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Beyond intuition: How consumer choices on packaging and valorization can reduce apple food waste and their impact

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A R T I C L E I N F O

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A B S T R A C T

Nowadays, a lot of effort goes into promoting food loss and waste reduction and this often *without* estimating the actual effectiveness and resource efficiency of different options concerning environmental impact reduction. In this study, we aim to go beyond intuitive choices on matters visible to the consumer: packaging in the supermarket and actions at household level for those apples the consumer no longer wishes to eat fresh. The intuitive choices could be phrased as: "go for large cardboard packages" and "valorise your apples into apple sauce or apple chips if they no longer appear crispy fresh, rather than throwing them in the bin". For our analysis, we build on our previously published study on the environmental impact of the Belgian apple-chain. First, we compare different packaging materials (only cardboard, cardboard—plastic combination or only plastic) and packaging sizes (per 4 or per 6) to assess the impact of reduced losses at the shop. Second, we studied which of two valorization steps (apple sauce or apple chips) should be recommended to consumers who might elsewise dispose of those apples that no longer appear crispy fresh to them. For the packaging, the life cycle assessment showed that packaging apples in plastic per 4 could have beneficial effects, but proper waste management should be assured. At the household level, the environmental benefits of valorizing waste apples strongly depend on how energy intensive the needed kitchen appliance is. The ranking of the different options was however similar across the various impact categories considered. In general, making apple sauce in a microwave was the preferable option compared to treating the apple as waste, while making apple chips was not preferable. The results illustrate that it is important to go beyond intuition when considering the best food loss and waste options and that proper life cycle assessment calculations are essential to do this.

1. Introduction

Currently, the world is facing several challenges, such as population increase, demographic shifts, and changes in diet. To fulfil the needs linked to these challenges, a more sustainable lifestyle should be targeted. This could be achieved by, among other things, implementing a more efficient food system aiming for less food losses and food waste (FLW). Such FLW occur in every stage of any agri-food chain, all with their own causes and related environmental, economic and social impacts. Hence, it is important to determine the interventions, i.e., prevention and/or valorization, that mostly reduce the environmental impact, and which are the most rewarding, while preserving the same quality and safety to consumers. Prevention is when avoidable FLW are reduced, while valorization refers to converting residual waste, FLW and unavoidable streams into useful products (Papargyropoulou et al., 2014). In this article, we generally use FLW for discarded apples, only at

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the consumer stage we specifically define discarded apples as just apple waste (and not loss).

A lot of effort goes into FLW reduction, but often *without* estimating the actual effectiveness (in terms of tonnes of food that are no longer being wasted) and resource efficiency (in terms of for example net carbon savings) of different options for reducing FLW (Goossens et al., 2019b). Monitoring and evaluating measures is crucial to know their effects and to design effective interventions in the future (Thyberg and Tonjes, 2016). However, the measurements and evaluation of measures can be challenging and expensive (Reynolds et al., 2019). Because of this, most measures are not systematically evaluated (Goossens et al., 2019b; Quested et al., 2013) resulting in lack of information on the potential effectiveness and resource efficiency of FLW reduction, especially when it comes to the long-term effects (Cox et al., 2010; Goossens et al., 2019b).

A common approach to assess the environmental effects of FLW prevention or valorization measures is Life Cycle Assessment (LCA). It is important to put FLW in a food chain perspective because waste is generated in every stage, and its associated impacts accumulate further along the chain (Goossens et al., 2019b; Sarlee et al., 2012). In other words, FLW in a specific life cycle stage, and its associated impacts, should be tackled in a targeted way while considering the indirect changes it may induce in other stages. Due to complexity of the FLW problem, it can be a challenge to find the most sustainable intervention to reduce FLW.

In this context, a case study is conducted aimed at reducing FLW and its environmental impacts in the Belgian apple chain. We hereby focus on pre-packed apples and build on our previously published study on the environmental impact of the Belgian Jonagold apple chain (Goossens et al., 2019a). In that study, pre-packed apples were found to contribute to 60 % of the market share of Jonagold apples sold by the retailer Colruyt Group. The apple food supply chain can be subdivided into the following stages: cultivation, auction & sorting, secondary packaging at the sorting facility, distribution, primary and secondary packaging at the distribution center (DC), the shop and the consumer stage. Goossens et al. (2019a) assessed the environmental impact of FLW along this entire chain. They found that, for all but two of the seven impact categories that were studied, at least 10 % of the impacts associated with the apple chain were due to lost and wasted apples. They further identified the packaging and consumer stages (among others) as hotspots of the apple chain impacts. In our case study, we will investigate if interventions to reduce food losses and waste in these hotspot stages can reduce the total impact along the food supply chain, even if the intervention potentially introduces new impacts in the stages we are targeting. Literature, for example, has shown that the total environmental impact of a product can be reduced by altering the packaging to lessen food losses, even if that means the environmental impact from the packaging itself increases (Verghese et al., 2013; Williams and Wikström, 2011). This is caused by the fact that producing one unit of food is a lot more resource-intensive than producing one packaging unit.

Current figures indicate that food waste from households in Flanders is managed in three ways: through home composting (9.9 %), through separate collection via vegetable, fruit and garden waste, intended for industrial composting and anaerobic digestion facilities (11.8 %) and 78.3 % still ending in the residual waste. This latter figure includes waste given to animals, but no figures are available on that matter. Fruit and vegetables, bread and prepared foods/sauces make up the top 3 in edible residual waste. When it comes to food losses at retail level, 17 % (including bread) is used for animal feed, 67 % goes to anaerobic digestion and 16 % goes to incineration, for example, for food safety reasons following inspections by the FASFC (Food Loss Monitor, 2020, 2023).

Along the supply chain, various actions can be undertaken to prevent, reduce or valorise (apple) food waste. Examples would be a revision of cosmetic and/or quality standards, optimisation of apple (long term) storage, innovative processing solutions such as a mobile juice processing unit, and a network or platform to better distribute and sell surpluses (Herzberg et al., 2023; Lehn et al., 2023; Zdravkovic et al., 2021).

Consumers can also contribute to preventing, reducing or valorising apple FLW. In this study, we focus on two FLW interventions that can be linked to consumer decisions. Firstly, as consumers are often confronted with different packaging sizes for pre-packed apples, we look at how these affect the environmental impact along the apple chain. Goossens et al. (2019a) found that, for pre-packed apples, one spoiled apple at retail level results in the entire package being discarded. This means that, if one apple in a package of six is spoiled, five perfectly good apples are thrown away. A smaller packaging size might reduce the number of unnecessarily thrown apples, thereby preventing FLW. As such, the present paper focusses on how different packaging sizes affect FLW along the chain, and from there, affect the total food chain impacts. Next to choosing different packaging sizes, consumers may also prefer certain packaging materials, for example, cardboard, because of its presumed status as a sustainable option. This study therefore also investigates different packaging materials, even though there is no direct link with apple FLW. Secondly, we look at consumer interventions aimed at valorising apple waste in the consumer stage. We hereby assess how making apple sauce and apple chips out of apples that would normally be discarded affects the impacts along the chain and compare this to the alternative scenario of consumers throwing the apples away and buying industrially made apple sauce and apple chips instead. For both consumer interventions (choice of packaging size and valorisation of apple waste), a range of scenarios will be assessed.

Based on economies of scale, a larger packaging size reduces the amount of packaging materials per kilogram of food. One might therefore intuitively think that larger packaging sizes are more environment-friendly than smaller packaging sizes. Also, following the current plastic pollution of our environment, cardboard packaging is believed to be less impactful than plastic packaging (TwoSides, 2020). Lastly, rather than throwing apples away, one might think it would be a good idea to use them and valorise them in another tasty dish. Whether these thoughts are correct will be investigated in this paper. Rather than relying on intuition, we want to provide evidence-based recommendations.

2. Methods

Possible measures to reduce food losses and waste were introduced in an updated version of the Belgian apple chain built by Goossens et al. (2019a). This updated version included using updated SimaPro (version 20.12.0.39) processes, including the impact of pesticide production and using the 2019 refinement to the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines (Buendia et al., 2019). Moreover, apple losses and waste percentages at consumer level were adapted, as described in Section 2.2. The "ILCD 2011 MidPoint+V1.10 method" was used to calculate the environmental impacts. The functional unit of "1 kg of apples purchased by the consumer" is used.

2.1. Alternative packaging options

According to Goossens et al. (2019a), 1 % of the apples that enter the post-harvest chain is lost at the auction, 3 % of pre-packed apples (pre-packed per 6) is lost at the DC and 1.42 % is lost at the shop (see dark-grey in Fig. 1). A switch to a smaller packaging size of four apples would result in losses at the shop of 0.95 % instead of 1.42 % (assuming a best-case scenario of one-third apples less that would have to be thrown away if one is spoiled).

Since a functional unit of "1 kg of apples purchased by the consumer" is used, this would mean that less apples would have to leave the farm and enter the food supply chain to get 1 kg to the shop (1.051 kg instead of 1.056 kg; see pink in Fig. 1), taking into account all losses along the supply chain. The research question then becomes: does this reduced number of apples that goes through the supply chain and the reduced

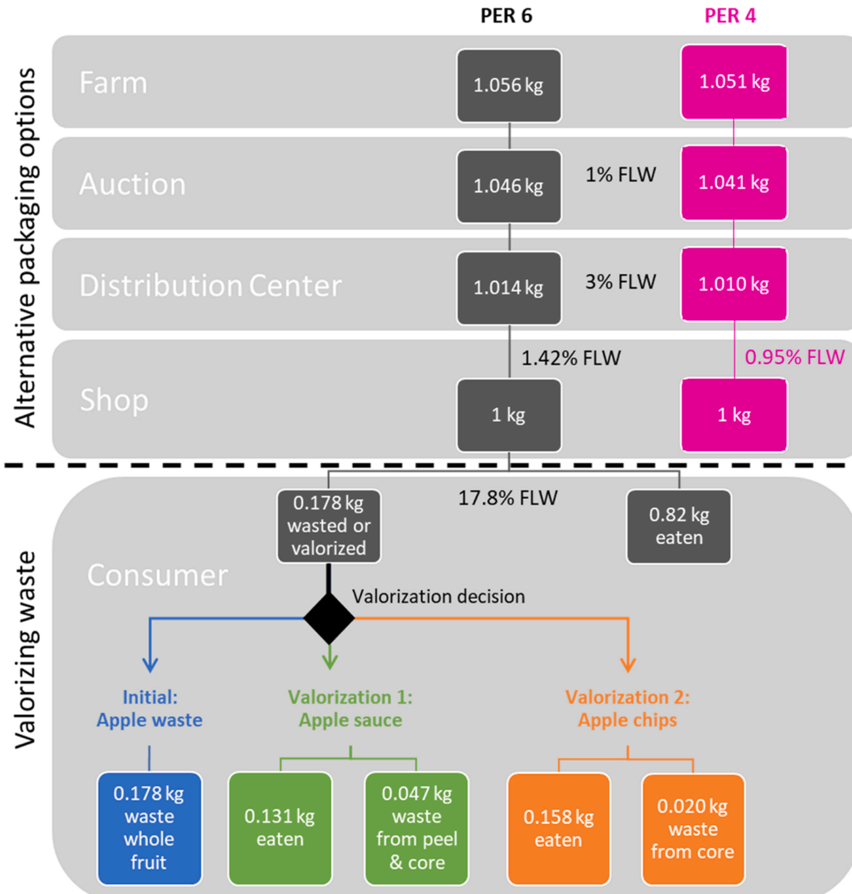

Fig. 1. Flowchart showing the apple food losses and waste (FLW) along the reference apple chain for pre-packed apples per 6 (grey) based on Goossens et al. (2019a). The adaptations for when 1 kg of apples is packaged per 4 is shown (pink) and the three considered scenarios of how apple losses and waste can be valorized at the household: as waste (reference chain; blue) or as an ingredient for apple sauce (green) or apple chips (orange).

number of apples that are thrown away at the shop cancel out the impact connected to the extra packaging material that is needed when packaging per four instead of six, given that the FU remains 1 kg of apples purchased?

Five different packaging scenarios were considered, based on real-world applications or on literature (Goossens et al., 2019a; Marks and

Table 1
Description of the different packaging scenarios. With FU: functional unit (1 kg of apples purchased in the shop), CB: cardboard, LDPE: low-density polyethylene, PVC: polyvinylchloride and EPS: expanded polystyrene.

	Reference: Per 6 in CB & plastic	Alternative 1: Per 6 in CB	Alternative 2: Per 4 in CB & plastic	Alternative 3: Per 4 in CB	Alternative 4: Per 4 in plastic
Example	 (Colruyt, 2021)	 (Delhaize 2020a)	 (Colruyt, 2021)	 (Delhaize 2020b)	 (Zoom by Ocado, 2024)
Size (lxwxh) of one package	255x155x70	255x155x70	155x155x70	155x155x70	155x155x70
Material to package 1 pack	3.21 g LDPE 21 g CB	31.96 g CB	2.37 g LDPE 15.52 g CB	21.68 g CB	3 g PVC 4 g EPS
Material to package 1 kg (FU)	3.21 g LDPE 21 g CB	31.96 CB	3.56 g LDPE 23.2 g CB	32.53 g CB	4.5 g PVC 6 g EPS
Shop losses	1.42 %	1.42 %	0.95 %	0.95 %	0.95 %
Source for packaging materials	Goossens et al. (2019a)	Own measurements of a pack of 6 apples (weighing 900 g) in CB, rescaled to 1 kg of apples using the data in Goossens et al. (2019a) for equivalency	Estimation based on: a pack of 6 in CB & LDPE (using the data in Goossens et al. (2019a) for equivalency) and own measurements of a pack of 4 in CB	Estimation based on: own measurements of a pack of 4 in CB, adapted for 1 kg using the data in Goossens et al. (2019a) for equivalency	(Marks & Spencer Plc, 2003)

Spencer Plc, 2003): six apples packaged in either (reference) cardboard and plastic or (alternative 1) only cardboard; and four apples packaged in either (alternative 2) cardboard and plastic, (alternative 3) only cardboard or (alternative 4) only plastic. Technical details of the packaging materials are provided in Table 1. For a package of four apples, 1.5 packs were needed to equivalent the 1 kg functional unit. Of course, buying 1.5 packs is not a realistic option for the consumer. One might argue that it would be more representative to have a functional unit of 2 kg, comparing two packs of six apples and three packs of four apples. However, this would only double the results obtained for 1 kg, while the interpretation remains the same.

The reference scenario is based on Goossens et al. (2019a). For Alternatives 1 and 3, we looked at some real-life examples in various supermarkets and weighed the amounts of packaging materials being used (Table 1). For Alternative 2, we based ourselves on the amounts of cardboard needed in the reference situation. Furthermore, we assumed the same kinds of packaging materials (cardboard and HDPE), and similar transport and packaging processes are used as in Goossens et al. (2019a). For Alternative 4, a stronger kind of plastic material was needed (Marks and Spencer Plc, 2003). Inputs needed for labeling or printing were not accounted for. Packaging processes and transport distances to appropriate production facilities were adapted accordingly. Where appropriate, the amounts of packaging materials for the alternatives were rescaled to fit 1 kg of apples.

The waste management applied for both packaging waste and food waste is the same as in Goossens et al. (2019a). For matters of practicality, these are repeated in Table 2.

2.2. Valorizing waste apples at the household

The percentage of apples that go to waste at household level was adapted, as compared to the percentage used by Goossens et al. (2019a). Of the 1 kg of pre-packed apples that is bought in the shop by the consumer, the present paper assumes that 17.8 % is thrown away at the household. This percentage of wasted purchased apples at the consumer is the mean of 6.5 % that was used in Goossens et al. (2019a) and 29 % according to DEFRA (2010). Another study at European level (Caldeira et al., 2019) confirms these high levels: on average about 20 % of the fruit arriving at home or at food services is wasted, while De Jong et al. (2023) indicate how among these EU countries, Belgium is producing above level food waste volumes per capita. Thus, in our calculations, the consumer ends up eating only 0.82 kg of the apples that were bought (assuming the core and peels are eaten as well; reference situation “Apple waste”, blue in Fig. 1).

In this study, we considered two valorization scenarios at the household level. For both scenarios, the avoided impacts of purchased ready-to-eat product (produced on an industrial scale) were taken into account. An overview of the considered scenarios is shown in Table 3. The waste treatment applied for apple waste at the consumer can be found in Table 2.

In the first valorization scenario, instead of throwing the 17.8 % apples away, the consumer decides to make apple sauce from them, either on the stove or in the microwave. It is assumed that those apples are peeled and have their core removed. It was estimated by peeling and removing the core of thirty apples on different days by three different people, that an average of 11.2 % represents the core and 15.0 % represents the peels. Therefore, there was still a waste of 0.047 kg (valorization scenario 1 “Apple sauce”; green in Fig. 1), whereas 0.131 kg of apples can now be used to make apple sauce.

A basic recipe was considered for making apple sauce of 0.1 liter water and 1 tablespoon of sugar (2 g) per kg of apples (unpeeled and including the core), resulting in 0.151 kg of apple sauce (ignoring weight losses due to evaporation during cooking). The apple sauce was assumed to be cooked for 20 min on a stove (assumption: 50 % is cooked

Table 3
Overview of the considered scenarios for valorizing waste apples at the household.

	Reference situation	Valorization 1	Valorization 2
Functional unit	Purchase of 1 kg apples		
Use at household	0.822 kg is eaten and 0.178 kg is wasted	0.822 kg is eaten and 0.178 kg is used for apple sauce	0.822 kg is eaten and 0.178 kg is used for apple chips
Considered impacts until purchase	Production and distribution of 1 kg apples (pre-packed per 6, using CB and plastic, as shown in the Reference in Table 1)		
Considered impacts between purchase and apple waste/ valorization	Consumer transport, cooling (household fridge), packaging waste treatment		
Considered impacts of apple waste/ valorization	Waste treatment of 0.178 kg apples	Waste treatment of 0.047 kg apples (peel & core) & Cooking impact and additional ingredients for making 0.151 kg apple sauce from 0.131 kg apples	Waste treatment of 0.020 kg apples (core) & Drying impact for making 0.034 kg apple chips from 0.158 kg (unpeeled) apples
Avoided burdens	None	Avoided impact of 0.151 kg ready-to-eat apple sauce	Avoided impact of 0.034 kg ready-to-eat apple chips

Table 2
Description of the waste management treatment for packaging and food waste, taken from Goossens et al. (2019a).

Life cycle stage	Description of waste treatment
At supermarket	The pre-packed apples go (with their packaging) to a digester facility where they are being unpacked. Packaging waste: - Cardboard: Assuming recuperation of pure fractions of cardboard materials, these cardboard wastes are collected by municipal waste collection services (using default distances) and sent to “Waste paperboard, sorted {GLO}| market for | Alloc Def, U”. - Plastic foil: The resulting plastic wastes are collected by municipal waste collection services (using default distances), followed by municipal incineration (“municipal incineration, waste plastics mixture”). Food waste: “Biowaste, treatment of manure and by anaerobic digestion”.
At consumer	Packaging waste: - Cardboard: municipal waste collection service for paper/cardboard (using default distances) followed by “Waste paperboard, sorted {GLO}| market for | Alloc Def, U”. - Plastic foil: municipal household waste collection (using default distances), followed by municipal incineration (“municipal incineration, waste plastics mixture”) Food waste: - 43 % municipal collection of biowaste: waste stream “Biowaste, treatment of composting” which includes collection service (default distances) and use of composting facilities. - 36 % home composting: inclusion of gaseous emissions related to home composting; exclusion of material inputs such as plastic compost container. - 21 % municipal househould waste: waste stream “Biowaste, market for” which includes municipal collection service (default distances) followed by incineration of household waste and anaerobic digestion (including the necessary processing facilities).

on an electric stove, 50 % on a natural gas stove) or for 2 min in the microwave at 700 W (Table 4). The Belgian energy grid mix was used for heating. Because apple waste is valorized into apple sauce, the impact of 0.151 kg of ready-to-eat apple sauce can be avoided. The avoided impact was retrieved from the Agribalyse 3.0 database and adapted to the Belgian energy grid mix from distribution onwards.

In the second valorization scenario, the consumer dries the apples in an oven, making apple chips. These apples only have their core removed, leading to a waste of 0.020 kg (valorization scenario 2 “Apple chips”; orange in Fig. 1) and 0.158 kg of apples being used for the chips. The apples are sliced and put in an oven at 100°C for 2 h, independent of the used amount. The Belgian energy grid mix was used for heating. Because of this valorization, the impact of bought ready-to-eat dried apples was avoided. These ready-to-eat apple chips are made using an evaporative drying process with a vacuum rotary instead of an oven, as found in the Agribalyse 3.0 database and adapted to the Belgian energy grid mix from distribution onwards. The weight loss of the homemade chips due to drying were considered equivalent to the weight losses considered in the process for making the ready-to-eat product in the Agribalyse database: 0.034 kg apple chips could be made from 0.158 kg apples (Table 5).

3. Results

3.1. Alternative packaging options

Fig. 2 shows the results of the total apple chain for the different packaging scenarios, relative to apples packaged per six using cardboard and plastic (0 %). Negative values refer to a reduction of impact as compared to the reference scenario, whereas positive values indicate an increase of impact. In general, the lowest environmental impacts are linked to a pack of four apples packaged in plastic (for 15 of the 16 impact categories, the exception being Freshwater ecotoxicity), while the highest can be found for a pack of six apples packaged in only cardboard (for all impact categories, see Appendix for absolute impact values). If the packaging options would be ranked according to their overall tendency across all different impact categories, it would be, from best to worst option for the environment: per 4 in plastic, per 6 in cardboard & plastic, per 4 in cardboard & plastic, per 4 in cardboard and per 6 in cardboard.

Table 4
Inputs considered for the ready-to-eat apple sauce and homemade sauce made of the 0.131 kg apples that would normally be wasted at the household level following a functional unit of 1 kg of apples purchased at the shop. The sauce is prepared either on the stove for 20 min or in the microwave for 2 min (indicated as “preparation option 1 or 2”).

Input	Value	Unit	Process	Database
Homemade, using 0.131 kg of 1 kg purchased apples				
Water	0.018	kg	Tap water {RER}| market group for | APOS, U	Ecoinvent 3
Sugar	0.0012	kg	Sugar, from sugar beet {GLO}| market for | APOS, U	Ecoinvent 3
	0.0012	kg	Sugar, from sugarcane {GLO}| market for | APOS, U	Ecoinvent 3
Preparation option 1: Stove	0.5	p	Boiling, vegetables with electric electricity: stove, at consumer (WFLDB)/ GLO U → altered to the specific heat value for apples: 3.7E−06 MJ/(g*K) (Lisowa et al., 2002) & to the Belgian energy grid mix	World Food LCA database (WFLDB)
	0.5	p	Boiling, vegetables with natural gas stove, at consumer (WFLDB)/GLO U → altered to the specific heat value for apples: 3.7E−06 MJ/(g*K) (Lisowa et al., 2002) & to the Belgian energy grid mix	
Preparation option 2: Microwave	1	p	Microwaving, 700 W, at consumer home (WFLDB)/ GLO U → altered to the Belgian energy grid mix	WFLDB
Ready-to-eat				
Apple sauce	0.151	kg	Apple compote, processed in FR | Chilled | PS | No preparation | at consumer/FR → altered to BE energy grid mix from distribution onwards	Agribalyse 3.0

Table 5
Inputs considered for homemade apple chips made of the 0.158 kg apples that would normally be wasted at the household level following a functional unit of 1 kg of apples bought at the shop. The sauce is prepared in an oven at 100°C for 2 h.

Input	Value	Unit	Process	Database
Homemade, using 0.158 kg of 1 kg purchased apples				
Oven	1	p	Preheating, electric oven, 80°C (176 °F), at consumer home (WFLDB)/ GLO U → extrapolated to 10 min preheating at 318.18 Wh & altered to the Belgian energy grid mix	WFLDB
	2	h	baking without preheating, with electric oven, 80°C (176 °F), at consumer home (WFLDB)/GLO U → extrapolated to 100°C, which needed 3.715 Wh/min & altered to the Belgian energy grid mix	
Ready-to-eat				
Dried apple	0.034	kg	Apple, dried, processed in FR | Ambient (average) | LDPE | No preparation | at consumer/FR → altered to the Belgian energy grid mix from distribution onwards	Agribalyse 3.0

The contribution analysis of two impact categories is shown in Fig. 3. Climate change, on the one hand, because of its’ societal relevance and Freshwater eutrophication, on the other hand, because that impact category showed the biggest difference in impacts between the options. The graphs show how the contribution of the primary packaging (which includes the production of the packaging material, its’ transport to the DC and the packaging process at the DC; light blue bar) changes between the different packaging options. Primary packaging in only plastic has the lowest absolute impacts and contributes the least to the total impact of all the primary packaging options.

It is important to note that except for the primary packaging stage (which is determined by the used packaging material), all other stages have a lower impact for when packaging per four apples instead of per six apples (this difference is not clearly visible in the figure). The lower impact is caused by the lower FLW percentage when packaged per four, leading to a lower amount of apples to go through the chain to get 1 kg of apples to the consumer.

3.2. Valorizing waste apples at the household

In Fig. 4, the results for valorizing the 17.8 % of purchased apples are shown using the scenario where the 17.8 % is thrown in the bin as a reference scenario (0 %). The homemade apple sauce is prepared either on the stove or in the microwave. Again, negative values refer to a reduction of impact as compared to the reference scenario, whereas positive values indicate an increase of impact. In general, the best option for the environment is to make apple sauce from your normally discarded apples, rather than throwing them away. This was the case for 14 out of the 16 impact categories. Freshwater eutrophication and water resource depletion were the only exception for which apples were better

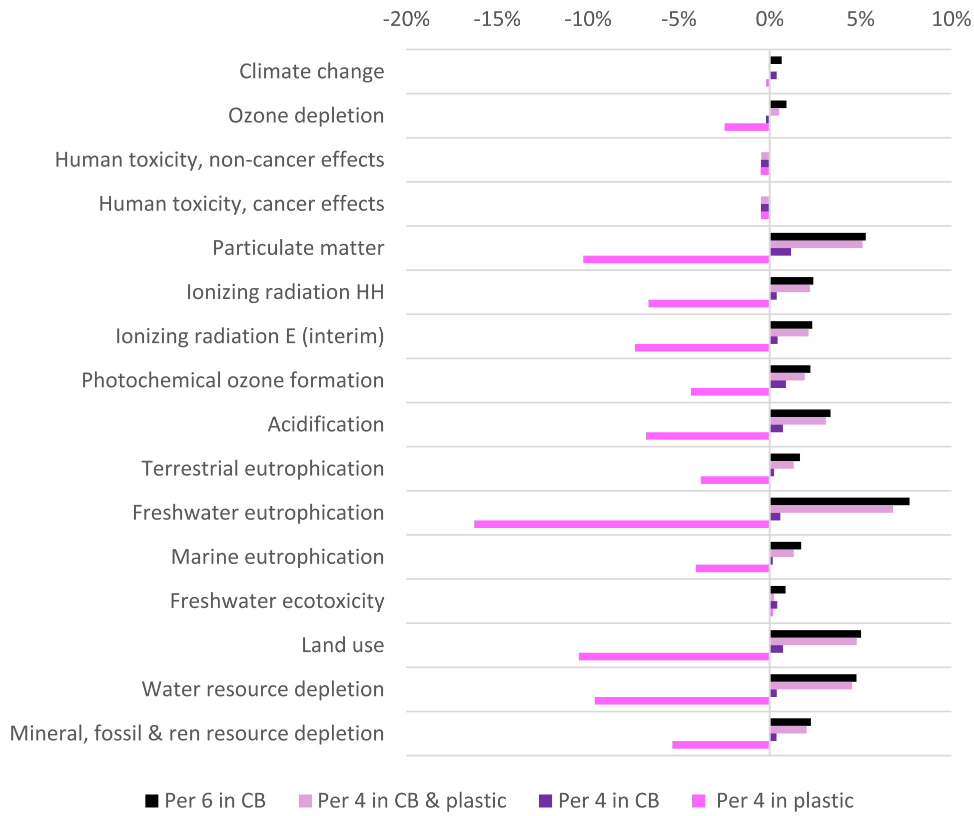

Fig. 2. Impacts of the four alternative packaging options for pre-packed apples, relative to the impacts of the reference packaging of per 6 in cardboard (CB) and plastic. The functional unit is "1 kg of apples purchased by the consumer". See Appendix A for the absolute impact values.

discarded. If the applesauce is homemade, then lower environmental impacts are generated when it is prepared using a microwave instead of on a stove. When prepared in a microwave, homemade applesauce is even preferable for 15 of the 16 impact categories (except for Water resource depletion). Adding one teaspoon of cinnamon to the homemade sauce (results not shown), did not change the interpretation of the results.

In the valorization scenario where apple chips are made from the normally discarded apples, the reverse is true. It was environmentally better to discard the apples and buy ready-to-eat apple chips instead of making it at the household. This was true for 14 of 16 impact categories, with the exceptions being Land Use and Mineral, fossil and renewable resource depletion. If sugar or cinnamon is added to the homemade apple chips at the household level (results not shown), the impacts – of course – increase even more, but the overall results would be equivalent.

The contribution analysis of two impact categories is shown in Fig. 5. Climate change, on the one hand, because of its' societal relevance and Land use, on the other hand, as a second illustrative example. The graphs show how the avoided impact of the ready-to-eat products can steer the decision whether valorizing waste apples is beneficial for the environment or not. For Climate change, the avoided impact of ready-to-eat apple chips only causes a minimal reduction to the impact of that valorization option. As such, the net climate change impact for valorizing the apples into apple chips is higher than the reference scenario in which the apples are discarded. For apple sauce, the net climate change impact is lower than the reference scenario.

For Land use, the avoided impact of ready-to-eat apple chips is large enough to cause homemade apple chips to be the best option for handling apple waste. When it comes to the apple sauce, the avoided land use impacts are even higher. It should be noted though, that this is a consequence of the modelling choices assumed within the Agribalyse database: within Agribalyse, the cooking of 1 kg of food is based on equal-weight average of the three cooking processes boiling, oven-baking and deep frying in rape oil (ADEME, 2022). Following these assumptions, 83 % of the land use impact of 1 kg of ready-to-eat apple sauce was found to be attributed to rape oil. In reality though, one would not apply deep-frying to make apple sauce. It was out of scope of this study to adapt the cooking processes used within the ready-to-eat apple sauce. However, we expect the LU impacts to decrease dramatically when leaving out the rape oil, which would in turn decrease the avoided land use impacts within this valorization scenario. This shows the importance of modeling choices in third-party databases.

4. Discussion

4.1. *Alternative packaging options*

WRAP (2011) reported a retail apple waste of 2–3 % in the United Kingdom. According to that report, apples could be sold either loose with polystyrene inserts within plastic returnable trays or cardboard box to give protection, in polyethylene bags or in bulk. In Sweden, Eriksson et al. (2012) found a retail apple waste of 3.8 %, while Mattsson et al. (2018) listed an in-store waste quota of 1.9 %. In this study, a waste percentage of 1.42 was used at the shop for pre-packed apples and Goossens et al. (2019a) also mention a loss of 2.4 % for bulk apples at the Belgian shop. It seems that bulk has a larger waste, however, if we account for losses at the DC as well, pre-packed apples have an additional 3 % loss as an additional sorting step is being carried out prior to packaging, whereas this step does not take place for bulk apples resulting in 0 % loss at the DC (Goossens et al., 2019a).

In this study, it was hypothesized that the extra impact connected to additional packaging materials needed when packaging apples per four is counteracted by the reduced apple losses since only four apples are thrown away when one is spoiled instead of six (as is the case for a package of six apples). The results (Fig. 2) showed packaging apples per four in only plastic as the environmentally favorable option. It has to be

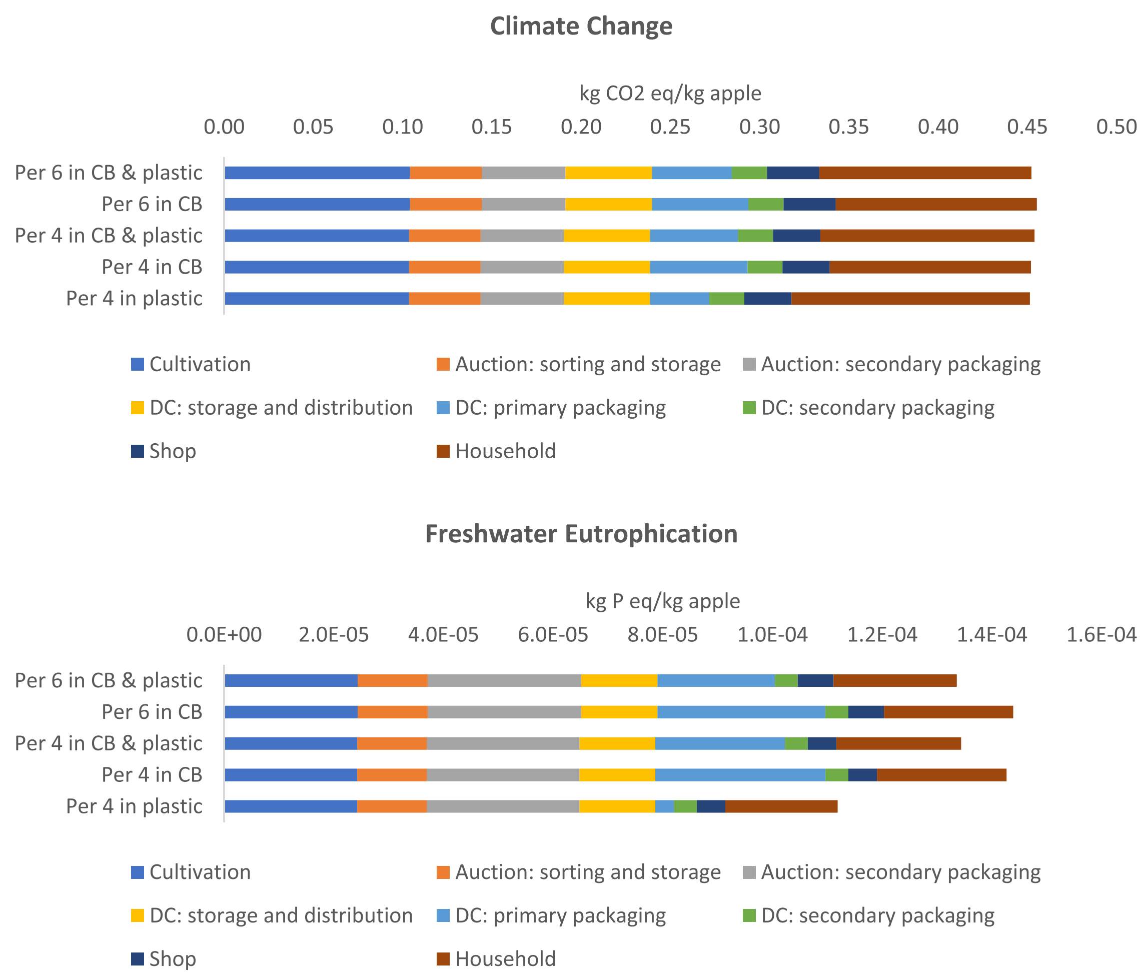

Fig. 3. Contribution to the total impact of the various stages along the pre-packed apple chain; focus on two impact categories (CB = cardboard and DC = Distribution Center). The functional unit is "1 kg of apples purchased by the consumer".

kept in mind that this conclusion is solely based on the environmental impacts, assuming correct waste handling by the consumer.

For apples packed per four, the preferable option would be to use only plastic. For apples packed per six, packaging in cardboard and plastic is preferable over only cardboard. It seems there is an environmental preference for plastic over cardboard. Though, in the past, the use of plastics has shown to result in significant environmental impacts related to the need of fossil fuels for its production and improper waste management leading to littering (Axelsson-Bakri et al., 2020). In this study, improper waste management resulting in littering was not accounted for, since we assumed that no plastic ended up in the environment. Instead, all plastic was assumed to be collected as municipal waste and subsequently incinerated. It would be interesting to model (a fraction of) plastic recycling in future studies. Yet, here we take a conservative approach.

The lower weight of plastic packaging compared to cardboard leads to a lower transport impact. For cardboard boxes, high impacts are related to the manufacturing stage (forestry, wood supply and production) (Abejón et al., 2020). However, cardboard packaging is described with terms such as "nice", "homely" and "fresh", while plastic packaging is associated with terms such as "strange", "unnecessary" and "expensive" (Fernqvist et al., 2015). If proper waste management can be assured for plastic packaging, it would be relevant to try to refine these negative connotations.

The packaging material clearly is the determining factor when choosing the best packaging option. While packaging apples in cardboard and plastic, six apples are preferred over four; the reverse is true when only packaging in cardboard. Thus, while a reduction of food waste when packaging per four might be a promising avenue, buying apples per four cannot be used as a clear guideline for consumers. However, only the reduced losses at shop level were accounted for in this study. A smaller package might also reduce the food waste in the household. Smaller packages allow consumers to buy what they actually need, instead of forcing them to buy more than they need. Different sources (Verghese et al., 2013; Williams et al., 2012; WRAP, 2014) suggest reducing packaging sizes or having them be more flexible in order to reduce FLW. Lanfranchi et al. (2016) found that more than one-third of consumers claim they would generate less food waste if the portions or the packaging of their favorite foods suited their needs more.

Specifically for apples, a survey with 1037 Flemish consumers (D'Udekem et al., 2021) showed that only 15 % (excluding people without an opinion and people who do not buy pre-packaged apples) agreed that being able to buy a smaller package size would lead them to waste less apples. This indicates that it depends on the kind of produce (e.g., apples versus potatoes) if reducing packaging sizes will have a positive effect on the FLW at the household level. Smaller packaging sizes would also inevitably lead to a higher cost per unit of volume/weight. Research (Lyndhurst, 2008) suggests that consumers are not necessarily averse to paying a little more per unit of volume/weight in order to avoid being left with unnecessary surplus.

We did not take into account how the different packaging options can cause a difference in apple loss, related to how adequately they enclose and protect food, and increase shelf-life. We also did not take into account other functions of packaging, such as facilitating usage and

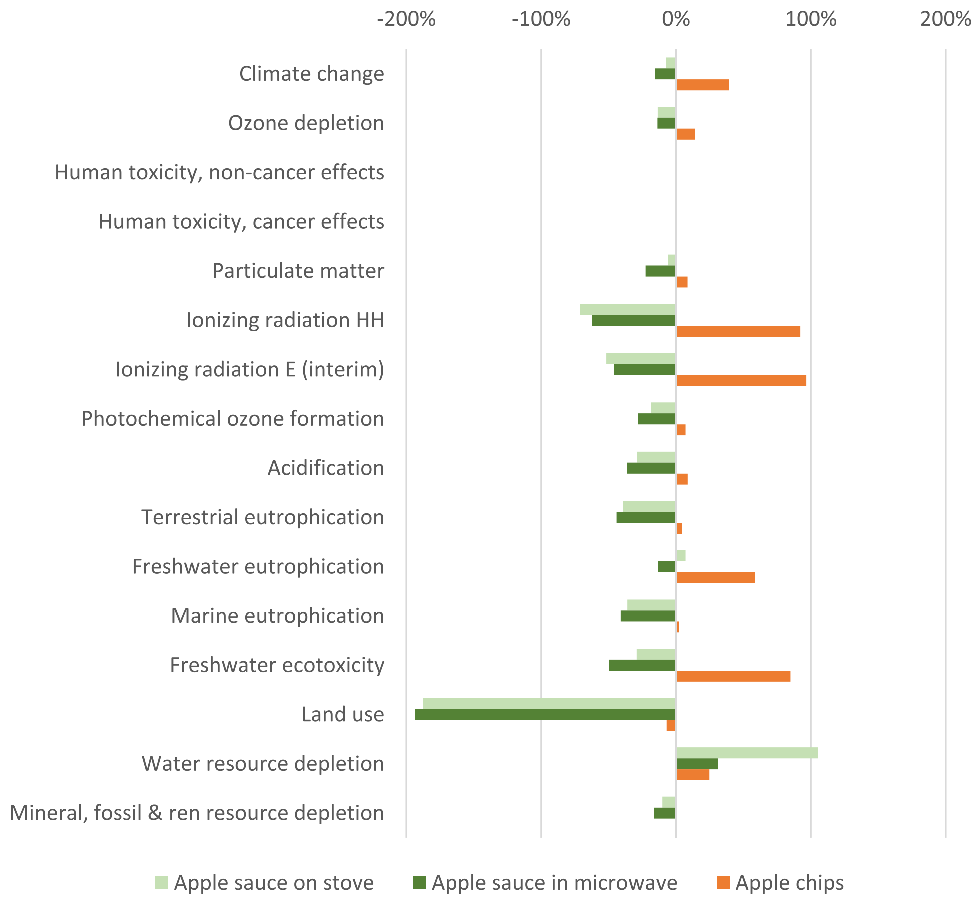

Fig. 4. Impacts of the valorization scenarios of apple waste at the household, relative to the impacts of the reference situation of discarding 17.8 % apples that are purchased. The functional unit is "1 kg of apples purchased by the consumer". Water resource depletion is not shown since it has a negative reference impact. See Appendix B for the absolute impact values.

transport, communication information, promoting the product and allowing for efficient handling throughout the food supply chain (The Consumer Goods Forum, 2011). Though we assume that each packaging option can provide all these functions equally adequately, since they are all actively used in the supermarket.

The packaging should also be designed for optimal ease of proper waste management. Proper sorting by the consumer is the most straightforward when apples are packaged only in cardboard, and less so when multiple packaging materials are used. However, when packaged in both cardboard and plastic, the two materials are easily divided since there is a cardboard plate and a plastic wrapper. The packaging that consists of only plastic is the least straightforward for recycling since two different types of plastic are used (both PVC and EPS), making this the least preferable option when it comes to waste management ease.

Williams et al. (2012) emphasize that those different functions can play an important role in the amount of food waste at the household, since in their study 20–25 % is related to packaging design attributes. It should be noted that even though packaging apples per four in plastic leads to general lower impacts, they are still larger than when bulk apples are bought (Goossens et al., 2019a).

An alternative could be that when one apple is spoiled from a set of pre-packed apples, the package is opened, the spoiled apple would be discarded, and the remainder would be sold in bulk. However, this is not possible for practical reasons: only a few cultivars are sold in bulk, and many more cultivars are sold packaged. Hence, there is no designated spot for selling different cultivars, with potentially different prices, in bulk. Moreover, as one apple spoils, the other apples may very well be already infected, but not visibly spoiled yet (latent infection). Finally, unpacking the apples would create more labor for the retail companies, which is not always appreciated.

4.2. Valorizing waste apples at the household level

In some studies (Beretta et al., 2013; Quested and Johnson, 2012; WRAP, 2009) apple cores are seen as unavoidable food waste and peels as possibly avoidable food waste, thus, food that some people eat, and others don't. Corrado and Sala (2018) emphasize that some parts of fruit and vegetables (like the apple peels) are suitable for human consumption and have a nutritious value but are still considered unavoidable food waste because they are generally not eaten. In this study, apple cores were only seen as unavoidable waste when preparing apple sauce or apple chips at the household, and peeling waste was only accounted for when considering homemade apple sauce.

Furthermore, 17.8 % was considered a reasonable estimation of apple waste (considering every part of the apple as avoidable waste) at the household level. This fits into the apples waste estimations/measurements of other sources: 6.5 % of purchased apples (Goossens et al., 2019a), 12 % avoidable waste and 22 % all waste (Quested and Johnson, 2012), 29 % edible apple parts (DEFRA, 2010) and 31 % avoidable waste and 46 % all waste (WRAP, 2009). However, the last source indicated that those values might be slightly overestimated due to windfall apples making their way into the household waste statistics (WRAP, 2009). In general, apples are said to be wasted because they were not used in time (Quested and Johnson, 2012; WRAP, 2009).

We found that the cooking technique (especially the energy use) for apple sauce or chips, stove/microwave and oven, respectively, largely dominated the environmental impacts linked to making the product. In that regard, Oliveira et al. (2012) found in their user observation study

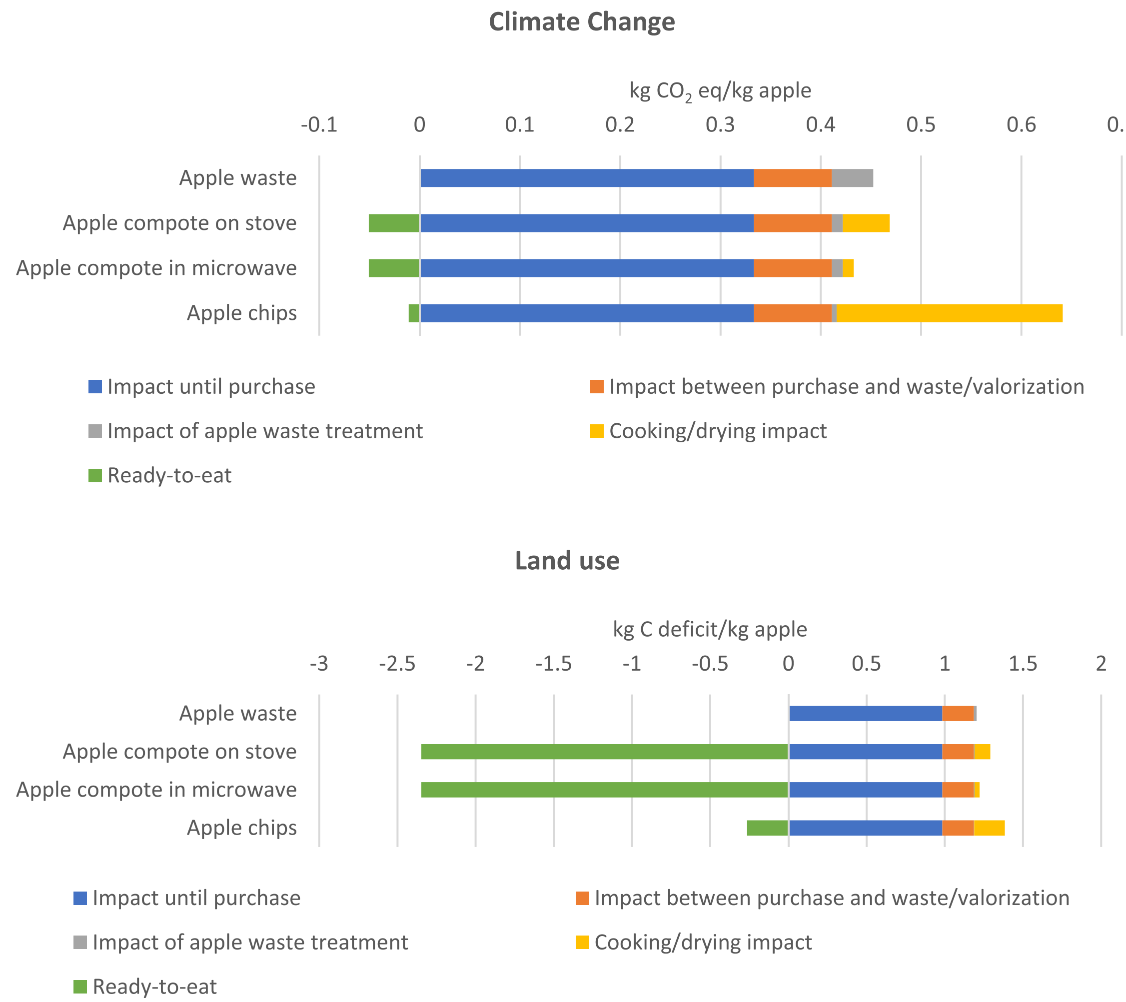

Fig. 5. Contribution to the total impact of the various stages (see Table 2) along the apple chain when apples are wasted or valorized at the household; focus on two impact categories. The functional unit is "1 kg of apples purchased by the consumer".

that participants on average uses three times more energy than necessary (i.e., than someone using energy saving tips such as using a lid), which would lead to even higher environmental impacts related to the household cooking process. For making apple sauce, using the microwave was clearly preferential to using a stove. This is in line with the findings of Frankowska et al. (2020), who found that even though cooking in a microwave and boiling on a stove are similar cooking techniques for preparing fruit, the greenhouse gas emissions drop by 41–78 % when using a microwave compared with boiling or steaming. The present study therefore advises making apple sauce using a microwave instead of throwing away waste apples.

When normally discarded apples are used for making apple chips, the total environmental impact is largely dominated by the use of an oven. Similarly, Frankowska et al. (2020) found that cooking in an oven is the least sustainable cooking method due to the high energy demand and long cooking times. They, therefore, advise precooking some food in a microwave in order to lower the oven cooking time, thereby lowering greenhouse gas emissions without significantly changing sensorial properties. However, we do not see this helping the drying process of apples. Thus, as with the packaging options, we cannot provide a clear guideline to consumers on how to handle their apple waste. It depends on which food product they would like to make if discarding the food is environmentally preferable over preparing them. However, we can advise them to opt for the least energy-intensive cooking technique, where possible.

5. Conclusions

This study built on our previously study on the environmental impact of the Belgian apple-chain (Goossens et al., 2019a), focusing on FLW at two levels: packaging and household. For packaging, the life cycle assessment showed that packaging apples in plastic could have beneficial effects, but proper waste management should be assured. Reducing the packaging size could lead to lower impacts (if less losses are assumed at the shop), but not all packaging materials will offset the increased impact due to the smaller size. When reducing packaging sizes, the packaging material should be chosen carefully. At the household level, the environmental benefits of valorizing waste apples strongly depend on how energy intensive the needed kitchen appliance or process is. Making apple sauce from normally discarded apples in a microwave is environmentally preferable over discarding these apples, but this is not the case when drying the apples in the oven. In that case, it is better to throw the apples away. The results illustrate that it is important to go beyond intuition when considering the best food waste and loss options and that proper LCA calculations are essential to do this.

CRediT authorship contribution statement

Freya Michiels: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Astrid Stalmans**: Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Methodology, Investigation, Formal analysis, Data curation. **Yanne Goossens**: Writing – review & editing, Visualization, Supervision, Resources, Methodology, Conceptualization. **Annemie Geeraerd**: Writing – review & editing, Visualization, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Alternative packaging options

See Table A1

Table A1
Absolute impact values for the five apple packaging options using a functional unit of 1 kg apples purchased by the consumer, with a green – white – red scale indicating relatively low – medium – high impact values (CB = cardboard)

(*continued on next page*)

Table A1 (*continued*)

Impact category	Unit	Per 6 in CB & plastic	Per 6 in CB	Per 4 in CB & plastic	Per 4 in CB	Per 4 in plastic
Climate change	kg CO2 eq	4,52E-01	4,55E-01	4,54E-01	4,52E-01	4,51E-01
Ozone depletion	kg CFC-11 eq	1,70E-07	1,71E-07	1,69E-07	1,71E-07	1,66E-07
Human toxicity, non-cancer effects	CTUh	6,03E-05	6,03E-05	6,00E-05	6,00E-05	6,00E-05
Human toxicity, cancer effects	CTUh	9,96E-04	9,96E-04	9,91E-04	9,91E-04	9,91E-04
Particulate matter	kg PM2.5 eq	2,46E-04	2,59E-04	2,49E-04	2,58E-04	2,20E-04
Ionizing radiation HH	kBq U235 eq	1,22E-01	1,25E-01	1,22E-01	1,25E-01	1,14E-01
Ionizing radiation E (interim)	CTUe	3,28E-07	3,35E-07	3,29E-07	3,35E-07	3,03E-07
Photochemical ozone formation	kg NMVOC eq	1,39E-03	1,42E-03	1,40E-03	1,41E-03	1,33E-03
Acidification	molc H+ eq	2,84E-03	2,93E-03	2,86E-03	2,92E-03	2,64E-03
Terrestrial eutrophication	molc N eq	8,70E-03	8,85E-03	8,72E-03	8,82E-03	8,37E-03
Freshwater eutrophication	kg P eq	1,34E-04	1,44E-04	1,34E-04	1,43E-04	1,12E-04
Marine eutrophication	kg N eq	8,57E-04	8,71E-04	8,58E-04	8,68E-04	8,22E-04
Freshwater ecotoxicity	CTUe	5,28E+00	5,33E+00	5,30E+00	5,29E+00	5,29E+00
Land use	kg C deficit	1,20E+00	1,26E+00	1,21E+00	1,26E+00	1,08E+00
Water resource depletion	m3 water eq	-4,62E-03	-4,84E-03	-4,63E-03	-4,83E-03	-4,17E-03
Mineral, fossil & ren resource depletion	kg Sb eq	5,22E-05	5,33E-05	5,24E-05	5,32E-05	4,94E-05

Valorizing waste apples at the household

See Table B1

Table B1
Absolute impact values for the waste apple valorization options using a functional unit of 1 kg apples purchased by the consumer, with a green – white – red scale indicating relatively low – medium – high impact values

(*continued on next page*)

Table B1 (*continued*)

Impact category	Unit	Apple waste	Apple sauce on stove	Apple sauce in microwave	Apple chips
Climate change	kg CO2 eq	4,52E-01	4,18E-01	3,82E-01	6,30E-01
Ozone depletion	kg CFC-11 eq	1,70E-07	1,47E-07	1,46E-07	1,94E-07
Human toxicity, non-cancer effects	CTUh	6,03E-05	6,03E-05	6,02E-05	6,03E-05
Human toxicity, cancer effects	CTUh	9,96E-04	9,96E-04	9,96E-04	9,96E-04
Particulate matter	kg PM2.5 eq	2,46E-04	2,31E-04	1,90E-04	2,67E-04
Ionizing radiation HH	kBq U235 eq	1,22E-01	3,52E-02	4,58E-02	2,34E-01
Ionizing radiation E (interim)	CTUe	3,28E-07	1,58E-07	1,77E-07	6,44E-07
Photochemical ozone formation	kg NMVOC eq	1,39E-03	1,13E-03	9,94E-04	1,48E-03
Acidification	molc H+ eq	2,84E-03	2,01E-03	1,80E-03	3,08E-03
Terrestrial eutrophication	molc N eq	8,70E-03	5,27E-03	4,86E-03	9,09E-03
Freshwater eutrophication	kg P eq	1,34E-04	1,43E-04	1,16E-04	2,12E-04
Marine eutrophication	kg N eq	8,57E-04	5,47E-04	5,05E-04	8,74E-04
Freshwater ecotoxicity	CTUe	5,28E+00	3,74E+00	2,66E+00	9,76E+00
Land use	kg C deficit	1,20E+00	-1,06E+00	-1,12E+00	1,12E+00
Water resource depletion	m3 water eq	-4,62E-03	-9,48E-03	-6,06E-03	-5,76E-03
Mineral, fossil & ren resource depletion	kg Sb eq	5,22E-05	4,69E-05	4,36E-05	5,18E-05

Data availability

All data used was provided for in the paper or has been duly referenced to.

References

Abejón, R., Bala, A., Vázquez-Rowe, I., Aldaco, R., Fullana-i-Palmer, P., 2020. When plastic packaging should be preferred: life cycle analysis of packages for fruit and vegetable distribution in the spanish peninsular market. Resour. Conserv. Recycl 155, 104666. https://doi.org/10.1016/j.resconrec.2019.104666.

ADEME, 2022. AGRIBALYSE 3.1 The French agricultural and food LCI database: Methodological report - Annexes.

Axelsson-Bakri, A., Nordenfelt, M., Ajdič, T., Nail, E.Le, 2020. Recycling food packaging & food waste in plastics revolution. Brussels, Belgium.

Beretta, C., Stoessel, F., Baier, U., Hellweg, S., 2013. Quantifying food losses and the potential for reduction in Switzerland. Waste Manag 33, 764–773. https://doi.org/10.1016/j.wasman.2012.11.007.

Buendia, E.C., Guendehou, S., Limmeechokchai, B., Pipatti, R., Rojas, Y., Sturgiss, R., Tanabe, K., Wirth, T., Romano, D., Witi, J., Garg, A., Weitz, M.M., Cai, B., Ottinger, D.A., Dong, H., MacDonald, J.D., Ogle, S.M., Rocha, M.T., Sanchez, M.J.S., Bartram, D.M., Towprayoon, S., 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The Intergovernmental Panel on Climate Change (IPCC). https://doi.org/10.21513/0207-2564-2019-2-05-13.

Caldeira, C., De Laurentiis, V., Corrado, S., van Holsteijn, F., Sala, S., 2019. Quantification of food waste per product group along the food supply chain in the european union: a mass flow analysis. Resour. Conserv. Recycl 149, 479–488. https://doi.org/10.1016/j.resconrec.2019.06.011.

Corrado, S., Sala, S., 2018. Food waste accounting along global and european food supply chains: state of the art and outlook. Waste Manag 79, 120–131. https://doi.org/10.1016/j.wasman.2018.07.032.

Cox, J., Giorgi, S., Sharp, V., Strange, K., Wilson, D.C., Blakey, N., 2010. Household waste prevention - a review of evidence. Waste Manag. Res. 28, 193–219. https://doi.org/10.1177/0734242X10361506.

Colruyt, “EVERYDAY Jonagold appelen,” 2021. [Online]. Available: https://www.colruyt.be/nl/producten/jonagold-appelen-28610. [Accessed: 27-Feb-2021].

D'Udekem, P., Herbert, S., Lenaerts, J., 2021. Voedselverspilling: daar hebben we nog een appeltje mee te schillen! KU Leuven.

DEFRA, 2010. Household Food and Drink Waste linked to Food and Drink Purchases.

De Jong, B., Boysen-Urban, K., De Laurentiis, V., Philippidis, G., Bartelings, H., Mancini, L., Biganzoli, F., Sanyé Mengual, E., Sala, S., Lasarte López, J., Rokicki, B., M'barek, R., 2023. Assessing the economic, social and environmental impacts of food waste reduction targets – a model-based analysis. Publications Office of the European Union, Luxembourg doi:10.2760/77251, JRC133971.

Delhaize, “Delhaize Appels | Granny Smith | Verpakt,” 2020a. [Online]. Available: https://www.delhaize.be/nl-be/shop/Verse-groenten-en-fruit/Vers-Fruit/Appelen-et-peren/Appelen/Appels-Granny-Smith-Verpakt/p/F2009121000332830000. [Accessed: 22-Jan-2021].

Delhaize, “Delhaize | Stoofappel | 4st,” 2020b. [Online]. Available: https://www.delhaize.be/nl-be/shop/Verse-groenten-en-fruit/Vers-Fruit/Appelen-et-peren/Appelen/Stoofappel-4st/p/F2009120300334920000. [Accessed: 27-Feb-2021].

Eriksson, M., Strid, I., Hansson, P.A., 2012. Food losses in six Swedish retail stores: wastage of fruit and vegetables in relation to quantities delivered. Resour. Conserv. Recycl 68, 14–20. https://doi.org/10.1016/j.resconrec.2012.08.001.

Fernqvist, F., Olsson, A., Spendrup, S., 2015. What’s in it for me? Food packaging and consumer responses, a focus group study. Br. Food J. 117, 1122–1135. https://doi.org/10.1108/BFJ-08-2013-0224.

Food Loss Monitor 2020 (2023) Public Waste Agency of Flanders (OVAM) in collaboration with Department of Agriculture and Fisheries. https://www.vlaanderen.be/publicaties/food-loss-monitor-2020.

Frankowska, A., Rivera, X.S., Bridle, S., Kluczkovski, A.M.R.G., Tereza da Silva, J., Martins, C.A., Rauber, F., Levy, R.B., Cook, J., Reynolds, C., 2020. Impacts of home cooking methods and appliances on the GHG emissions of food. Nat. Food 1, 787–791. https://doi.org/10.1038/s43016-020-00200-w.

Goossens, Y., Berrens, P., Custers, K., Van Hemelryck, S., Kellens, K., Geeraerd, A., 2019a. How origin, packaging and seasonality determine the environmental impact of apples, magnified by food waste and losses. Int. J. Life Cycle Assess. 24, 667–687. https://doi.org/10.1007/s11367-018-1522-0.

Goossens, Y., Wegner, A., Schmidt, T., 2019b. Sustainability assessment of food waste prevention measures: review of existing evaluation practices. Front. Sustain. Food Syst. 3. https://doi.org/10.3389/fsufs.2019.00090.

Herzberg, R., Trebbin, A., Schneider, F., 2023. Product specifications and business practices as food loss drivers – a case study in a retailer’s upstream fruit and vegetable supply chains. J. Clean. Prod., 137940 https://doi.org/10.1016/j.jclepro.2023.137940.

Lanfranchi, M., Calabrò, G., Pascale, A.De, Fazio, A., Giannetto, C., 2016. Household food waste and eating behavior: empirical survey. Br. Food J. 118, 3059–3072. https://doi.org/10.1108/BFJ-01-2016-0001.

Lehn, F., Goossens, Y., Kuntscher, M., 2023. Nachhaltigkeitsbewertung von Demonstrationsprojekten zur Reduzierung von Lebensmittelverlusten und -abfällen in den Sektoren Primärproduktion und Verarbeitung: Thünen Working Paper 211, Thünen Institute, Braunschweig, Germany, 104 pp. https://www.thuenen.de/media/publikationen/thuenen-workingpaper/ThuenenWorkingPaper_211.pdf.

Lisowa, H., Wujec, M., Lis, T., 2002. Influence of temperature and variety on the thermal properties of apples 43–52.

Lyndhurst, B., 2008. Research into consumer behaviour in relation to food dates and portion sizes.

Marks & Spencer Plc, 2003. Streamlined LCA Study of Apple Packaging Systems. Oxford.

Mattsson, L., Williams, H., Berghel, J., 2018. Waste of fresh fruit and vegetables at retailers in Sweden – measuring and calculation of mass, economic cost and climate impact. Resour. Conserv. Recycl 130, 118–126. https://doi.org/10.1016/j.resconrec.2017.10.037.

Oliveira, L., Mitchell, V., Badni, K., 2012. Cooking behaviours: a user observation study to understand energy use and motivate savings, 41, 2122–2128. https://doi.org/10.3233/WOR-2012-1016-2122.

Papargyropoulou, E., Lozano, R., Steinberger, K., Wright, J., Ujang, N., Bin, Z., 2014. The food waste hierarchy as a framework for the management of food surplus and food waste. J. Clean. Prod. 76, 106–115. https://doi.org/10.1016/j.jclepro.2014.04.020.

Quested, T., Johnson, H., 2012. Household Food and Drink Waste in the UK: Final Report, WRAP. Banbury, England. https://doi.org/10.1111/j.1467-3010.2011.01924.x.

Quested, T.E., Marsh, E., Stunell, D., Parry, A.D., 2013. Spaghetti soup: the complex world of food waste behaviours. Resour. Conserv. Recycl 79, 43–51. https://doi.org/10.1016/j.resconrec.2013.04.011.

Reynolds, C., Goucher, L., Quested, T., Bromley, S., Gillick, S., Wells, V.K., Evans, D., Koh, L., Carlsson Kanyama, A., Katzeff, C., Svenfelt, Å., Jackson, P., 2019. Review: Consumption-stage food waste reduction interventions – what works and how to design better interventions. Food Policy 83, 7–27. https://doi.org/10.1016/j.foodpol.2019.01.009.

Sarlee, W., Van Cuyck, J., Andries, A., Huygh, K., Roels, K., 2012. Voedselverlies in ketenperspectief. OVAM, Mechelen.

The Consumer Goods Forum, 2011. A Global Language for Packaging and Sustainability: A Framework and a Measurement System for Our Industry. Issy-les-Moulineaux, France.

Thyberg, K.L., Tonjes, D.J., 2016. Drivers of food waste and their implications for sustainable policy development. Resour. Conserv. Recycl 106, 110–123. https://doi.org/10.1016/j.resconrec.2015.11.016.

TwoSides, 2020. European packaging preferences 2020. In: A European study of consumer preferences, perceptions, and attitudes towards packaging, 16. TwoSides, Daventry, UK. 〈https://twosides.info/packaging2020/〉.

Verghese, K., Lewis, H., Lockrey, S., Williams, H., 2013. The role of packaging in minimising food waste in the supply chain of the future.

Williams, H., Wikström, F., 2011. Environmental impact of packaging and food losses in a life cycle perspective: a comparative analysis of five food items. J. Clean. Prod. 19, 43–48. https://doi.org/10.1016/j.jclepro.2010.08.008.

Williams, H., Wikström, F., Otterbring, T., Löfgren, M., Gustafsson, A., 2012. Reasons for household food waste with special attention to packaging. J. Clean. Prod. 24, 141–148. https://doi.org/10.1016/j.jclepro.2011.11.044.

WRAP, 2014. Prevention and reduction of food and drink waste in businesses and households.

WRAP, 2011. Fruit and vegetable resource maps. Wrap. https://doi.org/10.1016/j.icrp.2009.12.007.

WRAP, 2009. Household Food and Drink Waste in the UK. Banbury, England.

Zoom by Ocado, “M&S Pink Lady Apples 4 per pack”, 2024. [Online]. Available: https://zoom.ocado.com/m-s-pink-lady-apples-4-per-pack-518306011. [Accessed: 21-Oct-2024].

Zdravkovic, M., Snoeck, E.R., Zicari, A., Vranken, L., Heinz, V., Smetana, S., Aganovic, K., 2021. Sustainability assessment of mobile juice processing unit: farmers perspective. Future Foods 4, 100064. https://doi.org/10.1016/j.fufo.2021.100064.