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Review

Packaging-Related Food Losses and Waste: An Overview of Drivers and Issues

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Abstract: Packaging is often criticized as a symbol of today's throwaway society, as it is mostly made of plastic, which is in itself quite controversial, and is usually used only once. However, as packaging's main function is to protect its content and 30% of all food produced worldwide is lost or wasted along the supply chain, optimized packaging may be one of the solutions to reduce this staggering amount. Developing countries struggle with losses in the supply chain before food reaches the consumer. Here, appropriate packaging may help to protect food and prolong its shelf life so that it safely reaches these households. In developed countries, food tends to be wasted rather at the household's level due to wasteful behavior. There, packaging may be one of the drivers due to inappropriate packaging sizes and packaging that is difficult to empty. When discussing the sustainability of packaging, its protective function is often neglected and only revolves around the type and amount of material used for production. In this review, drivers, issues, and implications of packaging-related food losses and waste (FLW) are discussed, as well as the implication for the implementation in life cycle assessments (LCA).

Keywords: Packaging; food waste; food loss; sustainability; LCA

1. Introduction

Food production is associated with a significant consumption of resources. Today, approximately 30% of the earth's land and 70% of all extracted freshwater is used for growing crops. Additionally, the production and usage of pesticides and fertilizers can pollute air, water, and soil, and hence, poses a risk for human health and ecosystems as a whole [1]. Even worse is if this resource consumption is in vain when food misses its ultimate goal of human consumption and is lost or wasted instead.

According to the Food and Agriculture Organization of the United Nations (FAO), around 1.3 billion metric tons or approximately one-third of all food produced for humans is wasted worldwide each year [2]. In total, around 3.3 billion metric tons of CO_2 equivalent, 250 km^3 of blue water, and 1.4 billion hectares, which represents approximately one third of the world's agricultural area, is associated with not-consumed and, therefore, wasted food [3]. Further, other estimates point out that the amount of the world's food waste could be as high as 44% of the dry mass of agricultural crops [4]. In addition to environmental impacts, food waste also includes a social or ethical dimension, since 795 million or around 11% of the world's population suffer from hunger [5]. With the world's population projected to reach 10 billion people in 2050 [6], there is already a great deal of pressure on food availability and thus the urgency to reduce food waste.

At the international level, concern about food waste has been addressed by passing the Sustainable Development Goals (SDG). Goal 12.3 reads as follows: 'By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses' [7]. With the amendment to the European Union (EU) Waste Directive adopted in 2018, which adopts the wording of SDG 12.3, this will indeed be legally binding for EU member states [8].

When referring to food waste, one has to highlight that there is currently no standardized definition of this term [9]. Frequently, a distinction is made between food waste and food loss, as well as between waste, which is edible or inedible, avoidable or (partially) unavoidable. For example, Parfitt et al. (2010) refer to 'food loss' as a 'decrease in edible food mass throughout the part of the supply chain that specifically leads to edible food for human consumption' and that it occurs at the stages before reaching the customer [10]. Here, and in FAO reports [2,3], losses at the end of the food chain are called 'food waste' and rather relate to human behavior, while in the reports of the British 'Waste Resources and Action Programme' (WRAP) [11] and in the *EU Food Use for Socian Innovation by Optmising Waste Prevention Strategies* (FUSIONS) project [12], there is no distinction made between 'food waste' and 'food loss'. Some authors do not declare food that was initially intended for human consumption, but then was fed to animals as waste [13]. However, some losses at the primary production, as well as at the post-harvest and handling stages, can also be seen as wasteful [14]. Furthermore, losses at one stage of the food supply chain could be caused in different stages [15,16]. Against this background, the present study uses the expression food loss and waste (FLW) to avoid confusion due to differing definitions.

A comparison of different regions shows that the stages of FLW hotspots along the supply chain vary strongly [2]. Apparently, in industrialized regions, such as Europe and North America, the amount of wasted food at the consumption stage is significantly higher than in developing regions, such as sub-Saharan Africa, South and Southeast Asia, and Latin America, where food is more likely to be lost or wasted at the stages between primary production and retail [2]. The FAO states that 'losses at almost every stage of the food chain may be reduced by using appropriate packaging' and that the higher losses at pre- and post-harvest stages in developing countries are 'underscoring the need to focus on packaging solutions' [17].

The present paper addresses the question about the direct and indirect effects of packaging in terms of the contribution to FLW across the supply chain. There has been relatively little research on whether more, less, or different types of packaging cause FLW in relation to the available literature on FLW. Furthermore, new approaches to the integration of these effects into life cycle assessments (LCA) are discussed. For this review, literature searches were performed in the online database, ScienceDirect. The keywords for the search were 'food waste' as well as the two keywords, 'food waste' and 'packaging', combined with the inclusion of the search operator, 'AND'. The search for literature about the integration of FLW into the LCA of packaging was performed with the additional keyword, 'LCA'. For the literature selection, peer-reviewed research articles were preferred. However, reports of highly renowned organizations (e.g., FAO, WRAP) were also included. In total, 88 references were identified as suitable for this review and 17 additional references, which were necessary for laying the framework of this review.

2. Functions and Sustainability Aspects of Packaging

The main functions of packaging are to contain, to protect, to facilitate handling, and to communicate information (Figure 1) [18,19]. The protective function includes FLW-related features, such as mechanical protection, barrier (e.g., against oxygen or water vapor), and thermal and sealing properties. The 'facilitate handling' function includes features, such as unitization, apportionment, resealability, and emptying. FLW-related features of the communication function consist mostly of product and packaging information and instructions, as in how to properly store, open, and dispose of the package [18]. Additionally, packaging can contain instructions on how to prolong the shelf life of the packaged food by encouraging consumers to freeze leftovers [20]. Furthermore, the communication function is responsible for the fulfillment of legal obligations, such as the provision of nutritional information, best before/use by dates, and ingredients [21].

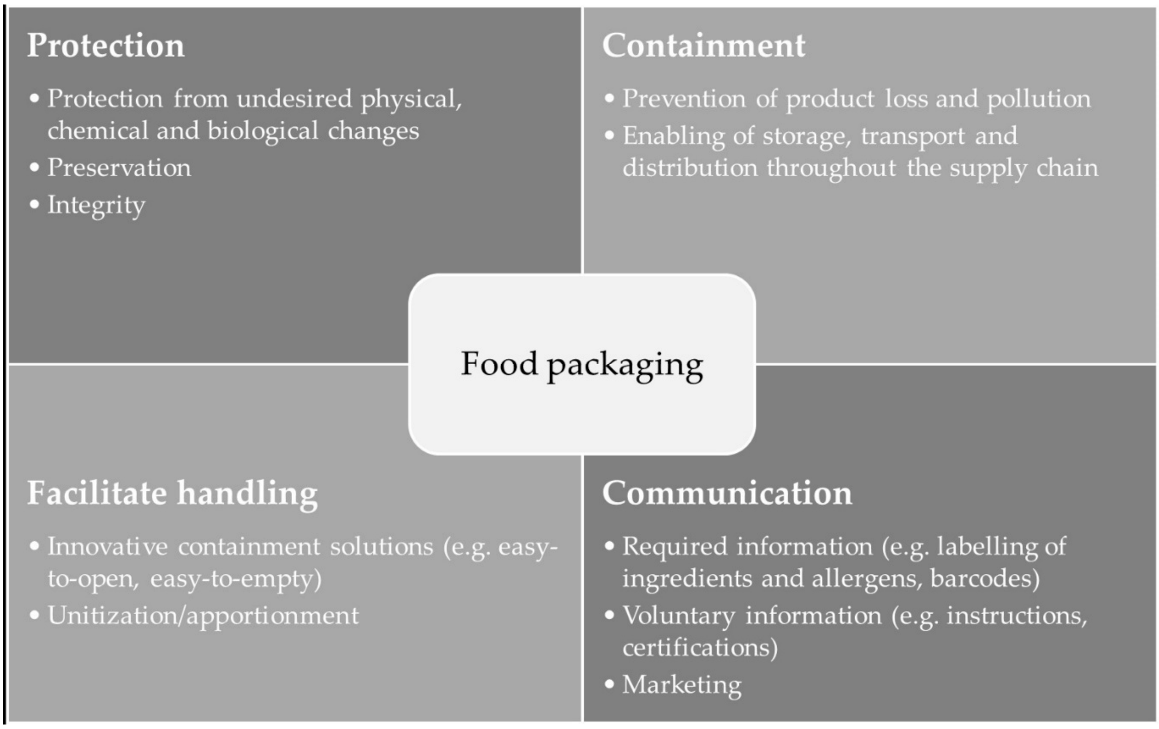

Figure 1. Packaging functions, based on [18,19].

However, while optimizing the protective function of a package, it is very important to pay particular attention to the needs and attitudes of consumers. As a survey in Norway shows, consumers with high amounts of food waste tend to be less environmentally aware with regard to packaging solutions (i.e., recyclability, material perceived as eco-friendly) than 'no-wasters', but show a higher willingness to pay more for packaging that helps to keep food fresh than no-wasters. One possible reason may be that high-wasting consumers buy bread more frequently, as well as more bread per shopping trip [22].

In a report by the American Institute for Packaging and the Environment (AMERIPEN), the authors emphasize the protective function and refer to packaging as an 'under-utilized solution that could significantly reduce food waste' [23]. One of the arguments is derived from a negative correlation between the proportion of packaged goods and the observed FLW. However, there is a growing public discourse about the environmental impact of using increased amounts of packaging and its actual contribution to sustainability. Globally, 348 million metric tons of plastic are produced each year [24], which gives rise to about 400 million tons of CO_2, including waste management [25]. In Europe, 39.7% of the plastic is used for packaging. However, only 40.8% of this plastic packaging is also recycled [24]. Every year, 4.8–12.7 metric tons of plastic waste enters the ocean, including plastic packaging [26]. In a business-as-usual scenario, by 2050, there could be more plastic than fish in the sea [25]. Another criticism of plastic packaging concerns impacts on human health. Particularly, some additives, such as bisphenol A or phthalates, are recognized as having endocrine effects [27,28].

Several environmental non-governmental organizations (NGOs) take an opposing position to the packaging industry in their report, 'Unwrapped' [29], which states that since 2005, the amount of food waste in European households has increased along with the amount of plastic packaging used. From this correlation, the authors of the study deduce that 'while some packaging has a role to play in protecting food and extending shelf life, many packaging practices increase wastefulness of both food and packaging'. Although the conclusions of both the AMERIPEN and the Unwrapped report are based on correlations and not on actual or implicit causalities, they hint at the importance of having a deeper look at the interrelation between food waste and packaging.

However, consumers identify a food product's sustainability more with minimal or the complete absence of packaging rather than with packaging that keeps food fresh longer [30,31]. Furthermore, in a report by WRAP [32], half of the surveyed consumers stated that packaging is harmful to the environment and only a quarter agreed that packaging extends the shelf life of a product. Further, consumers identify the key benefits of packaging as 'keeps products safe and hygienic', 'provides important information on labels', and 'protects the food from the factory to the shop and on the way home', while only 13% think that packaging also protects the food at home. When asked whether packaging or food waste would be more environmentally harmful, opinion is divided. This is more or less in agreement with an Italian survey [33], where 60% of the consumers were convinced that packaging has a greater environmental impact than food waste. However, contrary to the conception of consumers, the contribution of FLW to the carbon footprint in a food packaging system is, in most cases, higher than that of the production and waste management of the packaging [34]. In general, the more resource-intensive the food production is, the more worthwhile is a more elaborate packaging [35]. In most cases, packaging accounts for only 1%–12% (typically around 5%) of greenhouse gas emissions in a life cycle assessment of a food packaging system [36]. Following this line of argument, prevention of FLW may arguably be seen as one, if not the most, important strategy for packaging optimization for most types of food [37,38]. Nevertheless, as long as consumers are not aware of the importance of FLW reduction by appropriate packaging, this represents a conflict of objectives and, hence, the main challenge for all stakeholders in the packaging design process.

3. Causes of Food Losses and Food Waste Related to Packaging

A first approach to determine packaging-related food loss or waste is to identify the stages in a food supply chain in which food is in a package. Once a product is packed—whether for transport or product packaging—this packaging can or may lead to a loss of contents. An estimate based on a survey of Swedish households' waste behavior showed that packaging-related FLW (PFLW) contributes to 20% to 25% of a household's total amount of food waste [39], but otherwise such data are scarcely available [40].

If FLW occurs, it does not necessarily mean that the food was originally inedible. Edible food may also be discarded only because the expiration date is exceeded. Hence, packaging-related FLW can refer to edible or inedible food. What is meant by a so-called expiration date are actually two dates, the 'best before' and the 'use by' date. The 'best before' date is a date of the minimum shelf life and signals the date until the food retains its quality, such as flavor and texture. Retailers are permitted to sell food after the best before date has passed. For food that is 'highly perishable' and, after a short period, is likely to 'constitute an immediate danger to human health', the best before date is to be replaced by a 'use by' date [21]. After the 'use by' date, food is deemed to be unsafe, in contrast to the exceedance of the 'best before'. Interestingly, 64% of consumers in the EU misinterpret the meaning of the best before date [41]. While consumers often confuse best before and use by dates, they state that they need more information about the shelf life of food once a package has been opened [42].

Looking at the food supply chain, there are many different stages and reasons why food may be wasted. As packaging is generally first introduced right after harvest, the identified stages of the food supply chain where PFLW can occur start with the post-harvest stage and end with the serving of food (see Table 1). Mechanical damage to food and/or its packaging and therefore the discarding of the product can occur during any stage of transportation while in transport packaging [17].

Table 1. Packaging-related food loss and waste along the food supply chain.

Stage		Type of Packaging-Related Food Losses and Waste	References
Food in the supply chain	Primary production	-	-
	Post-harvest handling and storage	Damage of products due to contaminants, sharp edges or splinters of field containers, over-packing of field crates	[43,44]
	Processing and packaging	Problems in the filling process Packaging failures while sealing Packaging changes due to marketing reasons	[45–48] [49] [16]
	Distribution and retail	Packaging does not provide enough mechanical protection (inappropriate packaging material, poor stackability, no packaging at all) Damage to barcodes on packaging	[45,50,51]
Food in households		Difficult to open packaging Difficult to empty packaging Inappropriate packaging size	[52,53] [39,54] [55–60]

Source: Own elaboration, references for the different food supply stages: [10,61,62].

3.1. PFLW in the Supply Chain

As there is no packaging involved in the primary production of food, packaging-related FLW may start during the post-harvest handling and storage stage of food. If produce is harvested and packed in field containers, these should be properly cleaned beforehand to not introduce any contaminants into the food [43], as well as be free of any sharp edges or splinters that could damage the food [44].

At the processing stage, the main causes of FLW are overproduction, misshaped food, and packaging damage [63,64]. Technical malfunctions are mainly comprised of filling problems. During a manual filling process, food can be lost through bad handling due to poor work conditions [45]. In an automatic filling process, losses can occur when packaging and filling machines are not well matched or if there is a malfunction of the machinery, e.g., resulting in bottle overfilling [46]. As there are strict requirements for food companies on the filling level, companies tend to overfill rather than underfill their containers [48]. Furthermore, losses can occur due to the batch process itself and corrections that are needed before the filling machine can run correctly [47]. After filling, packaging may leak due to a failure in the closure (e.g., the heat seal) [49]. Another issue at the packaging stage, for which the retail sector is actually a key driver, is ongoing changes to the packaging of food products for marketing reasons [16]. As packaging is often bought in large amounts, this may lead to packaging waste, but could also contribute to FLW if already packed food is discarded.

While in distribution, food losses may occur due to damage of the packaging, the exceedance of expiration dates, or poor stock management [65]. Products may be packed poorly, e.g., without sufficient protection, or loaded without any packaging at all. Roads in bad condition increase the risk of damaging the food during transport [45]. An important packaging function to consider concerning PFLW while storing and distributing food is stackability. If crates cannot be well stacked, damages can lead to a collapse of the lower levels due to the pressure from high loads. This led to a loss of around 30% in the case of an investigated supply chain of citrus fruits [50]. Inappropriate stacking of trays was also one of the main causes of FLW reported in the case of strawberries in the UK [66]. In a comparative assessment of two different product and transport packages (corrugated cardboard and plastic crates) for eggs, an average breakage rate of 1.1% was observed while the results of the four different packaging scenarios varied between 0.56% and 2.38%. These damages were attributed to poorly stacked crates, as well as the inadequate quality of the corrugated board used and mismatched primary, secondary, and tertiary packaging [51].

After distribution, food is stored in the retail sector, a sector which is responsible for around 5% of FLW in Europe [67]. As reported by the retail chains, expired shelf life is the main reason for the generation of FLW [37,68]. This may be due to delays at the pre-distribution stages, while premature spoilage may occur due to improper packaging and storage temperatures or rough handling [37]. Packaging damage is rather rare and may just mean that the imprinted barcodes are unreadable [45].

Since it is time-consuming to remove food from a package, some supermarkets may forgo this procedure [49,69]. If a package contains only partly spoiled food, this may lead to the disposal of otherwise saleable goods [70]. Food and packaging are then disposed of as a whole as residual waste instead of as separated organic waste for food, and plastic or municipal waste for the packaging. The separation does not necessarily occur in the downstream waste treatment either and even if it does, food-contaminated packaging reduces the possibility of a potential mechanical recycling of the packaging, further contributing to a higher environmental impact [71].

3.2. Packaging-Related FLW at the Consumer

3.2.1. Effects of Packaging Design

Besides the primary function of protecting its content, a package has also to be able to facilitate handling. Therefore, the packaging manufacturer has to enable the easiness of unpacking, openability, and emptying of a package with the design [18]. Poor openability can lead to FLW as consumers may spill food or beverages if the opening of a package proves difficult. This is particularly true for elderly people or for those with disabilities [52,53].

When talking about the ability to empty the packaging entirely a distinction can be made between the terms, 'easy-to-empty' and 'easy-to-access', according to Plastics Recyclers Europe. In their online recyclability assessment tool for plastic packaging, *RecyClass* [72], the easy-to-empty index is intended for 'packaging where the content is not accessible for emptying (i.e., bottles, tubes)' and the easy-to-access index for packaging 'where the content is accessible for emptying (i.e., pots)'. 'Easy to empty' means that a package can be emptied without force (i.e., flipping and holding the open package vertically for a period of time) and 'easy to access' simulates a regular use by a consumer (i.e., using a spoon to empty a yogurt cup). Plastics recyclers are concerned about food residues, as these may interfere with the recycling process of the packaging [73].

Food residues in packaging were addressed in an exploratory study with Swedish households [39]. In this study, yogurt and sour milk in liquid packaging board contributed 75%, liquid margarine, jam, porridge, mayonnaise, and soups in plastic, glass, fiber-based, or metal packaging 25% to the 'difficult-to-empty' waste. The viscosity of the food is likely to play an important role, as products with high viscosity were more inclined to stick to the inside of the packaging. In total, waste due to the poor emptiability of packaging led to approximately 4% of the total amount of FLW generated by the surveyed households. The process of emptying a package is not only influenced by the packaging design, but also the person responsible for opening it, particularly in the case of the 'easy to access' function. As the authors state, the waste associated with emptying a yogurt package was very different between the two surveyed groups, one with education about environmental issues and one without [39]. This was further substantiated with a test of the emptying behavior of 1000 mL milk packages, where residues of 4.7–14.7 mL were found. The authors point out that the simulation of a final stirring process by the consumer significantly influenced the resulting waste. Further important factors that influenced the emptying behavior could be attributed to the presence of a fold at the bottom of the package and corrugations in its internal wall, as well as the shape of the package itself [54].

3.2.2. Effects of Packaging Size

At the household level, spoiled food may be seen as a symptom of many different problems and not as a reason for waste per se. Hence, one has to look at the root causes of what leads to a household not eating purchased food in time [68]. Of course, this may be due to unexpected events, however, there is evidence to suggest that inadequate packaging sizes are a key factor in the generation of FLW. Packaging size is a growing concern for consumers as well as retailers, but for the latter, more in the context of packaging waste instead of FLW [16].

The potential amount of FLW may be dependent on the packaging function 'apportionment', i.e., when a product is divided from the large-scale production units into the desired amount and size. If a product is offered in two packs of 75 g that can be separately opened instead of one 150 g pack, there is a greater amount of packaging used per packed food. This may result in a higher environmental impact of packaging, as consumers have to buy multiple packages in a single visit [55], but also may result in a higher chance of consuming food in time [18]. An optimized apportionment not only helps households in reducing FLW, but also the retail sector by enabling a better management of stock [50]. Only 17% of surveyed consumers in Italy state that portions 'generally reflect their needs' [60]. At the same time, consumers who buy larger packages also waste more food. As the household size has a strong influence on the total amount of generated food waste, it is clear that packaging size has too. Single households generate the most food waste per capita and by comparison, people in four-person households waste less than half than a person in a single household [56].

When asked about which activities or interventions would help to reduce food waste in their homes, most households state meal planning, the change of preferences and food habits, and of the need for different packaging options at retail [58]. Interestingly, households that state that purchasing too large packages is 'at least sometimes a reason for wasting food' have greater amounts of food waste than others. This is even more significant in households that say it is the reason 'most of the time' or 'always'. Households that believe they may be able to reduce food waste by buying smaller packages waste more food than others [59]. All in all, a third of the households claim that they would generate less food waste if the packaging size of food products would be more suited to their needs [60].

Furthermore, consumers in Germany and Italy point out that the packaging sizes of many types of fresh produce, as well as dairy products, baking ingredients, meat products, and pasta, are too big, while complaining about the higher price of smaller packages in comparison to larger ones [56]. Buying large packages contributes significantly to excessive purchasing, which is true in particular for low-income households, where this leads to over-preparing and thus to the generation of FLW [57]. The simple solution would be to just shrink packages then, but understanding the impact of packaging size on FLW is anything but trivial [74].

That is to say, it is hard to estimate how much consumers waste due to packaging size or apportionment [75], as long as there is a lack of empirical studies.

3.2.3. Effects of Packaging Technology

Currently, both packaging and future developments in material technology have a huge potential to minimize FLW [15,17] and to contribute to food safety and security [45]. In the context of technology, packaging potentially prolongs shelf life. As material technology is always making advances, more and more polymer-based multilayer packaging is used, which extends the shelf life of food while reducing packaging weight [76]. Due to good barrier properties, multilayer materials are suitable for modified atmosphere packaging (MAP). Such packages contain a modified gas composition, mainly nitrogen, carbon dioxide, or oxygen, which aims to reduce microbial growth and chemical deterioration of the packaged food and therefore increases its shelf life [77]. The downside of multilayer packaging is that it is usually landfilled or incinerated due to poor recyclability [78].

Another promising technology is active and intelligent packaging, which is set to become more prevalent in the future. Active packaging contains 'deliberately incorporated components intended to release or absorb substances into or from the packaged food or from the environment surrounding the food' [79] and has, therefore, the purpose to extend the shelf life of food [80,81]. Intelligent packaging is comprised of 'materials and articles that monitor the condition of packaged food or the environment surrounding the food' [79] and may be able to reduce FLW by abandoning the system of a fixed best before data by providing dynamic information about the actual condition of the food [82].

4. Integration of FLW in LCA of Packaging

As elaborated upon, it is important to emphasize the aspect of packaging-related FLW when talking about the environmental performance of packaging. A well-known and commonly used method to investigate environmental impacts of food across the supply chain is LCA [83]. However, in relation to available food LCAs, only a few studies integrate packaging-related FLW [84]. The studies investigated for this review include the calculation of the environmental impacts of (i) food loss probabilities dependent on the shelf life, (ii) break-even rates of FLW compared to packaging, (iii) scenarios of FLW amounts based on expert opinion, and (iv) a (e.g., protection) function-based approach in ex-ante LCA.

Most LCA studies of food use 1 kg produced or packaged food as a functional unit, a quantified performance in a system for use as a reference unit [85]. In contrast, a functional unit of 1 kg consumed food allows an accounting for the impact of packaging-related FLW [86–90]. This enables a comparison between packaging that wastes more and packaging that wastes less food. As a result, in some cases, the total carbon footprint of the respective food-packaging system may be lower with resource-intensive compared to resource-efficient packaging (Figure 2).

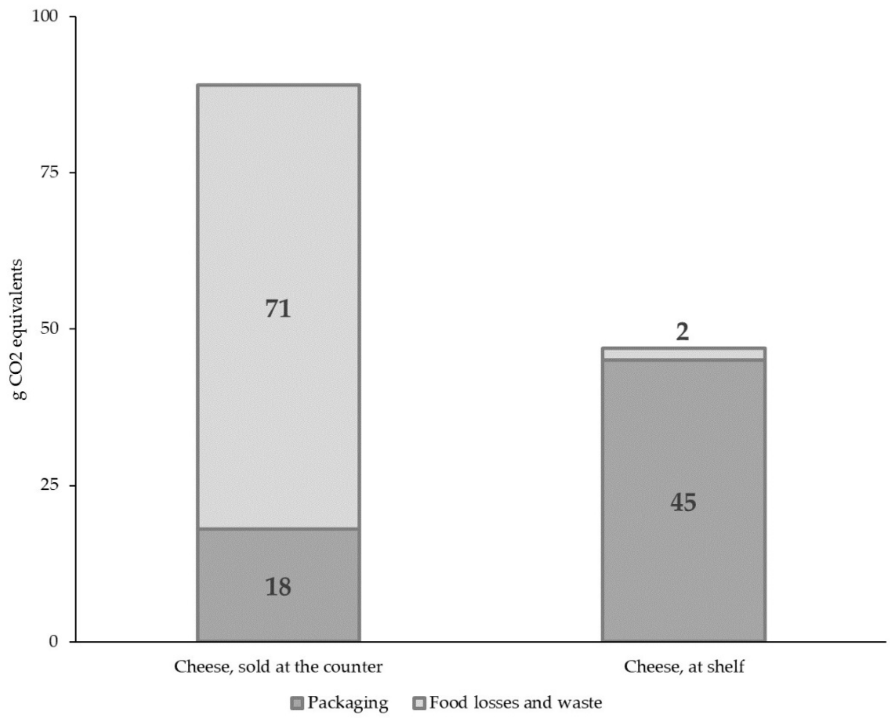

Figure 2. Carbon footprint of two packaging options for cheese, per 150 g cheese, adapted from [35].

Unfortunately, in most cases, there is no actual FLW data available for a specific food-packaging system [90]. To that end, methods have to be developed for estimating packaging-related FLW. A novel approach is the calculation of food loss probabilities of packages due to different best before dates [91,92]. For instance, by extending the shelf life of specific products, such as yogurt and cream, a considerable reduction of FLW can be reached [93]. There is, however, no direct relationship between a longer shelf life and FLW generation [94], meaning that an extended shelf life does not automatically translate to less FLW for every food product. The best before date can have a significant impact on the purchase decision [95] and depends not only on the product category, but also on the size of the retailer. Medium and larger supermarkets can benefit from faster turnovers, while for smaller supermarkets, it is better to place fewer orders and have products with a longer shelf life [96]. The issue of quantifying FLW reduction in relation to its shelf life is therefore challenging. If a packaging is already on the market, research suggests that the integration of the emptying behavior of a package in its LCA is feasible as well as advisable [54].

The calculation of break-even rates could be one way to deal with uncertainties about packaging-related FLW amounts. This means that packaging designers or LCA analysts could calculate when an increase in packaging would pay off in return for less FLW [97,98]. In addition, an LCA analyst may calculate scenarios with different packaging-related FLW rates based on expert opinion [99]. Another example is a function-based approach, to be used when altering or redesigning food packaging. An ex-ante LCA of food packaging may compare two different packaging design decisions by looking at parameters, such as stackability and oxygen or water vapor transmission rates, and calculate the LCA by adjusting the required amounts accordingly [100].

5. Discussion

Thirty percent of all food produced becomes waste. The use of appropriate packaging may be one way to reduce this percentage. Particularly in developing countries, a lack of packaging is stated as one of the main drivers of food losses or waste by the FAO [17].

In industrialized countries, the contribution of packaging to FLW is less clear-cut. Packaging plays an essential part in food protection and thus can reduce FLW. Examples include non-adequate packaging (too large packaging sizes, inappropriate material, contaminated packaging, technical failures in the packaging process) [43–45,48,50,51,55–60] or packaging that is too difficult to open [52,53] or to empty [39,54] so that its contents spill or are left in the package. Packaging saves food by mechanical protection or prolong its shelf life by a material with good barrier properties [76], through the use of modified atmosphere packaging [77] and, in the future, by intelligent or active packaging through the dynamic display of its microbiological status [82]. As increasingly more food is consumed outside the home [101], the food service sector contributes a significant share to the amount of FLW [12]. Here, an easy way to reduce FLW may be the use of a so-called ‘doggy-bag’, which can be used to take leftovers to be eaten at a later date [45].

Packaging designers should focus on the influence of the packaging design choices on FLW prevention. In order to reduce packaging-related FLW, packaging has to be designed with the interrelations between primary, secondary, and tertiary packaging in mind [51]. Although a systematic analysis and quantification of packaging design aspects has not yet been performed, optimal product protection and optimization of the shelf life can be considered essential. In addition, packaging may offer design features, such as compartments, that can be opened individually or packaging, which is easily reclosable. A design for easy portioning and small package sizes are further important assets [20,102]. Furthermore, packaging can contain instructions about how best to store the food and to encourage people to freeze leftovers [20], as well as how to serve food to avoid residues in the package [54].

Although FLW and packaging are getting attention in the scientific literature, packaging-related FLW (PFLW) is largely unexplored. As this review shows, there is no reliable data on quantities of PFLW. Furthermore, the quantification of PFLW proves to be difficult, whether with household surveys or waste analysis. Household surveys can lead to wrong quantifications of FLW because answers are often biased by social desirability, a lack of motivation for documenting waste, or simply due to forgetfulness [39]. Waste composition analyses have limitations on information about specific waste quantities by food category and do not include alternative disposal routes of households, such as a separate bio-waste collection, home composting, or the use as pet food [103], but above all, there is no generation of information about the causes of the FLW. These causes are rather complex and are often the result of multiple interacting activities [104] so it is challenging to identify FLW as (at least partially) packaging-related, even when interviewing consumers directly about whether their FLW is connected in any way with packaging [39]. Future research is needed to develop new methods for determining PFLW.

This review has identified further research needs in the implementation of PFLW into the LCA of packaging. Resource-intensive packaging can have an overall lower carbon footprint compared to FLW if its PFLW is lower than a resource-efficient packaging (Figure 2). As a result, the assessment of the contribution of packaging to a sustainable food system can be turned upside down. Therefore, the quantification and implementation of PFLW into the LCA of packaging is of great importance. However, there is a lack of LCA studies on packaging considering PFLW [84]. However, in the reviewed research articles, there is agreement on the importance of PFLW and a number of authors already support the call for further research on this topic [39,40,84,87,92,97].

6. Conclusions

Future packaging developments should focus on further advancements in packaging technology, but should not neglect the importance of indirect effects of packaging. Stakeholders in the packaging design should understand the demands of the packaging across the whole supply chain to optimize their product in reducing food losses and waste. This should be done by undertaking studies on consumer behavior as well as the provision of education and the collaboration between producers, manufacturers, and retailers [105]. More research is required to quantify packaging-related food loss and waste so that life cycle assessments can incorporate the direct as well as the indirect environmental effects of packaging to help facilitate the environmentally preferable choice.

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References

1. FAO. *FAO Statistical Yearbook 2013—World Food and Agriculture*; FAO: Rome, Italy, 2012.
2. Gustavsson, J.; Cederberg, C.; Sonesson, U. *Global Food Losses and Food Waste: Extent, Causes and Prevention; Study Conducted for the International Congress Save Food! at Interpack 2011, [16–17 May], Düsseldorf, Germany*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2011.
3. FAO. *Food Wastage Footprint: Impacts on Natural Resources Summary Report*; FAO: Rome, Italy, 2013.
4. Alexander, P.; Brown, C.; Arneth, A.; Finnigan, J.; Moran, D.; Rounsevell, M.D.A. Losses, inefficiencies and waste in the global food system. *Agric. Syst.* **2017**, *153*, 190–200. [CrossRef] [PubMed]
5. FAO; IFAD; WFP. *The State of Food Insecurity in the World 2015: Meeting the 2015 International Hunger Targets: Taking Stock of Uneven Progress*; FAO: Rome, Italy, 2015.
6. UN, Department of Economic and Social Affairs, Population Division. *World Population Prospects. The 2017 Revision: Key Findings and Advance Tables*; Working Paper No. EDA/P/WP/248; United Nations: New York, NY, USA, 2017.
7. UN. *General Assembly. Work of the Statistical Commission Pertaining to the 2030 Agenda for Sustainable Development. Resolution Adopted by the General Assembly on 6 July 2017: A/RES/71/313*; United Nations: New York, NY, USA, 2017.
8. Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on Waste: 2008/98/EC; 2018. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0851&rid=5 (accessed on 23 December 2018).
9. Chaboud, G.; Daviron, B. Food losses and waste: Navigating the inconsistencies. *Glob. Food Secur.* **2017**, *12*, 1–7. [CrossRef]
10. Parfitt, J.; Barthel, M.; Macnaughton, S. Food waste within food supply chains: Quantification and potential for change to 2050. *Philos. Trans. R. Soc. London Ser. B* **2010**, *365*, 3065–3081. [CrossRef] [PubMed]
11. Quested, T.; Johnson, H. *Household Food and Drink Waste in the UK: Final Report*; WRAP: Barbury, UK, 2009.

12. Östergren, K.; Gustavsson, J.; Bos-Brouwers, H.; Timmermans, T.; Hansen, O.-J.; Moller, H.; Anderson, G.; O'Connor, C.; Soethoudt, H.; Quested, T.; et al. *FUSIONS Definitional Framework for Food Waste: Full Report*; SIK—The Swedish Institute for Food and Biotechnology: Boras, Sweden, 2014.
13. Redlingshöfer, B.; Coudurier, B.; Georget, M. Quantifying food loss during primary production and processing in France. *J. Clean. Prod.* **2017**, *164*, 703–714. [CrossRef]
14. Xue, L.; Liu, G.; Parfitt, J.; Liu, X.; van Herpen, E.; Stenmarck, Å.; O'Connor, C.; Östergren, K.; Cheng, S. Missing Food, Missing Data? A Critical Review of Global Food Losses and Food Waste Data. *Environ. Sci. Technol.* **2017**, *51*, 6618–6633. [CrossRef]
15. Kowalska, A. The issue of food losses and waste and its determinants. *Logforum* **2017**, *13*, 7–18. [CrossRef]
16. Mena, C.; Adenso-Diaz, B.; Yurt, O. The causes of food waste in the supplier–retailer interface: Evidences from the UK and Spain. *Resour. Conserv. Recycl.* **2011**, *55*, 648–658. [CrossRef]
17. Manalili, N.M.; Dorado, M.A.; van Otterdijk, R. *Appropriate Food Packaging Solutions for Developing Countries*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2014.
18. Lindh, H.; Williams, H.; Olsson, A.; Wikström, F. Elucidating the Indirect Contributions of Packaging to Sustainable Development: A Terminology of Packaging Functions and Features. *Packag. Technol. Sci.* **2016**, *29*, 225–246. [CrossRef]
19. Singh, P.; Wani, A.A.; Langowski, H.-C. (Eds.) *Food Packaging Materials: Testing & Quality Assurance*; CRC Press Tayöpr & Francis Group: Boca Raton, FL, USA; London, UK; New York, NY, USA, 2017.
20. Wansink, B. Household Food Waste Solutions for Behavioral Economists and Marketers. *J. Food Prod. Mark.* **2018**, *24*, 500–521. [CrossRef]
21. Regulation (EU) No 1169/2011 of the European Parliament and of the Council of 25 October 2011 on the Provision of Food Information to Consumers, Amending Regulations (EC) No 1924/2006 and (EC) No 1925/2006 of the European Parliament and of the Council, and Repealing Commission Directive 87/250/EEC, Council Directive 90/496/EEC, Commission Directive 1999/10/EC, Directive 2000/13/EC of the European Parliament and of the Council, Commission Directives 2002/67/EC and 2008/5/EC and Commission Regulation (EC) No 608/2004: 1169/2011. 2011. Available online: https://www.fsai.ie/uploadedFiles/Reg1169_2011.pdf (accessed on 23 December 2018).
22. Østergaard, S.; Hanssen, O.J. Wasting of Fresh-Packed Bread by Consumers—Influence of Shopping Behavior, Storing, Handling, and Consumer Preferences. *Sustainability* **2018**, *10*, 2251. [CrossRef]
23. AMERIPEN. *Quantifying the Value of Packaging as a Strategy to Prevent Food Waste in America: January 2018*; American Institute for Packaging and the Environment: St. Paul, MN, USA, 2018.
24. PlasticsEurope. *Plastics—The Facts 2018: An Analysis of European Plastics Production, Demand and Waste Data*; PlasticsEurope: Brussels, Belgium, 2018.
25. World Economic Forum, Ellen MacArthur Foundation and McKinsey & Company. *The New Plastics Economy: Rethinking the Future of Plastics*; Ellen MacArthur Foundation: Cowes, UK, 2016.
26. Jambeck, J.R.; Geyer, R.; Wilcox, C.; Siegler, T.R.; Perryman, M.; Andrady, A.; Narayan, R.; Law, K.L. Marine pollution. Plastic waste inputs from land into the ocean. *Science* **2015**, *347*, 768–771. [CrossRef] [PubMed]
27. Foster, P.M.D. Disruption of reproductive development in male rat offspring following in utero exposure to phthalate esters. *Int. J. Androl.* **2006**, *29*, 140–147. [CrossRef] [PubMed]
28. Sonnenschein, C.; Soto, A.M. An updated review of environmental estrogen and androgen mimics and antagonists. *J. Steroid Biochem. Mol. Biol.* **1998**, *65*, 143–150. [CrossRef]
29. Schweitzer, J.-P.; Gionfra, S.; Pantzar, M.; Mottershead, D.; Watkins, E.; Petsinaris, F.; ten Brink, P.; Ptak, E.; Lacey, C.; Janssens, C. *Unwrapped: How Throwaway Plastic Is Failing to Solve Europe's Food Waste Problem (and What We Need to Do Instead)*; Institute for Euroean Environmental Policy AISBL: Brussels, Belgium, 2018.
30. Sealed Air Corporation. *Taking Stock: Retail Shrink Solutions: White Paper*; Sealed Air Corporation: Charlotte, NC, USA, 2015.
31. Bovensiepen, G.; Fink, H.; Schnück, P.; Rumpff, S.; Raimund, S. *Verpackungen im Fokus: Die Rolle von Circular Economy auf dem Weg zu mehr Nachhaltigkeit*; PriceWaterhouseCoopers GmbH Wirtschaftsprüfungsgesellschaft: Frankfurt am Main, Germany, 2018.
32. Plumb, A.; Downing, P.; Parry, A. *Consumer Attitudes to Food Waste and Food Packaging: A Qualitative and Quantitative Investigation into Consumer Attitudes to, and Behaviour Around, Food Waste and Food Packaging, Which Will Inform Action to Help Further Reduce Household Food Waste*; WRAP: Barbury, UK, 2013.

33. Principato, L.; Secondi, L.; Pratesi, C.A. Reducing food waste: An investigation on the behaviour of Italian youths. *Br. Food J.* **2015**, *117*, 731–748. [CrossRef]
34. Silvenius, F.; Katajajuuri, J.-M.; Grönman, K.; Soukka, R.; Koivupuro, H.-K.; Virtanen, Y. Role of Packaging in LCA of Food Products. In *Towards Life Cycle Sustainability Management*; Finkbeiner, M., Ed.; Springer: Dordrecht, The Netherlands, 2011; pp. 359–370.
35. Denkstatt. *Vermeidung von Lebensmittelabfällen durch Verpackung: Kooperationsprojekt mit Partnern aus den Bereichen Rohstoffherstellung, Verpackungsproduktion, Handel, Verpackungsverwertung und Forschung*; Denkstatt: Vienna, Austria, 2014.
36. Silvenius, F.; Grönman, K.; Katajajuuri, J.-M.; Soukka, R.; Koivupuro, H.-K.; Virtanen, Y. The Role of Household Food Waste in Comparing Environmental Impacts of Packaging Alternatives. *Packag. Technol. Sci.* **2014**, *27*, 277–292. [CrossRef]
37. Hanssen, O.J.; Møller, H.; Svanes, E.; Schakenda, V. Life Cycle Assessment as a Tool in Food Waste Reduction and Packaging Optimization: Packaging Innovation and Optimization in a Life Cycle Perspective. In *Life Cycle Assessment Handbook: A Guide for Environmentally Sustainable Products*, 1st ed.; Curran, M.A., Ed.; Scrivener Publishing: Beverly, MA, USA, 2012; pp. 345–367.
38. Williams, H.; Wikström, F. Environmental impact of packaging and food losses in a life cycle perspective: A comparative analysis of five food items. *J. Clean. Prod.* **2011**, *19*, 43–48. [CrossRef]
39. Williams, H.; Wikström, F.; Otterbring, T.; Löfgren, M.; Gustafsson, A. Reasons for household food waste with special attention to packaging. *J. Clean. Prod.* **2012**, *24*, 141–148. [CrossRef]
40. Wikström, F.; Verghese, K.; Auras, R.; Olsson, A.; Williams, H.; Wever, R.; Grönman, K.; Kvalvåg Pettersen, M.; Møller, H.; Soukka, R. Packaging Strategies That Save Food: A Research Agenda for 2030. *J. Ind. Ecol.* **2018**, *14*, 1346. [CrossRef]
41. EU Custom Research and Coordination Centre (GfK EU3C). *Consumer Market Study on the Functioning of the Meat Market for Consumers in the European Union: Final Report*; SANCO/2009/B1/010; GfK EU3C: Brussels, Belgium, 2012.
42. Rohm, H.; Oostindjer, M.; Aschemann-Witzel, J.; Symmank, C.; L Almli, V.; de Hooge, I.E.; Normann, A.; Karantininis, K. Consumers in a Sustainable Food Supply Chain (COSUS): Understanding Consumer Behavior to Encourage Food Waste Reduction. *Foods (Basel, Switzerland)* **2017**, *6*, 104. [CrossRef]
43. Schuur, C.C.M. *Packaging for Fruits, Vegetables and Root Crops*; Food and Agriculture Organization of the United Nations: Bridgetown, Barbados, 1988.
44. Paltrinieri, G. *Handling of Fresh Fruits, Vegetables and Root Crops: A Training Manual for Grenada*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2014.
45. HLPE. *Food Losses and Waste in the Context of Sustainable Food Systems: A Report by The High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*; HLPE: Rome, Italy, 2014.
46. Simões, M.; Martins, R.F.; Marmé, M. Failure analysis of a filling valve from a Brewery's beer filler. *Eng. Fail. Anal.* **2018**, *93*, 87–99. [CrossRef]
47. Williams, H.; Wikström, F.; Lundström, A.; Wickholm, K.; Lorentzon, A. Investigation of consumer attitudes, practices and food waste for three food items, to use as input in new packaging designs that aim to reduce food waste. Proceedings of 28th IAPRI World Symposium on Packaging, Unlocking the Full Potential of Packaging across the Value-Chain, Lausanne, Switzerland, 12 May 2017.
48. Ridgway, J.S.; Henthorn, K.S.; Hull, J.B. Controlling of overfilling in food processing. *J. Mater. Process. Technol.* **1999**, *92-93*, 360–367. [CrossRef]
49. Whitehead, P.; Palmer, M.; Mena, C.; Williams, A.; Walsh, C. *Resource Maps for Fresh Meat across Retail and Wholesale Supply Chains: Mapping out Resource Use in the Retail and Wholesale Supply Chain of Fresh Meat*; WRAP: Barbury, UK, 2011.
50. Hellström, D.; Olsson, A. *Managing Packaging Design for Sustainable Development: A Compass for Strategic Directions*; John Wiley & Sons: Chichester, UK, 2017.
51. Lipski, J.; Sadlowsky, B. Ei-Care, Optimierung der klassischen Eierverpackung. 2014. Available online: https://www.easyfairs.com/fileadmin/groups/9/VERPACKUNG_LuS_Nord/2014_Dokumente_und_Downloads/Vortraege/BFSV_e.G.__Praesentation_Eier-Care_fuer_Easy_Fair_23_01_13.pdf (accessed on 3 September 2018).
52. Duizer, L.M.; Robertson, T.; Han, J. Requirements for packaging from an ageing consumer's perspective. *Packag. Technol. Sci.* **2009**, *22*, 187–197. [CrossRef]

53. Rowson, J.; Yoxall, A. Hold, grasp, clutch or grab: Consumer grip choices during food container opening. *Appl. Ergon.* **2011**, *42*, 627–633. [CrossRef] [PubMed]
54. Meurer, I.R.; Lange, C.C.; Hungaro, H.M.; Bell, M.J.V.; dos Anjos, V.D.C.; de Sá Silva, C.A.; de Oliveira Pinto, M.A. Quantification of whole ultra high temperature UHT milk waste as a function of packages type and design. *J. Clean. Prod.* **2017**, *153*, 483–490. [CrossRef]
55. Gustavo, J.U.; Pereira, G.M.; Bond, A.J.; Viegas, C.V.; Borchardt, M. Drivers, opportunities and barriers for a retailer in the pursuit of more sustainable packaging redesign. *J. Clean. Prod.* **2018**, *187*, 18–28. [CrossRef]
56. Jörissen, J.; Priefer, C.; Bräutigam, K.-R. Food Waste Generation at Household Level: Results of a Survey among Employees of Two European Research Centers in Italy and Germany. *Sustainability* **2015**, *7*, 2695–2715. [CrossRef]
57. Porpino, G.; Parente, J.; Wansink, B. Food waste paradox: Antecedents of food disposal in low income households. *Int. J. Consum. Stud.* **2015**, *39*, 619–629. [CrossRef]
58. Parizeau, K.; von Massow, M.; Martin, R. Household-level dynamics of food waste production and related beliefs, attitudes, and behaviours in Guelph, Ontario. *Waste Manag.* **2015**, *35*, 207–217. [CrossRef]
59. Koivupuro, H.-K.; Hartikainen, H.; Silvennoinen, K.; Katajajuuri, J.-M.; Heikintalo, N.; Reinikainen, A.; Jalkanen, L. Influence of socio-demographical, behavioural and attitudinal factors on the amount of avoidable food waste generated in Finnish households. *Int. J. Consum. Stud.* **2012**, *36*, 183–191. [CrossRef]
60. Lanfranchi, M.; Calabrò, G.; de Pascale, A.; Fazio, A.; Giannetto, C. Household food waste and eating behavior: Empirical survey. *Br. Food J.* **2016**, *118*, 3059–3072. [CrossRef]
61. Priefer, C.; Jörissen, J.; Bräutigam, K.-R. Food Waste Generation in Europe: Reasons, Scale, Impacts and Prevention Strategies. *Technikfolgenabschätzung—Theorie Praxis* **2014**, *23*, 21–31.
62. Manzocco, L.; Alongi, M.; Sillani, S.; Nicoli, M.C. Technological and Consumer Strategies to Tackle Food Wasting. *Food Eng. Rev.* **2016**, *8*, 457–467. [CrossRef]
63. Monier, V.; Mudgal, S.; Escalon, V.; O'Connor, C.; Gibon, T.; Anderson, G.; Montoux, H. *Preparatory Study on Food Waste Across EU 27: Technical Report*; European Communities: Paris, France, 2010.
64. Priefer, C.; Jörissen, J.; Bräutigam, K.-R. *Technology Options for Feeding 10 Billion People: Options for Cutting Food Waste*; Science and Technology Options Assessment: Brussels, Belgium, 2013.
65. Priefer, C.; Jörissen, J.; Bräutigam, K.-R. Food waste prevention in Europe–A cause-driven approach to identify the most relevant leverage points for action. *Resour. Conserv. Recycl.* **2016**, *109*, 155–165. [CrossRef]
66. Terry, L.; Mena, C.; Williams, A.; Jenney, N.; Whitehead, P. *Fruit and Vegetable Resource Maps. Final Report*; Mapping Fruit and Vegetable Waste through the Retail and Wholesale Supply Chain; WRAP: Barbury, UK, 2011.
67. Stenmarck, Å.; Jensen, C.; Quested, T.; Moates, G. *Estimates of European Food Waste Levels*; IVL Swedish Environmental Research Institute: Stockholm, Sweden, 2016.
68. Kliaugaite, D.; Kruopiene, J. Food waste generation and prevention measures in retail sector: A comparative study. *EREM* **2018**, *73*. [CrossRef]
69. Naturvårdsverket. *Food Waste Volumes in Sweden*; Swedish Environmental Protection Agency: Stockholm, Sweden, 2014.
70. Göbel, C.; Teitscheid, P.; Ritter, G.; Blumenthal, A.; Friedrich, S.; Frick, T.; Grotstollen, L.; Möllenbeck, C.; Rottstegge, L.; Pfeiffer, C. *Verringerung von Lebensmittelabfällen—Identifikation von Ursachen und Handlungsoptionen in Nordrhein-Westfalen: Kurzfassung Studie für den Runden Tisch "Neue Wertschätzung von Lebensmitteln" des Ministeriums für Klimaschutz, Umwelt, Landwirtchaft, Natur- und Verbraucherschutz des Landes Nordrhein-Westfalen*; Fachhochschule Münster, Institut für Nachhaltige Ernährung und Ernährungswirtschaft—iSuN: Münster, Germany, 2012.
71. Brancoli, P.; Rousta, K.; Bolton, K. Life cycle assessment of supermarket food waste. *Resour. Conserv. Recycl.* **2017**, *118*, 39–46. [CrossRef]
72. Plastics Recyclers Europe. RecyClass—The Recyclability Tool for Plastic Package; 2018. Available online: http://www.recyclass.eu/en/home (accessed on 4 September 2018).
73. Maris, J.; Bourdon, S.; Brossard, J.-M.; Cauret, L.; Fontaine, L.; Montembault, V. Mechanical recycling: Compatibilization of mixed thermoplastic wastes. *Polym. Degrad. Stab.* **2018**, *147*, 245–266. [CrossRef]
74. Wilson, N.L.W.; Rickard, B.J.; Saputo, R.; Ho, S.-T. Food waste: The role of date labels, package size, and product category. *Food Qual. Preference* **2017**, *55*, 35–44. [CrossRef]

75. Chayer, J.-A.; Kicak, K. *Life Cycle Assessment of Coffee Consumption: Comparison of Single-Serve Coffee and Bulk Coffee Brewing: Final Report*; Quantis Canada: Montreal, QC, Canada, 2015.
76. Oki, Y.; Sasaki, H. Social and environmental impacts of packaging (LCA and assessment of packaging functions). *Packag. Technol. Sci.* **2000**, *13*, 45–53. [CrossRef]
77. Kirtil, E.; Kilercioglu, M.; Oztop, M.H. Modified Atmosphere Packaging of Foods. In *Reference Module in Food Science*; Elsevier: Amsterdam, The Netherlands, 2016.
78. Kaiser, K.; Schmid, M.; Schlummer, M. Recycling of Polymer-Based Multilayer Packaging: A Review. *Recycling* **2018**, *3*, 1. [CrossRef]
79. Regulation (EC) No 1935/2004 of the European Parliament and of the Council of 27 October 2004 on Materials and Articles Intended to Come into Contact with Food and Repealing Directives 80/590/EEC and 89/109/EEC: 1935/2004. 2004. Available online: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:338:0004:0017:en:PDF (accessed on 23 December 2018).
80. Dainelli, D.; Gontard, N.; Spyropoulos, D.; Zondervan-van den Beuken, E.; Tobback, P. Active and intelligent food packaging: Legal aspects and safety concerns. *Trends Food Sci. Technol.* **2008**, *19*, S103–S112. [CrossRef]
81. Zhang, H.; Hortal, M.; Dobon, A.; Bermudez, J.M.; Lara-Lledo, M. The Effect of Active Packaging on Minimizing Food Losses: Life Cycle Assessment (LCA) of Essential Oil Component-enabled Packaging for Fresh Beef. *Packag. Technol. Sci.* **2015**, *28*, 761–774. [CrossRef]
82. Poyatos-Racionero, E.; Ros-Lis, J.V.; Vivancos, J.-L.; Martínez-Máñez, R. Recent advances on intelligent packaging as tools to reduce food waste. *J. Clean. Prod.* **2018**, *172*, 3398–3409. [CrossRef]
83. Nemecek, T.; Jungbluth, N.; i Canals, L.M.; Schenck, R. Environmental impacts of food consumption and nutrition: Where are we and what is next? *Int. J. Life Cycle Assess* **2016**, *21*, 607–620. [CrossRef]
84. Molina-Besch, K.; Wikström, F.; Williams, H. The environmental impact of packaging in food supply chains—does life cycle assessment of food provide the full picture? *Int. J. Life Cycle Assess.* **2018**, *21*, 492. [CrossRef]
85. ISO. *Environmental Management—Life Cycle Assessment—Requirements and Guidelines: 14044:2006(en)*; International Organization for Standardization. ISO Central Secretariat: Geneva, Switzerland, 2006.
86. Grant, T.; Barichello, V.; Fitzpatrick, L. Accounting the Impacts of Waste Product in Package Design. *Procedia CIRP* **2015**, *29*, 568–572. [CrossRef]
87. Heller, M.C.; Selke, S.E.M.; Keoleian, G.A. Mapping the Influence of Food Waste in Food Packaging Environmental Performance Assessments. *J. Ind. Ecol.* **2018**, *5*, 134. [CrossRef]
88. Gruber, L.M.; Brandstetter, C.P.; Bos, U.; Lindner, J.P.; Albrecht, S. LCA study of unconsumed food and the influence of consumer behavior. *Int. J. Life Cycle Assess.* **2016**, *21*, 773–784. [CrossRef]
89. Wikström, F.; Williams, H.; Venkatesh, G. The influence of packaging attributes on recycling and food waste behaviour–An environmental comparison of two packaging alternatives. *J. Clean. Prod.* **2016**, *137*, 895–902. [CrossRef]
90. Manfredi, M.; Fantin, V.; Vignali, G.; Gavara, R. Environmental assessment of antimicrobial coatings for packaged fresh milk. *J. Clean. Prod.* **2015**, *95*, 291–300. [CrossRef]
91. Gutierrez, M.M.; Meleddu, M.; Piga, A. Food losses, shelf life extension and environmental impact of a packaged cheesecake: A life cycle assessment. *Food Res. Int. (Ottawa, Ont.)* **2017**, *91*, 124–132. [CrossRef]
92. Conte, A.; Cappelletti, G.M.; Nicoletti, G.M.; Russo, C.; Del Nobile, M.A. Environmental implications of food loss probability in packaging design. *Food Res. Int. (Ottawa, Ont.)* **2015**, *78*, 11–17. [CrossRef] [PubMed]
93. Spada, A.; Conte, A.; Del Nobile, M.A. The influence of shelf life on food waste: A model-based approach by empirical market evidence. *J. Clean. Prod.* **2018**, *172*, 3410–3414. [CrossRef]
94. Dilkes-Hoffman, L.S.; Lane, J.L.; Grant, T.; Pratt, S.; Lant, P.A.; Laycock, B. Environmental impact of biodegradable food packaging when considering food waste. *J. Clean. Prod.* **2018**, *180*, 325–334. [CrossRef]
95. Toma, L.; Costa Font, M.; Thompson, B. Impact of consumers' understanding of date labelling on food waste behaviour. *Oper. Res. Int. J.* **2017**, *22*, 453. [CrossRef]
96. Broekmeulen, R.A.C.M.; van Donselaar, K.H. Quantifying the potential to improve on food waste, freshness and sales for perishables in supermarkets. *Int. J. Prod. Econ.* **2017**. [CrossRef]
97. Yokokawa, N.; Kikuchi-Uehara, E.; Sugiyama, H.; Hirao, M. Framework for analyzing the effects of packaging on food loss reduction by considering consumer behavior. *J. Clean. Prod.* **2018**, *174*, 26–34. [CrossRef]

98. Bacenetti, J.; Cavaliere, A.; Falcone, G.; Giovenzana, V.; Banterle, A.; Guidetti, R. Shelf life extension as solution for environmental impact mitigation: A case study for bakery products. *Sci. Total Environ.* **2018**, *627*, 997–1007. [CrossRef]
99. Flysjö, A. Potential for improving the carbon footprint of butter and blend products. *J. Dairy Sci.* **2011**, *94*, 5833–5841. [CrossRef]
100. Aggarwal, A.; Schmid, M.; Patel, M.K.; Langowski, H.-C. Function-driven Investigation of Non-renewable Energy Use and Greenhouse Gas Emissions for Material Selection in Food Packaging Applications: Case Study of Yoghurt Packaging. *Procedia CIRP* **2018**, *69*, 728–733. [CrossRef]
101. GfK Consumers Panels und Bundesvereinigung der Deutschen Ernährungsindustrie e.V. *Consumers' Choice '15: Die Auflösung der Ernährungsriten—Folgen für das Ess- und Kochverhalten*, 6th ed.; GfK SE: Nürnberg, Germany, 2015.
102. Quested, T.E.; Parry, A.D.; Easteal, S.; Swannell, R. Food and drink waste from households in the UK. *Nutr. Bull.* **2011**, *36*, 460–467. [CrossRef]
103. Lebersorger, S.; Schneider, F. Food loss rates at the food retail, influencing factors and reasons as a basis for waste prevention measures. *Waste Manag.* **2014**, *34*, 1911–1919. [CrossRef] [PubMed]
104. Quested, T.E.; Marsh, E.; Stunell, D.; Parry, A.D. Spaghetti soup: The complex world of food waste behaviours. *Resour. Conserv. Recycl.* **2013**, *79*, 43–51. [CrossRef]
105. Verghese, K.; Lewis, H.; Lockrey, S.; Williams, H. *The Role of Packaging in Minimising Food Waste in the Supply Chain of the Future: Final Report*, 3rd ed.; RMIT University: Melbourne, Australia, 2013.