comprehensively tested. There are evidently opportunities for LCA practitioners to explore in more detail how Short Food Supply Chains[3] (SFSCs), as well as re-usable and zero-package retail, can impact environmental performance.

### DISPOSAL AND ENVIRONMENTAL LEAKAGE

The end-of-life disposal of packaging remains a key environmental impact. Studies tend to apply waste management scenarios which suppose given levels of waste treatment (e.g. for landfill, incineration and recycling).

Meneses, Pasqualino and Castells (2012) assumed 100% recycling of aseptic cartons (contains plastic and aluminium), although they admit that the separation of the different layers is not a widespread practice. Similarly, Bø, Hammervoll and Tvedt (2013) concluded that refillable PET bottles generate 18% more GHG emissions than non-refillable bottles because recycling was assumed to be a highly energy-efficient process. The Quantis (2015) study on coffee assumed capsule packaging recycling to be at average North American residential rates, although there was no indication that the selected packaging is actually recyclable. In practice, coffee capsules are acknowledged to be particularly challenging for recyclers due to their small format, multi-material composition, and the fact that the coffee grounds within are not recyclable, a necessity for a separate waste stream (France 24, 2017). More needs to be done to develop waste management scenarios which reflect the conditions in specific markets.

Assuming the recyclability of small format, flexible or multilayer packaging products implies the existence of waste management infrastructures equipped to deal with these products, which is unlikely to be the case in practice (Denkstatt, 2014).

Furthermore, none of the studies attempt to take inappropriate disposal into account. This means that analyses assume 100% collection of waste streams go to landfill, incineration or recycling. This is at odds with reality, where a substantial fraction of packaging ends up in the terrestrial and marine environment.

The UNEP/SETAC report acknowledges that marine debris is of 'general public' concern but fails to address how environmental leakage of packaging might be accounted for in decision-making (Flanigan, Frischknecht and Trisha, 2013). Whether or not incorrect disposal can be integrated into LCA methodologies is unclear. It could be argued that some environmental leakage is linked to consumer behaviour, or is accidental, and is thus beyond the reach of packaging designers or LCA design. However, the prevalence of environmental leakage suggests that this conclusion, while convenient, is inappropriate in the context of developing policies on packaging.

Local conditions for waste management are clearly important in defining the environmental impacts of packaging available on the market in that location. Basing impacts on the best available technology for waste management, or ignoring the risk of leakage, is therefore likely to underestimate the environmental impact of a product. LCA practitioners should consider waste management capabilities in the market in which a product is to be sold.

## CHEMICAL MIGRATION AND FOOD CONTACT MATERIALS

Eco-toxicity is one of the environmental impacts commonly considered in LCA methodologies. However, none of the studies of food packaging reviewed here, including the UNEP/SETAC paper (Flanigan, Frischknecht and Trisha, 2013), considered the impact of exposure to the chemicals linked to food contact materials. Eco-toxicology is relevant for food packaging because any food contact material can result in the contamination of foodstuffs. There is growing awareness of the risks associated with the chemical transfer of contaminants from packaging materials to foods. This can include both chemicals deliberately added to products and non-intentionally added substances (NIAS) formed in the production process. Common additives to plastic used in packaging such as Bisphenol A are known to pose a potential risk to human health, although uncertainties about exposure and concentrations from chemical migrations persist. Further questions arise in respect of recycled materials, where the material content of packaging is less certain and difficult to determine – as outlined in the Commission Communication on the interface between chemical, product and waste legislation (COM(2018)32).

Attempts have been made to develop LCA methodologies that include the health impacts of chemical exposure from food packaging (Ernstoff et al, 2014). Arguably, eco-toxicity is one such impact that should be considered as part of the decision-making process for food packaging (Ernstoff et al, 2016). As the knowledge base on food contact materials develops, these considerations should be integrated into the assessment of packaging design and material choice.

## THE FOOD WASTE FACTOR

Food waste considerations are important in selecting the appropriate packaging. The UNEP/SETAC study of LCAs of food and beverage packaging notes:

'Whether or not the product and product losses are considered will depend on LCA goals and the practitioner's reasons for carrying out the study. Only if the alternative designs are associated with equal product losses throughout the supply chain may the product and/or losses be unnecessary for inclusion. Including product losses within system boundaries will be important if loss rates are expected to differ among alternative packaging designs—particularly when the packaging's environmental impact is anticipated to be small compared to the packaged product's impact (and therefore small compared to the impact of packaged product losses). Under these conditions, product losses may be the deciding factor in reducing impact rather than the packaging material or design. If product losses are not considered, it is important to justify their exclusion' (Flanigan, Frischknecht and Trisha, 2013).

Food waste was considered in nine of the studies reviewed. However, the LCAs that included food waste as a factor in their analyses did not discuss the extent to which food spoilage could be avoided through different kinds of packaging or indeed zero-packaging solutions. Rather, their approach was to compare the estimated environmental impact of production and waste management of one unit of packaging with the environmental impact of one unit of food waste, and by showing that the former is smaller than the latter, to conclude that it is more efficient to focus on food waste than on packaging. This is particularly the case in the OVAM (2015), Quantis (2015), Silvenius et al (2011), and Williams and Wikström (2011) studies, which calculated the number of units of packaging that would be equivalent to a food/beverage unit and then concluded that more packaging can be beneficial for the environment. The formulation of their conclusions gives the impression that the amount of packaging has a positive correlation with the food saved from waste. In view of the complex drivers of food waste through the food system, such a conclusion considerably simplifies the reality.

Food waste is not only a result of inadequate packaging but can occur at different stages of the value chain, including at household level during and after food preparation and cooking, where packaging cannot protect it. Assuming that all food waste can be addressed with better packaging and extended shelf-life thus ignores a domestic reality. This goes hand-in-hand with these studies' exclusion of packaging-related food waste throughout the supply chain. For example, food may be discarded or trimmed in order to fit packaging design, potentially leading to significant levels of waste (Colbert, Schein and Douglas, 2017). Furthermore, packaging fixes the portion size or the number of units sold, driving over-purchasing by consumers and leading to further waste. Packaging is also used to attract customers, inviting them to buy a product even if it is not necessary to satisfy their wants and needs (WRAP, 2014). Lastly, in some cases food is discarded unopened, still in its packaging (WRAP, 2008).

Although the inclusion of the product in the LCAs of packaging applications helps to identify the significant environmental impacts linked to the food supply chain, as well as to raise the issue of reducing food waste as one of the primary utilities of packaging, relationships between packaging and reducing food waste are often simplified. LCAs should be combined with knowledge on food waste drivers in order to better understand the extent to which packaging can reduce product waste.

## FOOD SYSTEMS, CIRCULAR ECONOMY AND SYSTEMIC SOLUTIONS

Assuming that current policy objectives aim towards a food system which can contribute to both sustainable development and the transition to a circular economy requires that these objectives are reflected in how policies for food packaging are developed.

The LCA studies examined here generally assess packaging options, such as comparing alternative materials and packaging designs. However, the analysis outlined in the main report demonstrates that optimising packaging design is often contingent on system boundaries and supply chain configurations beyond the packaging itself, such as the length of the supply chain, mode of transport, energy mix, feasibility of reverse logistics, and consumer practices. This is partly noted in the UNEP/SETAC report, which acknowledges that a range of different variables should be considered when assessing reusable packaging, including the frequency of reuse, transport, and cleaning of packaging (Flanigan, Frischknecht and Trisha, 2013).

All of the studies examined here focused on single products or several typical products, mostly in conventional supply chains. As such, these studies adopt typical supply chain lengths, transport and energy mixes and retail practices in their analyses. Alternative approaches to food supply chains, for example those linked to short food supply chains (SFSCs) and zero-waste retail are not included. These studies thus permit a comparison of packaging options under a clearly defined system but ignore potentially preferable (lower impact) outcomes within realistic alternative systems. While LCAs have previously been employed to compare, for example, the relative impacts of local and non-local food (Kneafsey et al., 2013), little has been done to combine packaging analysis with analysis on food systems as a whole.

From an industry perspective, LCAs of packaging options in a given supply chain are logical, as they try to optimise and create efficiencies within the spectrum of their own activities. By contrast, policy-makers have the responsibility to develop instruments and policy mixes to support sustainable development in all parts of the food supply chain and economy, including opportunities to better employ LCA methodology to explore food and packaging more systemically. Wider aspects, such as the role of SMEs and local and regional initiatives, as well as opportunities for social innovation (e.g. reverse logistics and sharing models), would be valuable inclusions in future assessments.

## CONCLUSIONS

While LCAs are widely used to inform discussions on food packaging, the studies reviewed here suggest some potential challenges with such methodologies. The LCAs reviewed here also demonstrate the complexity inherent in capturing the environmental impacts of food packaging in a single methodology.

Many environmental impacts, such as environmental leakage and chemical migration, may not be well suited to LCA. Some aspects, however, could be better integrated into studies, e.g. using real-life waste scenarios in their assessments, thereby allowing for more realistic representations of the end-of-life of packaging products. This is particularly important when considering the waste management capabilities of locations/countries where not all waste is collected at the end of its life, making the risks of environmental leakage significantly higher. Similarly, changing waste management practices for food waste, including increasing redistribution, or separate collection of organic waste for composting and anaerobic digestion, also has the potential to reduce the impact of waste and LCAs could be used to explore the waste reduction potential of these activities. Overall, many existing LCA results do not support the implementation of the waste hierarchy or vice versa, and in these cases more should be done to better understand the hotspots where the sustainability challenges of waste are created and how they can be addressed (UN Environment, 2017).

LCAs should be combined with knowledge on food waste drivers to better understand the extent to which packaging can reduce product waste, given that many food waste drivers (e.g. over-purchasing, storage and preparation techniques) are not linked to packaging, while some others are (e.g. trimming and multipacks). If food waste is taken into account (i.e. via shelf-life extension), other drivers of food waste could be similarly considered, particularly where these can be linked to packaging design.

As the knowledge base on chemical migration from food contact materials grows, these aspects should be better integrated into the assessment of packaging design and material choice. In the absence of such strong evidence, the precautionary principle should be adopted. The risks and complexity of identifying chemicals and their toxicity, becomes more complex in recycled products, as identified in the Commission's Communication on options to address the interface between chemical, product and waste legislation (COM(2018) 32). Targets to increase recycling and the recycled content of products will also bring new challenges in how the chemical composition of food contact materials are managed.

There is a clear opportunity for LCA practitioners to carry out assessments of food supply chains which are outside of the conventional food system, including closer examination of short food supply chains, package-free solutions, and reusable packaging.

The conclusions presented here are the basis of a preliminary assessment of LCA studies examining food packaging. A further, more comprehensive review is recommended in order to validate these findings. Efforts to develop guidance for LCA practitioners on integrating current thinking on sustainable food systems with packaging design and the circular economy, would be both welcome and valuable.

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## ENDNOTES

1. Pack4Food is a Flemish consortium of companies involved in food packaging.
2. Two studies comparing packaged and unpackaged foods were identified from Flexible Packaging Association (FPA): 'The value of flexible packaging in extending shelf life and reducing food waste' and 'The role of flexible packaging in reducing food waste'. However, the full versions of these reports were not publicly available and could not be included in the analysis.
3. Shortening of the physical distance between the production and consumption of food and/or a reduction in the number of intermediaries in a value chain.