



*Master's Thesis – Master Sustainable Business & Innovation (SBI)*

# Assessing the suitability of refillable packaging systems for Dutch supermarkets

A case study of ALDI in the Netherlands

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## Abstract

**Introduction.** Given the considerable environmental impact associated to single-use packaging, this study researched the suitability of transitioning from single-use to refillable packaging systems for Dutch supermarkets. The selected packaging systems were: refill on the go laundry detergent (rf-go-liquid), refill on the go pasta (rf-go-pasta), refill at home cleaning detergent (rf-home-powder), and refill at home laundry detergent (rf-home-liquid). ALDI in the Netherlands served as the case study and source of data. **Theory.** To assess suitability, this study focused on feasibility and impact within a supply chain perspective. Feasibility was operationalized through barriers and considerations aggregated from existing literature. **Methods.** Feasibility was analyzed through 5 expert interviews and an online survey on the willingness to engage of 173 ALDI in the Netherlands customers. The impact was analyzed through Life Cycle Assessment (LCA) and Life Cycle Costing (LCC). A simplified tool developed by the KIDV was used to this end. The LCA and LCC included one impact category, namely climate change (in CO<sub>2</sub>-eq emissions per use) and cost per use (from a supermarket perspective). The data was collected internally at ALDI in the Netherlands and complemented with data from literature and desktop research. **Results.** An important interview finding constitutes the use of clear and transparent communication on the price incentive and environmental impact reduction to change consumer behavior. This was confirmed in the consumer survey, where price and environment positively influenced the willingness to engage. All packaging systems were deemed relatively attractive by ALDI in the Netherlands customers. In the LCA baseline scenario, all packaging systems implied a reduction in environmental impact, except for rf-go-pasta. Similarly, all showed potential for cost reduction in the LCC baseline scenario, except rf-go-pasta. The unattractiveness of rf-go-pasta was mainly due to the impact of cleaning. Through sensitivity analyses, it was found that bulk packaging size and cleaning frequency decrease the environmental impact of rf-go-pasta, and thus increase its attractiveness compared to single-use pasta. For the other three packaging systems, the material choice of the refillable bottle, the end-of-life treatment of opaque PET and adding a cleaning method were tested. **Discussion/Conclusion.** This study presents a structured feasibility framework that can be used by supermarkets and other interested stakeholders to assess the suitability of refillable packaging systems. Moreover, rf-go-liquid, rf-home-powder and rf-home-liquid are recommended options for Dutch supermarkets to pursue. However, rf-go-pasta is characterized by relatively too much uncertainty regarding environmental impact, economic impact, and feasibility considerations.

*Key words:* refillable packaging systems, refill on the go, refill at home, Life Cycle Assessment, Life Cycle Costing

## Executive summary

This research aimed to assess the suitability of refillable packaging systems for Dutch supermarkets. In cooperation with ALDI in the Netherlands, four refillable packaging systems were selected and assessed based on their feasibility and potential impact. The main recommendations for ALDI in the Netherlands are discussed below. The refillable packaging systems are ranked according to their expected likelihood of success in terms of feasibility and potential environmental and economic impact.

### **Rf-home-powder: refill at home for concentrated powder cleaning detergent**

When the bottle of cleaning detergent is empty, the customer would buy a refill packaging in a store. This refill packaging is a paper sachet containing concentrated powder, which can be poured in the empty bottle at home and diluted with water to create new cleaning detergent. Since this packaging system would eliminate the transport of water, the environmental impact would be significantly less than single-use cleaning detergent. Interestingly, this results in a break-even point of merely 1 use. So, even if the refillable bottle is only used once, rf-home-powder would still perform better than its single-use alternative. However, if cleaning (rinsing with hot water) of the refillable bottle is considered, then the bottle would have to be used at least twice. In terms of the LCC, the bottle would also have to be used at least twice for the packaging system to cost less per use. Moreover, ALDI in the Netherlands customers were most inclined to this packaging system with 80% of the customers indicating that they would be willing to engage with it. Nevertheless, there are some feasibility considerations for ALDI in the Netherlands to take into account. First, customers appear to be positively influenced by price as an incentive and decreased environmental impact. Therefore, ALDI should ensure that rf-home-powder is cheaper than the single-use alternative and clearly communicated this incentive, as well as how much CO<sub>2</sub>-eq emissions would be saved, through campaigns and point-of-sale communication. Strong point-of-sale communication would also increase the refill packaging's visibility on the shelves. Another implication of the relatively small packaging for the refill powder is ensuring that all required information is labelled. This should be well thought out so that the look and feel of the packaging is still attractive. One option here could be to bundle different refill units in one larger packaging. Finally, ALDI in the Netherlands should ensure that the material choice of the refill packaging is recyclable and compatible with the soluble nature of the refill powder.

### **Rf-go-liquid: refill on the go for liquid laundry detergent**

When the bottle of laundry detergent is empty, the customer would bring it to a store and refill it at an automated dispenser. This dispenser then prints a ticket containing the necessary information, which can be scanned at the check-out. For a smooth transition from the current single-use packaging, it is recommended to use the same PET bottle for the refillable bottle. When assuming that this bottle is incinerated, rf-g-liquid will perform better than single-use laundry detergent as soon as the refillable bottle is used twice. If cleaning (or rinsing with hot water) the packaging items is accounted for in the LCA, rf-go-liquid has a lower environmental impact when the refillable bottle is used three times. In terms of the economic impact (or costs per use from the supermarket's perspective), rf-go-liquid becomes economically viable when the refillable bottle is used twice. Even though the ALDI customers were considerably willing to engage with rf-go-pasta (77%), it is important to ensure that the refillable bottle is used at least 3 times. To this end, there are some feasibility considerations ALDI in the Netherlands can take into account. First, price as an incentive and decreased environmental impact are again influential factors in ensuring customer engagement. Clear and transparent communication

should therefore again emphasize these benefits through campaigns and point-of-sale. Additionally, point-of-sale communication can aim to decrease the perceived inconvenience of rf-go-liquid. ALDI in the Netherlands would also have to ensure the cleanliness of the dispenser to decrease this perceived inconvenience among the customers. Another store management alteration would be the labelling of the bottles and the cashier processes. It is recommended to print sticky labels from the dispenser that can be glued over previous labels so that the cashier scans the right label. This label would also have to include the batch number, ingredients and other base information that is required on a label.

#### **Rf-home-liquid: refill at home for non-concentrated liquid laundry detergent**

With this packaging system, the customer would refill its empty laundry detergent at home after purchasing a refill packaging (plastic pouch) at a store. This refill product is the same product as with the single-use packaging. As with rf-go-liquid, it is again recommended to use a refillable bottle that is identical to the single-use bottle (in order to ensure a smooth transition). When assuming that this PET bottle is incinerated, rf-home-liquid would have to be used at least twice to perform better than single-use laundry detergent. However, if the PET bottle would be recycled or if cleaning the refillable bottle (rinsing with hot water) is accounted for, then the refillable bottle would have to be used at least three times to reach a break-even point. In term of the LCC, it is again necessary that the ALDI in the Netherlands customer uses the refillable bottle at least twice for the packaging system to be economically viable. Even though 76% of the ALDI in the Netherlands customers are willing to engage with rf-home-liquid, there are again some feasibility considerations to take into account. First, perceived price as an incentive and decreased environmental impact are again influential to the willingness to engage of customers. However, communicating on these aspects entails a risk of perceived greenwashing, since water is still transported in single-use refill packaging (pouches). Therefore, ALDI in the Netherlands would have to transparent in its communication by acknowledging this and e.g. striving for other sustainability improvements simultaneously. Good point-of-sale communication would again be necessary to increase the visibility of the pouches on the shelves.

#### **Rf-go-pasta: refill on the go for pasta**

The last refillable packaging system entails an in-store dispenser for dry and loose produce, in this case pasta. The customer can either bring its own container or use a cellulose bag offered in-store to release pasta from the dispenser, weigh it, label it, and pay for it at the check-out. It was found that the ratio %cellulose bag/%container among customers determines the performance of rf-go-pasta compared to single-use pasta (sold in plastic flow packs). When the pasta is transported to the ALDI stores in 5 kg bulk packaging and it is assumed that the container is washed after every use, then rf-go-pasta only performs better than single-use pasta when 100% of the customers use a cellulose bag. Larger bulk packaging (e.g. 10 kg) and a decreased cleaning frequency (e.g. every 2 uses) would decrease the environmental impact of rf-go-pasta and thus increase its attractiveness compared to single-use pasta. It is important to note here that single-use pasta has a relatively low environmental impact to begin with. This raises the questions whether this product is the best fit for refillable packaging at ALDI in the Netherlands. In addition, rf-go-pasta would imply a slightly higher cost per use (+4%) in the baseline scenario. As such, given the high uncertainty in terms of environmental and economic impact related to rf-go-pasta, it is not recommended for ALDI in the Netherlands to pursue this packaging system. Still, if ALDI in the Netherlands would consider implementing rf-go-pasta, for instance because 62% of the customers would be willing to engage with it, there are some feasibility considerations to take into account. First, it is again important that the customer perceives the price as an incentive. ALDI in the

Netherlands would also have to communicate to the customer how to properly use this dispensing system to decrease the perceived inconvenience. To further decrease the perceived inconvenience, ALDI in the Netherlands could opt for a fully automated dispensing system which facilitates weighing for the customer and prints the label. Moreover, such a system would enable batch tracing and restrict the chance of spilling. Finally, it is important to ensure a decrease in environmental impact and continuously monitor the performance of this system compared to single-use pasta.

Overall, refillable packaging is a direction worth pursuing for ALDI in the Netherlands since they offer mostly in-house brands. This decreases competition with other brands in the shelves and allows them to directly have an impact in terms of sustainable packaging. Given that today's society is more and more sensitive to the sustainability efforts of retailers, this is especially relevant in terms of remaining competitive in the Dutch market.

## Table of contents

Abstract .....	3
Executive summary.....	4
List of abbreviations .....	9
List of figures .....	10
List of tables.....	11
1 Introduction.....	12
2 Theory.....	14
2.1 Refillable packaging.....	14
2.1.1 Packaging types .....	14
2.1.2 Product types .....	14
2.2 Analyzing refillable packaging systems from a supply chain perspective.....	15
2.2.1 Feasibility.....	15
2.2.2 Impact.....	17
2.3 Conceptual framework.....	18
3 Methodology .....	19
3.1 Research design.....	19
3.2 Feasibility assessment .....	20
3.2.1 Expert interviews .....	20
3.2.2 Consumer survey.....	21
3.3 Impact assessment.....	23
3.3.1 Goal of the study .....	23
3.3.2 Scope of the study.....	23
3.3.3 Sensitivity analyses .....	25
4 Life Cycle Inventory.....	27
4.1 Technical lifespan and return rate .....	27
4.2 Packaging production.....	30
4.2.1 Rf-go-liquid: refill on the go for laundry detergent .....	31
4.2.2 Rf-go-pasta: refill on the go for pasta.....	32
4.2.3 Rf-home-powder: refill at home for cleaning detergent .....	33
4.2.4 Rf-home-liquid: refill at home for liquid laundry detergent .....	34
4.3 Transport between facilities.....	35
4.4 Use .....	36
4.5 Disposal .....	36
4.6 Costs.....	38
5 Qualitative results.....	39
5.1 Feasibility of refillable packaging in general.....	39
5.2 Feasibility of the four refillable packaging systems .....	40
5.2.1 Rf-go-liquid: refill on the go for laundry detergent .....	40
5.2.2 Rf-go-pasta: refill on the go for pasta.....	41

5.2.3	Rf-home-powder: refill at home for cleaning detergent .....	41
5.2.4	Rf-home-liquid: refill at home for laundry detergent .....	42
6	Quantitative results: consumer survey .....	43
6.1	Description of the data .....	43
6.2	Variables affecting the willingness to engage .....	44
6.3	Insights from the consumer survey .....	46
7	Quantitative results: LCA .....	47
7.1	Results baseline .....	47
7.2	Results sensitivity analyses .....	49
7.2.1	Rf-go-liquid and rf-home-liquid .....	49
7.2.2	Rf-home-powder .....	52
7.2.3	Rf-go-pasta: % container use, cleaning frequency, and bulk size .....	52
8	Quantitative results: LCC .....	54
8.1	Results baseline .....	54
8.2	Break-even point for rf-go-liquid, rf-home-powder and rf-home-liquid .....	55
9	Discussion .....	56
9.1	Theoretical implication .....	56
9.2	Practical implication .....	57
9.3	Limitations .....	59
9.4	Future research .....	60
10	Conclusion .....	62
11	References .....	63
	Appendix A .....	71
	Interview guide and consent form .....	71
	Appendix B .....	75
	Summary of sampled experts .....	75
	Appendix C .....	76
	NVivo coding scheme .....	76
	Appendix D .....	77
	List of main assumptions in the KIDV tool .....	77
	Appendix E .....	78
	Cost inventory data .....	78
	Appendix F .....	81
	Qualitative results interviews: systematic overview feasibility framework .....	81
	Appendix G .....	83
	Quantitative results consumer survey: Chi-square tests .....	83
	Appendix H .....	84
	Quantitative results of the LCA sensitivity analysis .....	84
	Appendix I .....	88
	Quantitative results of the LCC sensitivity analysis .....	88

## List of abbreviations

LCA = Life Cycle Assessment

LCC = Life Cycle Costing

Rf-go-liquid = refill on the go packaging for liquid laundry detergent

Rf-go-pasta = refill on the go packaging for pasta

Rf-home-powder = refill at home packaging for powder cleaning detergent

Rf-home-liquid = refill at home packaging for liquid laundry detergent

## List of figures

<b>Figure 1</b> Conceptual framework for assessing the suitability of refillable packaging systems .....	18
<b>Figure 2</b> Schematic overview of the survey content .....	23
<b>Figure 3</b> Main processes included in the system boundaries of the four refillable packaging systems: (a) rf-go-liquid, (b) rf-go-pasta, (c) rf-home-powder, and (d) rf-home-liquid. The boxes represent activities performed in the supply chain, for which a dashed outline refers to an activity not included in this study. The grey boxes are activities that are also accounted for in the alternative single-use packaging systems.....	29
<b>Figure 4</b> Feasibility framework for refillable packaging systems .....	40
<b>Figure 5</b> Distribution of respondents across socio-demographic variables .....	43
<b>Figure 6</b> Adoption rates of the four refillable packaging systems .....	44
<b>Figure 7</b> Contribution of different life cycle stages to the total environmental impact of each refillable and single-use packaging system .....	47
<b>Figure 8</b> Total environmental impact in kg CO <sub>2-eq</sub> emissions per use for every scenario tested .....	49
<b>Figure 9</b> Break-even point (in terms of the return rate of the refillable bottle) for the different scenarios affecting rf-go-liquid.....	51
<b>Figure 10</b> Break-even point (in terms of the return rate of the refillable bottle) for the different scenarios affecting rf-home-liquid .....	51
<b>Figure 11</b> Break-even point (in terms of the return rate of the refillable bottle) for rf-home-powder ..	52
<b>Figure 12</b> Break-even points when (a) the ratio % cellulose bag/% container varies, and (b) the pasta is transported in 10kg bulk packaging .....	53
<b>Figure 13</b> Comparative overview of the estimated total cost per use per refillable packaging system and its single-use alternative .....	54
<b>Figure 14</b> Break-even points (in terms of number of uses of the refillable bottle) for (a) rf-go-liquid, (b) rf-home-powder, and (c) rf-home-liquid.....	55

## List of tables

<b>Table 1</b> <i>Summary of the four refillable packaging systems included in this research</i> .....	19
<b>Table 2</b> <i>List of activities included or excluded in the KIDV tool and in the LCA</i> .....	25
<b>Table 3</b> <i>Overview of conducted sensitivity analyses</i> .....	25
<b>Table 4</b> <i>The technical lifespan, return rate, and number of uses accounted for per packaging system</i> .	30
<b>Table 5</b> <i>Inventory data of rf-go-liquid and its single-use alternative</i> .....	31
<b>Table 6</b> <i>Inventory data of rf-go-pasta</i> .....	32
<b>Table 7</b> <i>Inventory data for the single-use packaging of pasta</i> .....	33
<b>Table 8</b> <i>Inventory data of rf-home-powder and its single-use alternative</i> .....	33
<b>Table 9</b> <i>Inventory data of rf-home-liquid and its single-use alternative</i> .....	34
<b>Table 10</b> <i>Overview of the four packaging systems (applies to both single-use and refillable alternative)</i> .....	35
<b>Table 11</b> <i>Overview of the transported mass per FU (in g/FU)</i> .....	36
<b>Table 12</b> <i>Summary of end-of-life treatment per packaging type</i> .....	37
<b>Table 13</b> <i>Results of the regression analyses for the willingness to engage with each packaging system: coefficients, adjusted R-squared and the number of observations</i> .....	45
<b>Table 14</b> <i>Break-down of total environmental impact (in kg CO<sub>2-eq</sub> emissions per use) per packaging system</i> .....	47
<b>Table 15</b> <i>Break-even points (in terms of the ratio % cellulose bag/% container that equals the impact of refillable over the impact of single-use) for rf-go-pasta when (a) the cleaning frequency varies, and (b) the size of the bulk packaging varies</i> .....	53
<b>Table 16</b> <i>Breakdown of total cost per use (in euro) per refillable and single-use packaging system</i> .....	55
<b>Table 17</b> <i>Comparative analysis of the four most-implemented refillable packaging systems</i> .....	59

# 1 Introduction

Packaging has many beneficial and important functions, including protection, communication, and preservation (Lofthouse et al., 2017). Single-use plastic packaging has increasingly become the norm as it allows retailers to comply with strict food safety regulations, as well as simplify logistical complexities and reduce overall costs (Coelho et al., 2020a). However, these advantages are potentially outweighed by the environmental cost that accompanies single-use plastic packaging (Rivera et al., 2019). The EU Directive on single-use plastics illustrates the gravity of this problem and advocates for reusable alternatives where possible to reduce plastic pollution (Directive 2019/904). Considering SDG 12 Sustainable Consumption and Production, it is therefore important to strive for more sustainable packaging (UN, 2021).

From a circular economy perspective, solutions should aim to intensify resource use and close the loop for material flows (Kirchherr et al., 2017). Researchers have traditionally focused on innovative high-tech recycling techniques (Lazarevic et al., 2010; Thiounn & Smith, 2020; Singh et al., 2017). However, following the R hierarchy, recycling ranks at the bottom of the ten strategies, implying that other strategies should rather be the priority (Kirchherr et al., 2017). Some authors have therefore suggested reusable packaging as a promising direction for reducing plastic waste (Ellen MacArthur Foundation [EMF], 2019; Gardas et al., 2019; Long et al., 2020; Mahmoudi & Parviziomran, 2020; Muranko et al., 2021). Reusable packaging can be defined as a product-service system in which the focus shifts from selling products to selling products combined with services. In this case, the packaging allows the consumer to obtain new products, implying a sustainable partnership between the producer/retailer and the consumer (Lofthouse & Bhamra, 2006; Manzini & Vezzoli, 2002). It is estimated that up to 20% of current single-use packaging could be replaced by reusable packaging, which would offer various benefits (e.g. reduced transport and packaging costs, potential economics of scale, the possibility of data gathering) (EMF, 2019). However, care should be taken when implementing such packaging solutions due to the complex logistics, issues with cleaning and food safety and possible increased material use (Coelho et al., 2020a). Attention also must be paid to consumer behavior because their perceptions and associations will determine the level of uptake of these packaging systems (Greenwood et al., 2021; Wikström et al., 2016).

Given this trade-off between benefits and risks, there is a need for comparative research on the transition from single-use to reusable packaging (Coelho et al., 2020a). The literature distinguishes between B2B and B2C reusable packaging. There is a tendency towards comparing B2B rather than B2C packaging systems, implying a need for more research on B2C reusable packaging (EMF 2019; Coelho et al., 2020a). Two broad categories of B2C reusable packaging exist: return and refill. With the former, the packaging is returned to the retailer, either by the customer or picked up by the retailer itself (EMF, 2019). Returnable packaging implies a change of packaging ownership, requires complex reverse logistics, and is especially suited for e-commerce where delivery of new product can be combined with the pick-up of used packaging (EMF, 2019; Mahmoudi & Parviziomran, 2020). Moreover, Dutch supermarkets have indicated that refillable packaging is the preferred reusable packaging system for short-term implementation (Kramer et al., 2021). Therefore, this research focuses on B2C refillable packaging, which entails that customers refill their packaging with new product, either on the go or at home (EMF, 2019). This research topic has received some attention already in academic literature.

Costa (2018) investigated consumer perceptions, while Kobayashi and Benassi (2015) researched what influenced the purchase intent for refillable instant coffee. Others investigated drivers and barriers for businesses to implement refillable packaging systems (Lofthouse et al., 2009), as well as packaging design considerations (Lofthouse & Bhamra, 2006). Few authors have compared the environmental impacts of refillable and single-use packaging systems through Life Cycle Assessment (LCA). In fact, Coelho et al. (2020b) showed that out of 32 reviewed papers on LCA's of reusable packaging, merely five related to refillable packaging<sup>1</sup>. For instance, Dolci et al. (2016) compared the environmental impact of refillable packaging for pasta, cereals, and rice with the traditional packaging. Furthermore, no research has focused on the economic impact of B2C refillable packaging (Coelho et al., 2020a). Given this research gap of little to no comparative research on B2C refillable packaging systems, this research aims to compare four refillable packaging systems with their single-use alternatives. These refillable packaging systems were selected to represent what is currently most implemented in the market. The following research questions are guiding:

*How suitable are refillable packaging systems for Dutch supermarkets?*

- a. How feasible are the most implemented refillable packaging systems considering the main barriers along the supply chain?*
- b. What is the environmental impact of the most implemented refillable packaging systems compared to single-use packaging?*
- c. What is the economic impact of the most implemented refillable packaging systems compared to single-use packaging?*

The in-house brand of the Dutch retailer ALDI in the Netherlands is taken as a case study and source of data. ALDI is an international discounter retailer with the vision to offer a limited product assortment at high-quality standards and low prices (ALDI, n.d.a). Part of ALDI in the Netherlands' corporate responsibility agenda is striving for more sustainable packaging through the following goals: reduce, reuse, and recycle (ALDI, n.d.b). Retailers play an important role in reducing packaging volumes since they engage with both suppliers and customers (Gustavo et al., 2018). Additionally, many retailers sell their own brand of products, allowing them to directly reduce packing waste and raise awareness among customers. In the Netherlands, supermarkets have set the target to reduce packaging by 20% by 2025, while emphasizing the potential of reusable packaging to reach this target (Centraal Bureau Levensmiddelenhandel [CBL], 2020). However, initial research has shown that Dutch supermarkets need further reassurance that the benefits will outweigh the risks of reusable packaging (Kramer et al., 2021). Therefore, this research aims to provide clear recommendations on refillable packaging systems to help the transition of Dutch supermarkets to reusable packaging. Moreover, there is no research to date assessing both the feasibility and the environmental and economic impact through a comparative analysis with single-use packaging. By doing so, this research provides a holistic assessment of the suitability of refillable packaging systems for ALDI in the Netherlands and Dutch supermarkets in general.

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<sup>1</sup> These are the following: Dolci et al., 2016; Nessi et al., 2012; Nessi et al., 2014; Potting & van der Harst, 2015; Woods & Bakshi, 2014.

## 2 Theory

### 2.1 Refillable packaging

#### 2.1.1 Packaging types

Three packaging types exist. Tertiary or transit packaging is used for transportation and storage (e.g. pallets and containers). Secondary packaging serves as an outer packaging layer that bundles and protects the products from damage and theft (e.g. cardboard boxes). The layer below is referred to as primary packaging, namely the packaging that directly holds the product (Palsson, 2018). Regarding refillable packaging, the design of primary packaging must be adapted to allow the consumer to refill the product (Lofthouse & Bhamra, 2006). However, when comparing different packaging systems, the impact of secondary and tertiary packaging cannot be neglected (Molina-Besch et al., 2019).

Different categorizations of refillable packaging systems exist. Lofthouse et al. (2009) identified 14 such systems based on the delivery mechanism and the interaction between business and consumer. However, this lacks to account for the required behavior/action from the consumer, which has been identified as a key factor to the success of refillable packaging systems (Greenwood et al., 2021; Gustavo et al., 2018). EMF (2019) suggested classifying packaging systems based on location and required consumer behavior. As such, refillable packaging can broadly be categorized as 'refill at home' and 'refill on the go'. Refill at home is similarly categorized as Refillable Parent Packaging by Coelho et al. (2020a) and distinguishes between refill packaging and parent packaging. The refill packaging should be produced with less material and/or resources than the parent packaging. It can take various forms to hold the concentrated refill product: bottles, pouches, containers, pods, tablets, and powders (Coelho et al., 2020a). On the other hand, refill on the go is similarly categorized as Refillable by Bulk Dispenser by Coelho et al. (2020a) and can be realized through two main dispenser technologies: gravity-fed dispensers and dispenser bins (Costa, 2018). More specifically, customers can either refill their reusable container by scooping product from open/lidded bins, or by holding their reusable container below a sealed-off gravity-fed dispenser while releasing product through a dispensing mechanism, such as a hand crank (Johnson, 1984; Johnson et al., 1985).

#### 2.1.2 Product types

Certain product types are more appropriate for refillable packaging systems than others. This depends on several aspects, such as the liquid or solid state of a product, the frequency of refill needed and a product's shelf life (Greenwood et al., 2020). Refill on the go is considered suited for food and non-food, health and beauty products and garden products (Costa, 2018). Food groceries that require refrigeration to keep their quality and remain fresh are not suitable for this refillable packaging type (e.g. meat, fish, cheese) (Beitzen-Heineke et al., 2017). On the other hand, refill at home is deemed suitable for non-food (e.g. detergents) and personal care products (e.g. cosmetics, tooth and mouth wash tabs, deodorant and shampoo) (Coelho et al., 2020a).

## 2.2 Analyzing refillable packaging systems from a supply chain perspective

When analyzing refillable packaging systems, it is important to consider the whole supply chain, from the production of packaging to the end-of-life (Mahmoudi & Parviziomran, 2020). This is the case mainly because refillable packaging systems could potentially entail negative impacts from a systems perspective (Coelho et al., 2020a). As such, several researchers have investigated refillable packaging systems in the context of their supply chain (Beitzen-Heineke et al., 2017; Scharpenberg et al., 2021). For instance, Scharpenberg et al. (2021) analyzed the strategies of packaging-free supermarkets along their supply chain, which differed from a general supply chain through added supply chain steps (cleaning and refilling/dispensing). Given that consumers can still discard the packaging, a cradle-to-grave approach is appropriate for refillable packaging systems (Scharpenberg et al., 2021).

### 2.2.1 Feasibility

Refillable packaging systems are not necessarily feasible to implement in every supply chain (Coelho et al., 2020a). In the corporate context, feasibility refers to assessing whether a given idea could be implemented under certain circumstances. Some authors apply the Four-Phase Feasibility Analysis, focusing on product/service, industry/market, organizational and financial feasibility (Berry, 2017). Others solely focus on technical and financial feasibility (Fellows, 1997). Herman & Thai (2020) propose a feasibility analysis framework centered around stakeholder, market, primary production, structure and enabling environment feasibility. Given that this framework is applicable in the context of sustainable supply chains, it will be guiding in this research. Furthermore, the proposed indicators differ for every product, sector and/or company. Therefore, the sections below draw upon refillable packaging barriers and challenges to operationalize the feasibility dimensions.

#### 1. Stakeholder feasibility

Stakeholder feasibility refers to the interests, needs and participation of actors along the supply chain (Herman & Thai, 2020). Retailers must consider both suppliers and consumers (Vadakkepatt et al., 2021). They must cooperate with their suppliers to implement refillable packaging systems (Beitzen-Heineke et al., 2017). It is particularly relevant to research customer acceptance, as their participation is key to the success of refillable packaging systems (Greenwood et al., 2021; Lofthouse et al., 2017; Wikström et al., 2016). Researchers have investigated consumer behavior towards refillable packaging through the behavior-intention gap (Kramer et al., 2021). However, Greenwood et al. (2021) points out that this approach neglects the fact that many consumers currently do not have the availability of refillable packaging systems. Therefore, the authors propose to research consumer willingness to engage, which is a proven indicator of future behavior. For this, an online survey is deemed useful as it allows to quickly and efficiently discover if and why a consumer would engage or not with a certain refillable packaging system. Additionally, Greenwood et al. (2021) investigates which factors influence the consumer's willingness to engage. While they focus on physical properties of packaging, other influential factors exist as well. First, whether consumers perceive a potential price discount to refillable packaging could influence their willingness to engage (Costa, 2018; Lofthouse & Bhamra, 2006; Lofthouse et al., 2017). Both the potential positive environmental impact of refillable packaging systems and their quality have also been identified as potential drivers for consumer willingness to engage (Lofthouse et al., 2017). Finally, convenience in terms of the additional time and effort needed to

engage with refillable packaging systems is deemed an influential factor (Beitzen-Heineke et al., 2017; Lofthouse & Bhamra, 2006).

## 2. Market feasibility

Market feasibility refers to investigating the market demand, as well as the product requirements that are essential to successful marketization (Herman & Thai, 2020). Society is increasingly aligning in the battle against climate change, and user preferences are changing accordingly (EMF, 2019). However, with refillable packaging, the importance of a price discount has been recognized (Minami et al., 2010). For instance, Kobayashi and Benassi (2015) found that lower prices increased the customers' purchase intention towards refillable coffee packs. Also important are preserving the quality of the product and communicating important information (e.g. nutritional value) to the customer (Beitzen-Heineke et al., 2017; Lofthouse et al., 2017). Packaging also serves to attract customers and create brand attachment, which could become more challenging in the case of refillable packaging (e.g. because of universal refills) (EMF, 2019; Lofthouse & Bhamra, 2006). Finally, refillable packaging systems are required to be easy-to-use (EMF, 2019; Lofthouse et al., 2017).

## 3. Primary production feasibility

This dimension relates to the sustainability of production-related aspects, such as the materials used and the production processes (Herman & Thai, 2020). An important factor influencing a refillable packaging system's sustainability is the material choice (Lofthouse et al., 2017; Scharpenberg et al., 2021). Even though refillable packaging is likely to reduce the overall material use (Keoleian & Spitzley, 1999), it might still happen that the proportion of recycled content decreases (Coelho et al., 2020a). The choice of material will also determine the durability of the refillable packaging, or how long the packaging can be reused (Lofthouse et al., 2017).

## 4. Structure feasibility

Structure feasibility is a rather broad dimension encompassing everything from the actors' role in the supply chain, to the required knowledge and expertise, distribution, and governance (Herman & Thai, 2020). Governance refers to the process of arranging the activities in the supply chain (Ponte & Gibbon, 2005). In the case of refillable packaging, this reflects how store employees arrange the shelf space and how their handling time could change (Lofthouse et al., 2009). For instance, with a bulk dispenser, the store would have to rearrange the shelves to position the bulk dispenser and offer refillable containers. Another important factor would be the implications for distribution, transport, and storage; these would have to be adjusted to reach the full potential of refillable packaging (Beitzen-Heineke et al., 2017; Coelho et al., 2020a).

## 5. Enabling environment feasibility

The final feasibility dimension entails the local, national, and international context of the supply chain. More particularly, this environment consists out of policies, regulations, institutions, and other factors that shape the operations (Herman & Thai, 2020). For instance, the European Commission requires single-use plastics to be pulled from the market or replaced by reusable packaging alternatives where possible (Directive 2019/904). Health and safety regulations have been identified as barriers for refillable packaging (EMF, 2019; Lofthouse & Bhamra, 2006), and even more so for Refillable by Bulk Dispenser packaging (Coelho et al., 2020a). For instance, the Packaging and Materials Decree

determines what materials can have direct contact with food and includes other requirements such as displaying quantity information (Rijksdienst voor Ondernemend Nederland [RVO], 2021).

### 2.2.2 Impact

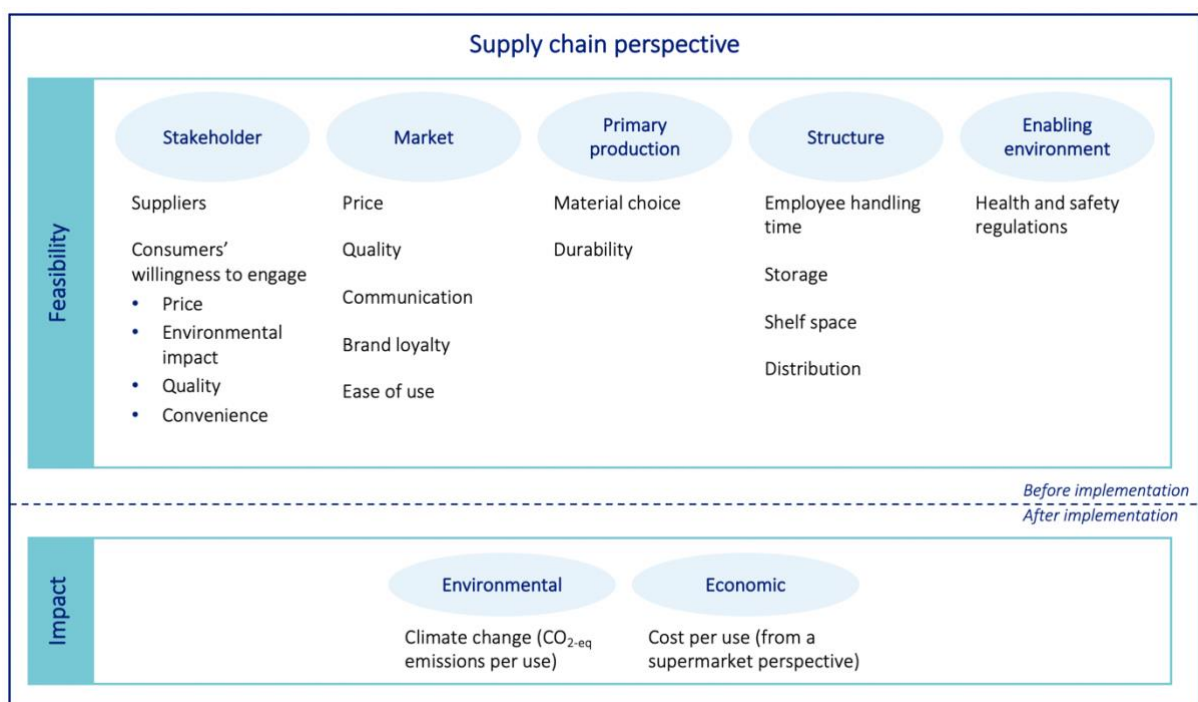
In order to assess the potential of refillable packaging systems for Dutch supermarkets, it is important to analyze their impact after implementation. This concerns both the environmental and economic impact of implementing refillable packaging (Mahmoudi & Parviziomran, 2020). Literature has mainly researched environmental impact through a supply chain perspective by performing an LCA (e.g. Dolci et al., 2016; Nessi et al., 2014). LCA is a widely applied tool to analyze the positive and negative environmental impacts across the entire supply chain of a certain product or service (ISO, 2006a). However, the ISO 14044 standard containing the requirements and guidelines for an LCA is deemed flexible to interpret and implement (Finkbeiner, 2014; ISO, 2006b). Therefore, the EU has published guidelines on the Product Environmental Footprint (PEF) methodology with the aim of harmonizing market claims of green products (Directive 2013/179). This methodology is based on LCA but redefines certain methodological requirements to decrease flexible interpretation of the ISO 14044 standard and consequently increase comparability and reliability of results. In the context of refillable packaging systems, the impact on climate change can be measured through the CO<sub>2-eq</sub> emissions along the supply chain (Coelho et al., 2020a; Greenwood et al., 2021). However, existing LCA studies on refillable packaging systems consider a variety of impact categories besides climate change, including ozone depletion, acidification, eutrophication, and human toxicity. Some include the impact in terms of food waste since packaging has an important food preservation function, implying a trade-off between food waste and packaging (Beitzen-Heineke et al., 2017; Verghese et al., 2013). Microplastics and their damaging effect on ecosystems and human health are also investigated with regards to the environmental impact of packaging (Guan et al., 2021). As such, LCAs have been criticized for not including indirect environmental impacts of packaging. The methodology rather tends to focus on direct environmental impacts of packaging related to e.g. its production and end-of-life treatment (Molina-Besch et al., 2019). However, the impact category climate change relates to greenhouse gas emissions from fossil resources, bio resources and land use change, which can arise across the entire supply chain (ISO, 2006a). Since plastic packaging alone is predicted to represent 15% of global CO<sub>2-eq</sub> emissions by 2050 (Zheng & Suh, 2019), this study considers climate change as a significant impact category and as an appropriate proxy for the entire environmental impact of packaging. Bala et al. (2010) also argues that simplified tools focusing on climate change are appropriate solutions for industries to overcome the inherent complexity of LCAs.

Besides the environmental impact, implementing refillable packaging systems can also have a positive or negative economic impact. Whether refillable packaging leads to economic gains or not depends on various aspects, including transport distances, market demand, frequency of refill, and customer lock-in (Coelho et al., 2020a; Lofthouse & Bhamra, 2006). Furthermore, the breakeven point is a critical parameter affecting the economic impact, as it indicates the point at which the revenues equal the costs of the refillable packaging system (Lofthouse & Bhamra, 2006). For Refillable by Bulk Dispenser, for example, investments will be required in providing dispensers, adapting the shelf space, and providing weighing scales. On the other hand, the cost might decrease since packaging can take up a large part of the product cost (Minami et al., 2010). The economic impact of reusable packaging systems

has been researched (to a limited extent) through a supply chain perspective (Coelho et al., 2020a). Specifically, Life Cycle Costing (LCC) studies aim to surpass conventional cost accounting by including the costs of a product across all stages of the supply chain, namely purchasing, processing and end-of-life costs (Klöppfer, 2008). Different types of LCC exist. A conventional LCC focuses on costs and benefits internal to an organization, whereas an environmental LCC further incorporates external costs that are expected to be relevant (e.g. CO<sub>2</sub> tax). A societal LCC aims to further incorporate all external costs and benefits (Ciroth et al., 2011). Given that this study aims to assess the suitability of refillable packaging systems for Dutch supermarkets with ALDI in the Netherlands as a case study, a conventional LCC is applied. In this context, the costs of refillable packaging systems can be compared with single-use packaging (Coelho et al., 2020a). This implies that cost is the sole impact category considered, even though the economic impact of packaging also depends on benefits and other factors. The break-even point is therefore understood as the point (number of uses) where a refillable packaging system costs less than its single-use equivalent, indicating whether transitioning is an economically viable decision or not.

## 2.3 Conceptual framework

The sections above outline the theoretical foundation for investigating how suitable refillable packaging systems are for Dutch supermarkets. Figure 1 visualizes how refillable packaging systems were analyzed from a supply chain perspective according to their feasibility and impact in order to provide recommendations for Dutch supermarkets and ALDI in the Netherlands specifically. This study understands feasibility as assessing whether implementation would be possible, which is operationalized through barriers and challenges identified in literature. By contrast, impact is understood as assessing refillable packaging systems after implementation and distinguishes between environmental and economic impact.



**Figure 1** Conceptual framework for assessing the suitability of refillable packaging systems


### 3 Methodology




This chapter illustrates how the suitability of the four most implemented refillable packaging systems was determined. The next sections describe in more detail how this study researched feasibility and impact of the refillable packaging systems.

#### 3.1 Research design

The research design is a mixed method research, in which qualitative and quantitative methods were combined to allow for a deeper understanding of the problem (Johnson et al., 2007). The four refillable packaging systems are described in Table 1. They were previously selected based on a market analysis, in which a relatively high number of companies implementing a certain refillable packaging system was seen as an indicator of success. In addition, the input of ALDI in the Netherlands was considered. Variables such as the sales volume of a certain product category and the business model of ALDI were considered. The feasibility of these refillable packaging systems was analyzed through a consumer survey and semi-structured expert interviews. This was complemented with an impact assessment (LCA and LCC), comparing both the environmental and economic impact between refillable and single-use packaging systems. Finally, the results allowed to give recommendations on which refillable packaging systems were deemed most suitable for Dutch supermarkets to implement. Since the LCA and LCC in this research were based on a simple model, the qualitative results complemented the quantitative results and provided more nuanced recommendations.

**Table 1** Summary of the four refillable packaging systems included in this research

No.	Description refillable packaging system	Single-use alternative	Picture
1	<p><b>Rf-go-liquid: refill on the go for laundry detergent</b></p> <p>The customer either brings a bottle of laundry detergent from home or gets a new and empty one at the dispenser. The customer then selects which type of laundry detergent he/she wishes to purchase on the touch screen. While holding the bottle underneath the spout, the customer waits for the machine to fill the bottle. The machine will then print a ticket with the price and necessary information. This ticket can be scanned at check-out. The customer will only pay for the content of the bottle if he/she brought a bottle from home.</p>	Single-use bottle of liquid laundry detergent (1.1 L)	

2	<p><b>Rf-go-pasta: refill on the go for pasta</b></p> <p>The customer either brings a container from home or gets a cellulose bag at the dispenser. A container needs to be weighed on the build-in weighing scale that remembers the tare weight. After pressing the button/touch screen, the customer dispenses the produce and weighs it. The weighing scale prints a ticket with weight, price, and necessary information of the produce. This ticket can be scanned at check-out. Given that the weighing scale automatically subtracts the tare weight, the customer will only pay for the produce if he/she brought their own container.</p>	Single-use flow pack of pasta (500gr)	
3	<p><b>Rf-home-powder: refill at home for powder cleaning detergent</b></p> <p>The customer buys a bottle of cleaning detergent in a store. When the bottle is (almost) empty, the customer returns to the store to buy a refill sachet containing concentrated detergent. At home, the customer pours the powder in the bottle and adds water.</p>	Single-use bottle of liquid cleaning detergent (1.25 L)	
4	<p><b>Rf-home-liquid: refill at home for liquid laundry detergent</b></p> <p>The customer buys a bottle of laundry detergent in a store. When the bottle is (almost) empty, the customer returns to the store to buy a refill pouch containing the liquid laundry detergent. At home, the customer can refill the laundry detergent bottle 2 times with this refill pouch.</p>	Single-use bottle of liquid laundry detergent (1.1 L)	

## 3.2 Feasibility assessment

To assess the feasibility of the refillable packaging systems, a short online consumer survey and five semi-structured expert interviews were conducted.

### 3.2.1 Expert interviews

The purpose of the interviews was to explore what elements increase or decrease the feasibility of the refillable packaging systems. With semi-structured interviews, the order of posing the questions and the degree of standardization across interviews is flexible to allow the researcher to further inquire and discover additional insights (Göttfert, 2015). An interview guide (Appendix A) based on five feasibility dimensions was used to guide the interview process. These dimensions were stakeholder, market, primary production, structure and enabling environment feasibility (see Figure 1). Additionally, the

interview guide included an opening to shed light on the purpose of the research and an overview of the refillable packaging systems being researched. Both this interview guide and a consent form were sent to the interviewees beforehand to allow them to prepare for the interview. The interviewees were selected through purposive sampling, which is a commonly applied sampling strategy in qualitative research to ensure information-rich cases (Palinkas et al., 2015). In this case, purposive sampling helped ensuring packaging-specific knowledge and expertise, both in general (external experts) and in the context of ALDI in the Netherlands (internal experts). The aim was to cover as much of the feasibility dimensions as possible with the knowledge from the different sampled experts. The resulting selection of experts is summarized in Appendix B.

Next, the interviews were transcribed and analyzed through the software NVivo. NVivo allows to organize and understand the data through coding, for which this research relied on an inductive approach. Through interpreting the data, concepts and relationships were identified, allowing the researcher to build a theory on specific concepts and overarching themes from the data (Strauss & Corbin, 1998). More specifically, the analysis was structured around three coding steps: open coding, axial coding, and selective coding (Corbin & Strauss, 1990). First, open coding entailed that all transcripts were read with the aim of coding all statements that relate to refillable packaging in general and to the four most implemented refillable packaging systems. Importantly, the codes were purely attributed to statements based on interpretation of the data (rather than a predefined coding scheme). This step resulted in some codes that were overlapping in meaning (but phrased differently), as well as some codes on similar concepts but with contradicting meaning. The codes “required effort is more important than price” and “price is more important than required effort” are an example of such similar codes with contradicting meaning. Both these types of codes (overlapping or contradicting) were merged and renamed (e.g. “trade-off between effort and price”). As a next step, axial coding implied that all the open codes were analyzed to find relationships between them. This resulted in overarching themes, encompassing multiple concepts that are related to each other. The final step included selective coding, which entailed refining the concepts and themes to establish a coding scheme that is fully relevant to the research question. In this process, some codes were omitted and most importantly, all concepts and themes were integrated in one scheme. This resulted in a coding scheme, consisting of 34 concepts and 15 themes and 3 overarching levels or dimensions (Appendix C).

### 3.2.2 Consumer survey

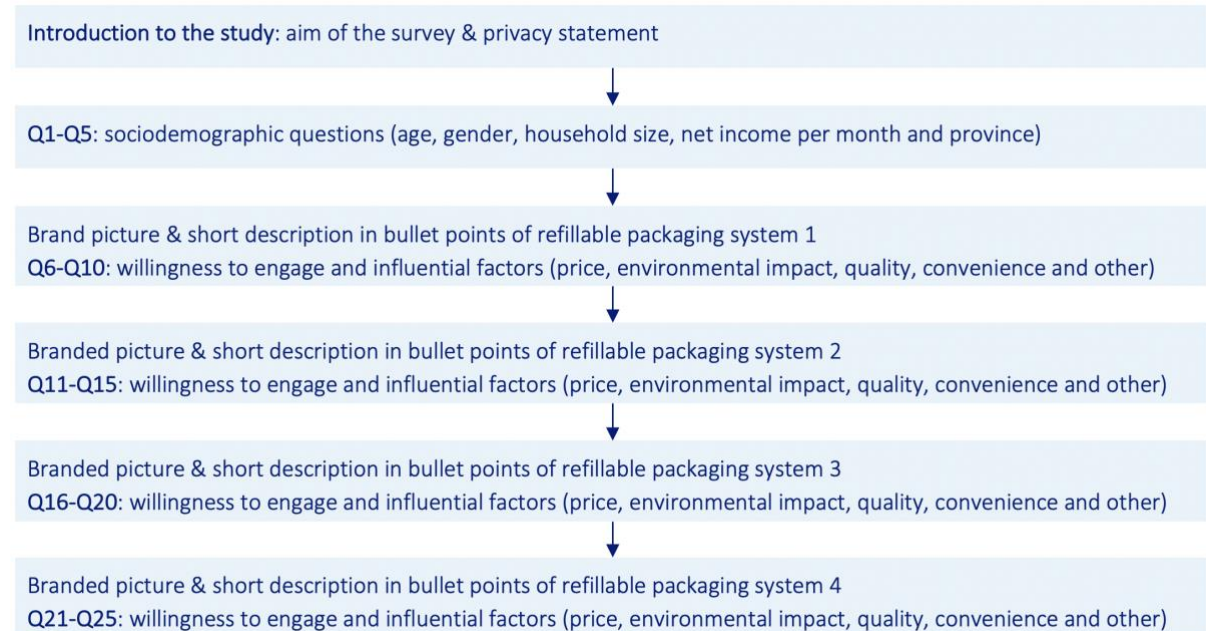
The interviews were complemented with an online consumer survey conducted through the online survey tool Qualtrics. The aim of this survey was to gain complementary insights on the consumers’ willingness to engage with refillable packaging systems. In other words, the aim is to further explore ‘stakeholder feasibility’ in Figure 1. Given that ALDI in the Netherlands is the case study of this research, its customers were sampled to represent Dutch supermarket customers. However, customers of other Dutch supermarkets might differ in their willingness to engage with refillable packaging systems. The sample was also self-selected, since the survey was distributed through the weekly newsletter of ALDI in the Netherlands. This means that the response rate and the actual sample size depended on the decision of the customers to participate or not, implying a self-selection bias (Lavrakas, 2008). Still, given the time and resource constraints in this research, the method was deemed fitting for the aim of the study. Moreover, the survey was open to respondents for one week and participating respondents could win a coupon of ALDI in the Netherlands. This data collection approach resulted in a total of 173

participating respondents. The content of the survey was based on Greenwood et al. (2021) (see section 2.2.1) and was tested on a few respondents beforehand. Figure 2 gives an overview of the survey content.

The resulting data was described and analyzed using the software Stata. Similarly to Martinho et al. (2017), a Chi-square test of Independence was performed to explore whether there is a statistically significant ( $p < 0.05$ ) relationship between the customers' willingness to engage and the socio-demographic and influential variables. In other words, the test analyzes whether there is a significant effect of one variable on another by checking if the distribution of frequencies differs with the expected distribution (Tallarida & Murray, 1987). It is worth noting that for some of the variables the frequency requirement of at least 5 values per category was not fulfilled. Still, given that all the survey data was nominal, that the values of the variables were mutually exclusive and that there were two independent groups (people willing and people not willing to engage), the non-parametric Chi-square test was deemed applicable (McHugh, 2013). Given that this test analyzes possible relationships between the willingness to engage with a packaging system and merely one other variable, it was also deemed relevant to investigate the effect of multiple independent variables on the willingness to engage. For this, linear regressions were performed for each packaging system, with willingness to engage as the dependent variable and socio-demographic and influential variables as independent variables. A linear regression shows how much variance in the dependent variable is explained by the all the independent variables included in a regression model (Vocht, 2022). In other words, it allows to find out which independent variables have a significant ( $p < 0.05$ ) effect on the dependent variable, given a certain model of multiple independent variables. It does not give any indication on relationships between the dependent variable and each independent variable on its own (Vocht, 2022).

All variables were coded as dummy variables to account for the categorical nature of the collected data. This implies that for each categorical variable a reference value was selected, which represented the "0" value of that variable. As an example, consider the gender of the respondent. The Qualtrics output contained a variable with value "1" representing female and value "2" representing male. To replace this variable, a dummy variable was subsequently created in Stata, corresponding to male if it had value "1" and female if it had value "0" (the reference category). As such, the mean value of this dummy variable indicated the percentage of respondents linked to value "1" (male) of that specific variable. For instance, if the mean value of the dummy variable *gender\_male* was 0.4335, then it can be concluded that 43.35% of the respondents were male. For categorical variables with more than one category (e.g. household size), categories were intuitively grouped based on the number of observations per group and subsequently coded through multiple dummy variables. The grouping of different Dutch provinces into one rural and one urban category was based on research by Haartsen et al. (2003). In any case, it was always ensured that for every categorical variable with  $k$  (grouped) categories,  $k-1$  dummy variables were created (Gujarati, 1970). Regarding the influential factors, the Qualtrics output consisted of two variables per influential factor, per packaging system. For instance, for *rf-go-liquid*, one variable tracked whether a respondent deemed the price important if they would engage with the packaging system, whereas another variable tracked whether that same respondent deemed the price important if they wouldn't engage with it. As such, every data line was characterized by 10 influential variables per packaging system, resulting in 40 influential variables in total. To increase understanding of the data, every two variables associated with an influential factor of a packaging system in Qualtrics were merged into one variable in Stata, indicating whether a certain respondent deemed e.g. price important in their

decision to engage or not with a certain packaging system. In other words, there was no more distinction between importance of price when a respondent was willing to engage and importance of price when a person was not willing to engage. This resulted in 20 influential factor variables, 1 per influential factor instead of 2.



**Figure 2** Schematic overview of the survey content

### 3.3 Impact assessment

As required by the ISO 14044 standard, the following sections contain the first step of an LCA and LCC, a discussion of the goal and scope (ISO, 2006b).

#### 3.3.1 Goal of the study

The goal of the attributional LCA and LCC is to compare the environmental and economic impact of the refillable packaging systems with their single-use alternatives. As such, it can be assessed whether transitioning would yield benefits in terms of decreasing CO<sub>2-eq</sub> emissions and of costs per use. This will help inform ALDI in the Netherlands whether refillable packaging is a suitable approach to reduce their packaging waste. The goal of the study is not to make public claims on behalf of ALDI in the Netherlands.

#### 3.3.2 Scope of the study

The product systems included in the LCA and LCC are packaging systems. As described in *Table 1* (section 3.1), the four refillable packaging systems included in this research are: rf-go-liquid, rf-go-pasta, rf-home-powder and rf-home-liquid. Each of these refillable packaging systems was then compared to its current single-use alternative. Both refillable and single-use packaging systems deliver the same functionality: preserving, protecting and facilitating consumption (Lofthouse et al., 2017). Similarly to Scharpenberg et al. (2021), a functional unit (FU) shared by all packaging systems was defined to allow

for comparison across the alternatives. As such, the following FU was applied: “primary and secondary/tertiary/bulk packaging needed to provide one unit of the product in conventional single-use packaging”. This FU was used to adjust the Life Cycle Inventory (LCI) data. Specifically in this study, the LCI data was adjusted in terms of an allocation factor and in terms of the estimated number of uses of a packaging item. The allocation factor of each packaging system was based on the volume of the single-use primary packaging, which entailed 1.1 L (for liquid laundry detergent), 500 g (for pasta), and 1.25 L (for liquid cleaning detergent). The number of uses was calculated based on the technical life span and the return rate of a packaging item. The technical life span refers to the number of uses a packaging item can technically withstand before it cannot fulfil its function anymore (e.g. it breaks or is too damaged). The actual number of uses for a packaging item still depends on its return rate, i.e. the average amount of times a packaging item is reused/refilled after being used. As such, formulas (1-3) were used to calculate the mass of packaging items. Similar formulas were applied to all costs.

$$(1) \quad mass\_FU(p) = \frac{mass(p) \times allocation\ factor(p)}{number\ of\ uses\ (p)}$$

Where:

- $p$  refers to a packaging item (e.g. the cap of a bottle, secondary packaging, ...)
- $mass\_FU(p)$  refers to the mass per functional unit of a packaging item, in grams/FU
- $mass(p)$  refers to the absolute mass of a packaging item, in grams
- $number\ of\ uses\ (p)$  refers to the number of use cycles a packaging item is expected to undergo, calculated based on the technical lifespan (i.e. maximum number of uses) and the return rate of the packaging. The following formula was applied:

$$(2) \quad \begin{aligned} & \text{if } return\ rate\ (p) = 1 \rightarrow number\ of\ uses(p) = technical\ lifespan\ (p) \\ & \text{if } return\ rate \neq 1 \rightarrow number\ of\ uses\ (p) = \min(technical\ lifespan\ (p), \frac{1}{1 - return\ rate\ (p)}) \end{aligned}$$

- $allocation\ factor(p)$  refers to the share of a packaging item that corresponds to one unit of volume of the primary single-use packaging. This share was calculated considering the volume capacity of the packaging item with the following formula:

$$(3) \quad allocation\ factor(p) = \frac{volume\ capacity\ primary\ single-use\ packaging}{volume\ capacity(p)}$$

In order to model the packaging systems and assess their impact, this study used a [tool](#) based on the PEF methodology and developed by the Netherlands Institute for Sustainable Packaging (KIDV, n.d.a). The tool follows the circular footprint formula of the PEF approach to deal with multi-functionality and allocation (e.g. for recycled content). The impact assessment is based on the ReCiPe method and includes the midpoint impact category climate change based on the IPCC 100 Global Warming Potential (GWP) values. For the LCC, one impact category measured in costs is included. The secondary data is based on the Ecoinvent 3.5 database and assumptions from literature where necessary. These assumptions are listed in Appendix D. Finally, the tool follows a cradle-to-grave approach by accounting for all life cycle phases, from raw resource extraction to end-of-life. Given the iterative nature of LCA, this study aimed to prioritize data collection efforts, by further narrowing down the scope of the KIDV tool. Table 2 illustrates which activities were included in the LCA and which not. Regarding the LCC, a

retailer perspective was applied during data collection, which implied that only the internalized costs were considered across the packaging life cycle. More specifically, the cost of packaging production (i.e. the purchase price), the cost of transport and the cost of end-of-life were taken into consideration in the LCC.

**Table 2** *List of activities included or excluded in the KIDV tool and in the LCA*

Activity	Included in KIDV tool?	Included in LCA?
Raw material production	Yes	Yes
Packaging production	Yes	Yes
Transport to product filling	Yes	No, it is assumed that this takes place in the same location as packaging production
Product filling	No, no significant impact expected compared to the single-use alternative	No
Transport to distribution centrum	Yes	Yes
Storage	No, no significant impact expected compared to the single-use alternative	No
Transport to customer	Yes	Yes
Use	No, no significant impact expected compared to the single-use alternative	No
Return transport	Yes	No, it is assumed that customers return to the store to do their groceries anyway
Cleaning	Yes	Yes, but only for the rf-go-pasta <sup>2</sup>
Transport to end-of-life	Yes	Yes
End-of-life	Yes	Yes

### 3.3.3 Sensitivity analyses

Seven sensitivity analyses on the environmental impact of the packaging systems were conducted. Table 3 provides an overview of these analyses. Four analyses focused on varying values for: 1) the return rate of detergent bottles, 2) the distribution between the customer's container and the cellulose bag for pasta, 3) the cleaning frequency of the customer's container for pasta, and 4) the size of the pasta bulk packaging. By contrast, the other three analyses focused on changing one distinct value each time: 1) the end-of-life treatment of opaque PET bottles, 2) the material choice of the refillable laundry detergent bottle, and finally 3) the cleaning method of packaging items in contact with detergents.

**Table 3** *Overview of conducted sensitivity analyses*

Nr.	Adjusted input variable	Baseline value	New value(s)	Packaging systems affected
1	End-of-life treatment of opaque PET bottle	Incineration	Recycling	<ul style="list-style-type: none"> <li>• Rf-go-liquid</li> <li>• Rf-home-liquid</li> <li>• Single-use laundry detergent</li> </ul>

<sup>2</sup> In the baseline scenario it was assumed that the impact of cleaning the refillable packaging systems of detergents is negligible. The impact of rinsing with hot water will be tested in a sensitivity analysis.

2	Material choice of refillable laundry detergent bottle	PET	HDPE	<ul style="list-style-type: none"> <li>• Rf-go-liquid</li> <li>• Rf-home-liquid</li> </ul>
3	Return rate of detergent bottles	90%	From 0% to 100%	<ul style="list-style-type: none"> <li>• Rf-go-liquid</li> <li>• Rf-home-powder</li> <li>• Rf-home-liquid</li> </ul>
4	Cleaning method of packaging items in contact with detergent	Not included	Rinsing with hot water	<ul style="list-style-type: none"> <li>• Rf-go-liquid</li> <li>• Rf-home-powder</li> <li>• Rf-home-liquid</li> </ul>
5	Distribution between customer's container and cellulose bag	40% vs 60%	0% to 100% vs 100 to 0%	<ul style="list-style-type: none"> <li>• Rf-go-pasta</li> </ul>
6	Cleaning frequency of the customer's container	Every use	Every 2, 3, 4, 5 uses	<ul style="list-style-type: none"> <li>• Rf-go-pasta</li> </ul>
7	Size of bulk packaging	5kg	1kg, 3kg, 10kg, 15kg, 20kg	<ul style="list-style-type: none"> <li>• Rf-go-pasta</li> </ul>

The first analysis touches upon the end-of-life treatment of laundry detergent bottles (manufactured from opaque PET). As will be discussed in section 4.5, opaque PET disturbs the recycling process of PET, resulting in lower quality rPET with a significantly lower market price (KIDV, n.d.b). However, since this implies that the bottles are still theoretically recyclable (independently of the quality), it was decided to analyze the difference in environmental impact between assuming the opaque PET bottles would be incinerated or recycled. Furthermore, regarding the second analysis, literature and interview findings showed that another material for the refillable laundry detergent bottle might be a good choice. It was therefore decided to analyze the environmental impact when producing HDPE bottles instead of PET<sup>3</sup>. Regarding the third, research has shown that the return rate is a key variable affecting the performance of refillable packaging systems (Coelho et al., 2020a). As shown in formula (2), the return rate affects the number of uses of refillable packaging systems. As such, it directly influences the minimum number of times a refillable packaging system must be reused to perform at least better than its single-use alternative (in terms of total CO<sub>2-eq</sub> emissions). As for the fourth analysis, the tool did not allow for including cleaning processes for all packaging items in contact with detergent (e.g. refillable cleaning/laundry detergent bottles, laundry detergent dispensers, ...). Therefore, it was chosen to model an additional cleaning method “rinsing with hot water” in parallel with the existing cleaning process “handwashing”, with exception of the impact of using soap. The last two analyses were selected based on findings from the expert interviews. Namely, some interviewees expressed concerns about a negative impact of offering cellulose bags at the rf-go-pasta station. Other suggested that some customers might not immediately clean their container (because merely dry foods were in there), but rather every 2/3/4/... uses. Finally, Dolci et al. (2016) researched multiple waste prevention scenarios for pasta distribution with different sizes of bulk packaging. As such, this study also investigated the effect of different sizes of bulk packaging for rf-go-pasta.

<sup>3</sup> According to a report by the OECD (2021), HDPE has more durable properties. Other reports and companies also selected HDPE as the material for refillable detergent bottles (Charnely et al., 2017; Nessi et al., 2014). In addition, ALDI in the Netherlands is planning to transition to HDPE for all non-food articles, as PET/rPET are more suitable for food articles. The HDPE bottles were assumed to hold the same volume of laundry detergent as in the baseline scenario, to weigh 68.2 g, to contain 25% of rHDPE and to be produced through extrusion blow molding (Charnely et al., 2017; Nessi et al., 2014; OECD, 2021; Tide, n.d.). According to the OECD (2021), there is a larger supply of rHDPE than of rPET, which strengthens the assumption of 25% rHDPE.

## 4 Life Cycle Inventory

The sections below describe how the packaging systems were modelled, including relevant assumptions made and data sources consulted. For each refillable packaging system, the system boundaries were developed to guide the LCI process. Figure 3 shows these system boundaries. Regarding the single-use packaging systems internal data from ALDI in the Netherlands and the product suppliers were used. If needed, assumptions were made based on academic -, grey literature and/or desktop research. Regarding the refillable packaging systems, previous LCA studies (Dolci et al., 2016; Nessi et al., 2014) or examples currently implemented in the market (e.g. SophieGreen) were guiding. Where necessary, additional assumptions were made based on academic -, grey literature and/or desktop research. As previously discussed, the mass and cost data were adjusted according to the formula (1).

### 4.1 Technical lifespan and return rate

Table 4 provides an overview of the number of uses accounted for in the inventory data of the refillable packaging items. As shown in formula (2), this is calculated based on the technical lifespan and the return rate of a packaging item. Single-use packaging items, such as the bulk packaging of pasta and the refill sachet of cleaning detergent, were assumed to have a technical lifespan of 1. The technical lifespan of the dispenser containers (for laundry detergent and for pasta) was calculated based on annual sales data of ALDI in the Netherlands.<sup>4</sup> Regarding the laundry detergent bottle, the average consumer uses 8kg of laundry detergent per year (Denmark Ecolabelling, 2011)<sup>5</sup>, leading to approximately 7 uses of a 1.25 kg bottle (as sold by the ALDI in the Netherlands brand). The technical lifespan of the cleaning detergent bottles was based on the retailer Splosh (Splosh, n.d.). Due to the lack of concrete market data, it was assumed that the cleaning detergent bottle was refilled every 10 weeks<sup>6</sup>. Both detergent bottles were assumed to be reused for 3 years<sup>7</sup> (Charnley et al., 2017), resulting in a technical lifespan of 21 uses (respectively 15) for the laundry detergent bottle (respectively cleaning detergent bottle). Finally, it was assumed that the technical lifespan of the customer's PP container is 50 use/cleaning cycles, since researchers commonly assume this (Gallego-Schmid et al., 2018; Greenwood et al., 2021; Miliutenko et al., 2020; YOYO.BoostReuse, 2020).

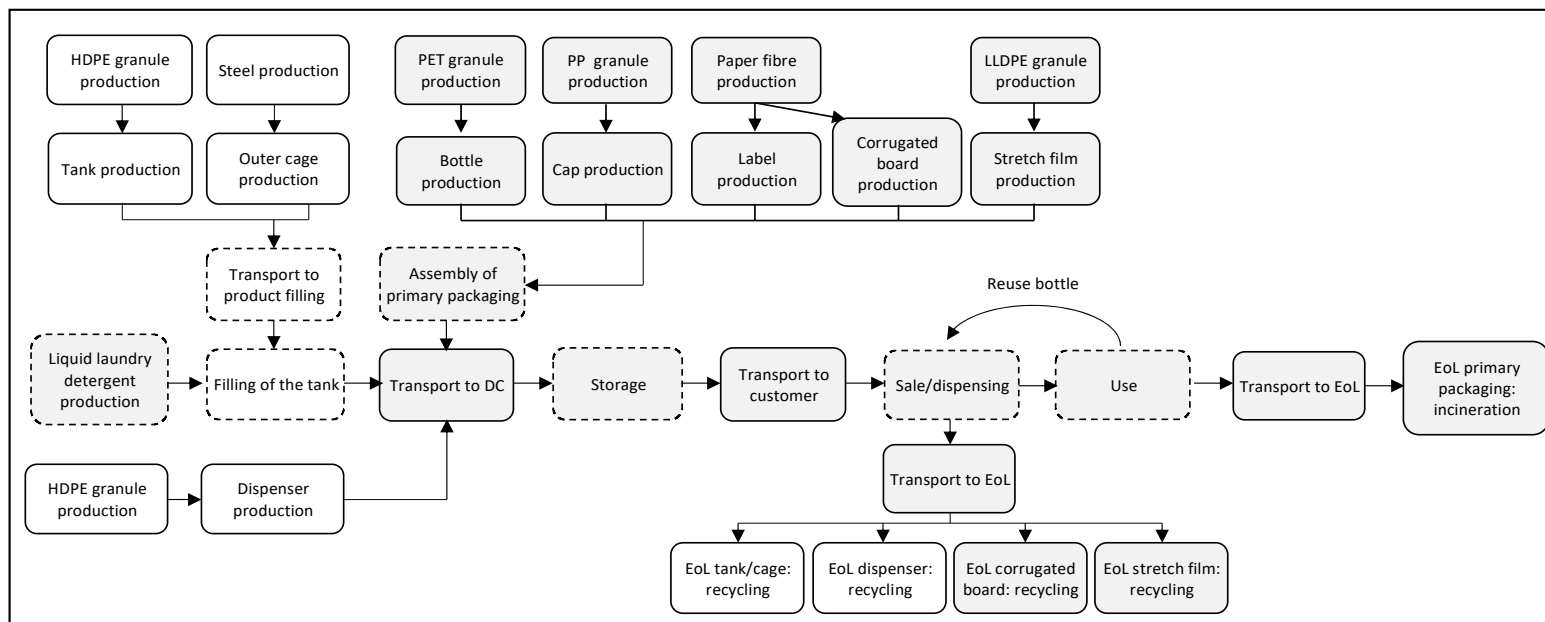
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<sup>4</sup> For the laundry detergent, the annual sales data was divided through the number of stores. These number of units sold per year per store were then translated to volume (in L) sold per year per store. In combination with the container's volume of 80L, this resulted in an estimated number of refills of 15.4 per year per store. As in Nessi et al. (2014), it was assumed the container would be used for 10 years, which resulted in a technical lifespan of 154. Similarly, for the pasta, annual sales data was divided through the number of stores. These number of units sold per year per store were then translated to weight (in kg) sold per year per store. In combination with the container's capacity of 10.6 kg, this resulted in an estimated number of refills of 87.5 per year per store. As in Dolci et al. (2016), it was assumed that the container would be used for 10 years, which resulted in a technical lifespan of 875.

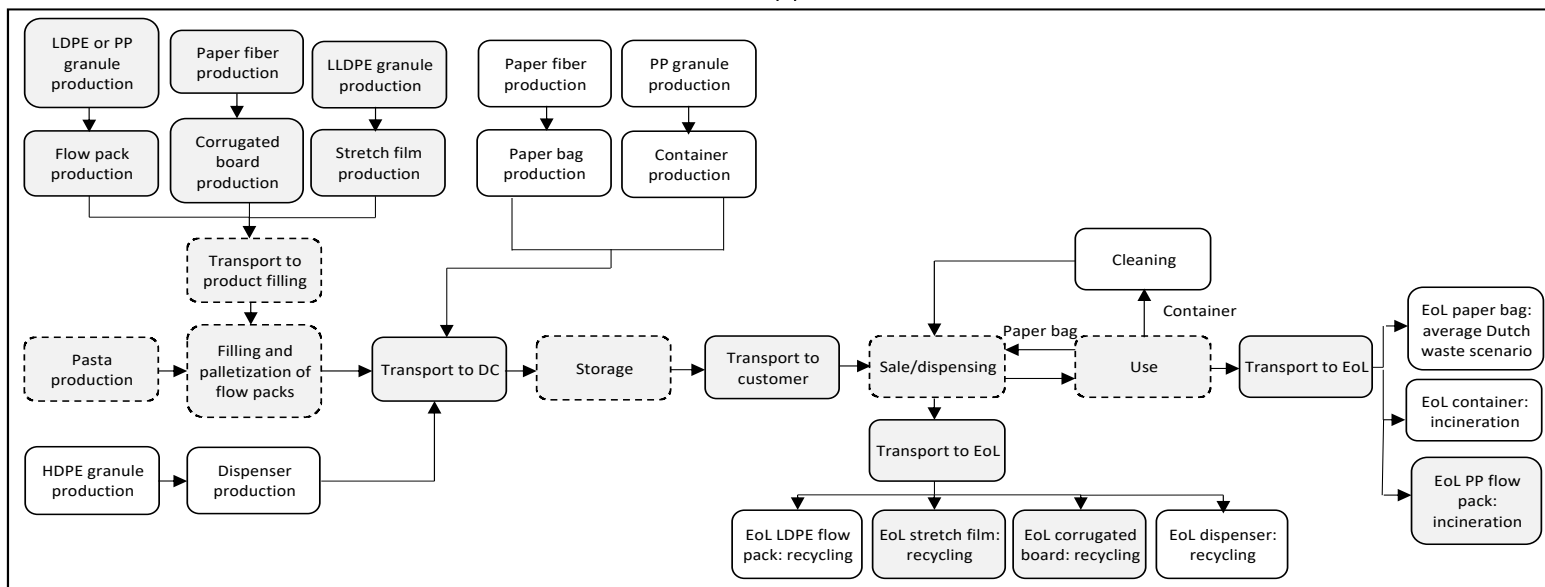
<sup>5</sup> The report includes data on Scandinavian countries, countries in Southern Europe and Germany. It was assumed that the average German consumer is the best proximate for the average Dutch consumer.

<sup>6</sup> Splosh offers 2 L refills for every period between 2 weeks and 20 weeks.

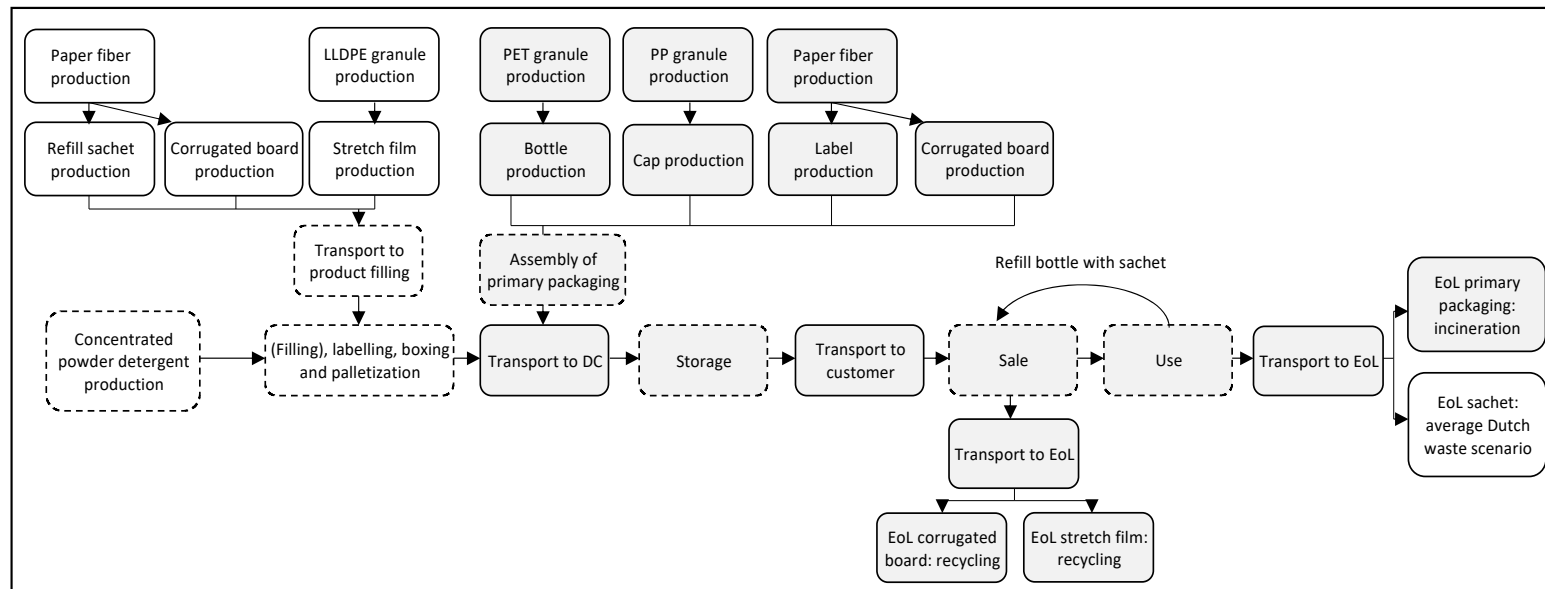
<sup>7</sup> Charnley et al. (2017) based their research on the UK detergent manufacturer Splosh, which based its business model on the consumer's needs and behavior.



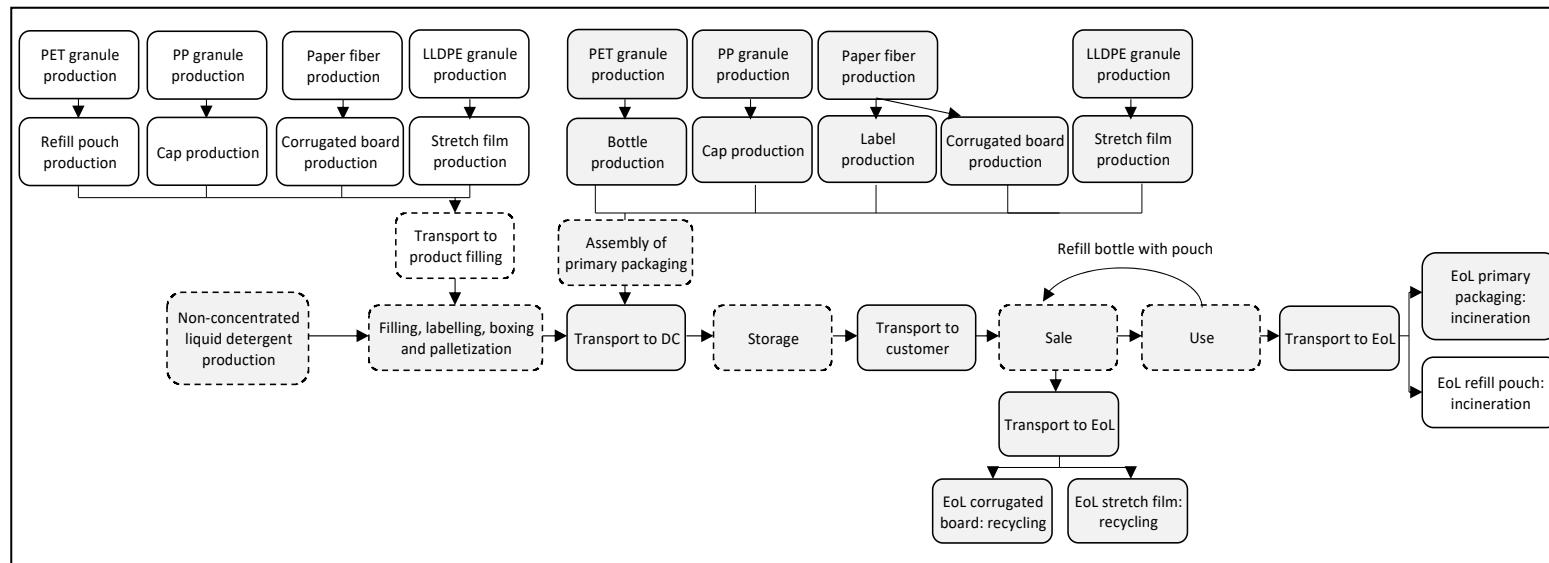
(a)



(b)



(c)



(d)

**Figure 3** Main processes included in the system boundaries of the four refillable packaging systems: (a) rf-go-liquid, (b) rf-go-pasta, (c) rf-home-powder, and (d) rf-home-liquid. The boxes represent activities performed in the supply chain, for which a dashed outline refers to an activity not included in this study. The grey boxes are activities that are also accounted for in the alternative single-use packaging systems.

Regarding the return rate, it was generally assumed that packaging items that remain owned by either a supplier or ALDI in the Netherlands (e.g. bulk tank for laundry detergent, dispenser) would have a return rate of 100%. Both detergent bottles were assumed to have a return rate of 90%, as Charnley et al. (2017) concluded that minimum 90% of the bottles initially bought, were reused by the consumer. The probability of a customer throwing away its PP dishwasher-proof container before using it 50 times is considered negligible, implying an assumed return rate of 100%. What differs, however, is the percentage of customers bringing their container to the store, which is discussed in section 4.2.2.

**Table 4** *The technical lifespan, return rate, and number of uses accounted for per packaging system*

Packaging system	Packaging	Technical lifespan	Return rate (%)	Nr of uses
Rf-go-liquid	Bulk packaging	50	100	50
	In-store dispenser	154	100	154
	Bottle	21	90	10
Rf-go-pasta	Bulk packaging	1	100	1
	In-store dispenser	875	100	875
	Customer's container	50	100	50
	Paper bag	1	100	1
Rf-home-powder	Bottle	15	90	10
	Refill sachet	1	100	1
Rf-home-liquid	Bottle	21	90	10
	Refill pouch	1	100	1

## 4.2 Packaging production

The material type, weight per FU and production process of every packaging item were relevant to calculate the total impact of a packaging item. This included secondary packaging, as well as tertiary packaging to some extent. Wooden pallets were excluded given the lack of internal data at ALDI in the Netherlands. Moreover, the LCA by Dolci et al. (2016) showed a negligible impact of pallets, when comparing single-use packaging with refillable dispenser units for pasta. Regarding the percentage of recycled content used in the packaging items, the tool automatically considers the industry average for most materials<sup>8</sup>. For the other materials, it was first assessed whether there was internal data at ALDI in the Netherlands on the recycled content. If no exact data was available, an average recycled content was assumed based on internal data of similar products. This was the case for e.g. all packaging items produced from paper<sup>9</sup>. If no data was available, the packaging was assumed to be entirely produced from virgin material (0% recycled content).

<sup>8</sup> These materials are corrugated board, PS, rubber, silicone, glass (white), glass (green), wood (soft wood), MDF, aluminum, carbon steel and stainless steel.

<sup>9</sup> Paper at ALDI in the Netherlands is always FSC certified, either FSC Recycled, FSC Mix or FSC 100%. Given the different definitions of the certifications, an average of 50% recycled content was assumed for all paper packaging items, excluding corrugated board (for which the industry average was considered by the tool).

#### 4.2.1 Rf-go-liquid: refill on the go for laundry detergent

In the refillable packaging system, consumers refill their bottle of laundry detergent at an in-store dispenser every time they run out of product. The inventory data is described in Table 5. The laundry detergent is supplied in bulk packaging to the store, which was assumed to be a 600 L tank in a steel outer cage (Nessi et al., 2014). In the store, the laundry detergent is poured from this tank into an 80 L container in the automated dispenser. The consumer then refills an empty bottle with laundry detergent from the automated dispenser. Based on the interviews, it was assumed that this bottle is a bottle from the ALDI in the Netherlands brand. Additionally, it was discussed internally that this choice allows to guarantee quality, and e.g. prevent contamination from previous soda drink bottles. As also mentioned in the interviews, if the automated dispenser would release fixed volumes of product, working with the same bottle would prevent possible spillages. As such, all packaging elements (including secondary and tertiary) of this bottle were assumed to be equal to the current single-use packaging system. For the different packaging items of the bottle, the mass (g) equals the inventory data of the single-use packaging system, whereas the mass per FU (g/FU) equals the inventory data of the refillable packaging system.

**Table 5** *Inventory data of rf-go-liquid and its single-use alternative*

Packaging type	Packaging item	Material	Mass (g)	Mass per FU (g/FU)	Recycled content (%)	Production process	References
Bulk packaging (600 L)	Tank	HDPE	13,000	0.48	0	Extrusion blow molding	Nessi et al., 2014; OECD, 2021
	Outer cage	Stainless steel <sup>10</sup>	20,000	0.73	Industry average	Sheet rolling	Nessi et al., 2014; The Chicago Curve, n.d.
In-store dispenser (80 L)	Container	HDPE	2,133	0.19	0	Extrusion blow molding	Nessi et al., 2014
Primary packaging (1.1 L)	Bottle	PET	60.00	6.00	0	Extrusion blow molding	Retrieved from supplier
	Cap/closure	PP	8.80	0.88	0	Injection molding	Retrieved from supplier
	Label	Bleached paper	0.88	0.09	50	Calendaring	Retrieved from supplier; Deshwal et al., 2019
Secondary packaging (per bottle)	Boxes	Corrugated board	50.50	5.05	Industry average	Cardboard box folding	Retrieved from supplier

<sup>10</sup> In Nessi et al. (2014), it is assumed that the outer cage is produced with galvanized steel. However, the KIDV tool only allows to choose between stainless steel and carbon steel. Since both stainless steel and galvanized steel share the main property of withstanding corrosion, it was assumed that stainless steel was a proper substitute for galvanized steel.

Tertiary packaging (per bottle)	Boxes & layer pads	Corrugated board	2.80	0.28	Industry average	Cardboard box folding	Retrieved from supplier
	Stretch film	LLDPE	1.07	0.11	0	Film extrusion	Retrieved from supplier; Polymer Data Services, n.d.

#### 4.2.2 Rf-go-pasta: refill on the go for pasta

In this refillable packaging system, consumers refill either their own container or a cellulose bag with pasta from an in-store automated dispenser. The inventory data is described in Table 6. The pasta is supplied in bulk packaging to the store, which is assumed to be a pouch containing 5 kg of pasta (Dolci et al., 2016). This appeared to be in line with the volume used by MIWA, a big player in the market for automated dispensers and a partner for retailers seeking to implement this refillable packaging system (SUPZero, n.d.). Then, the pasta is poured from the bulk packaging into the dispenser container. This container was assumed to contain up to 10.6 kg of pasta (Dolci et al., 2016). Although Dolci et al. (2016) chose polycarbonate as the material for the dispenser container, this study chose HDPE as the material. The main reason was that the KIDV tool did not include polycarbonate. Subsequently, HDPE was considered as the best proxy in terms of toughness and resistance of the resin (Fastradius, n.d.; Plastiko, n.d.). Even though the durability of the chosen material is important from a life cycle perspective, it should be noted that HDPE wouldn't provide the same transparency as polycarbonate, which could be important from the point-of-sale perspective. Next, the consumers would dispense pasta from this container, either in their own PP container or in a cellulose bag offered by ALDI in the Netherlands. The material for the consumer's container was chosen based on research by the KIDV and YOYO.BoostReuse, which concluded that non-transparent PP containers could withstand frequent washing the best (YOYO.BoostReuse, 2020). Additionally, PP reusable containers have a smaller environmental impact than glass ones (Miliutenko et al., 2020). The data on these two types of primary packaging was adjusted to the likelihood of customers using each type of packaging. It was assumed that 40% of the customers would bring their own container, based on a Dutch consumer survey showing that around 40% of Dutch consumer would avoid buying plastic where possible (PwC, 2019). This implies that it was expected that 60% of the consumer would use the cellulose bag offered in-store. Finally, the inventory data for the single-use packaging system is described in Table 7.

**Table 6** Inventory data of rf-go-pasta

Packaging type	Packaging item	Material	Mass (g)	Mass per FU (g/FU)	Recycled content (%)	Production process	References
Bulk packaging (5 kg)	Pouch	LDPE	46.20	4.62	0	Film extrusion	Dolci et al., 2016; Meckley, 2017
	Boxes (per pouch)	Corrugated board	176.00	17.60	Industry average	Cardboard box folding	Dolci et al., 2016
	Stretch film (per pouch)	LLDPE	4.17	0.42	0	Film extrusion	Dolci et al., 2016; Polymer Data Services, n.d.

In-store dispenser (10.6 kg)	Container	HDPE	2,214.05	0.12	0	Extrusion blow molding	Dolci et al., 2016; Fastradius, n.d.; Plastiko, n.d.
Primary packaging	Cellulose bag (250 g)	Unbleached paper	7.10	8.52	50	None <sup>11</sup>	Dolci et al., 2016
	Container (1100 ml)	PP	172.00	1.50	0	Extrusion blow molding & thermoforming	YOYO.BoostReuse, 2020; Muliutenko et al., 2020; Gallego-Schmid et al., 2018

**Table 7** Inventory data for the single-use packaging of pasta

Packaging type	Packaging item	Material	Mass (g)	Mass per FU (g/FU)	Recycled content (%)	Production process	References
Primary packaging (500 g)	Flow pack	PP	5.18	5.18	0	Film extrusion	Retrieved from supplier; Polymer Data Services, n.d.
Secondary packaging (per flow pack)	Boxes	Corrugated board	21.67	21.67	Industry average	Cardboard box folding	Retrieved from supplier
Tertiary packaging (per flow pack)	Stretch film	LLDPE	0.30	0.30	0	Film extrusion	Retrieved from supplier; Polymer Data Services, n.d.

#### 4.2.3 Rf-home-powder: refill at home for cleaning detergent

In this refillable packaging system, consumers refill their cleaning detergent at home by pouring a concentrated powder detergent (either loose or compressed) in their empty bottle and adding water. The inventory data is described in Table 8. Given that the leading example, SophieGreen, uses PET for its reusable bottle, it was assumed that the bottle in this refillable packaging system is equal to the current single-use (PET) packaging system (KIDV, n.d.c). Therefore, the mass (g) of these packaging items equals the inventory data of the single-use packaging system, whereas the mass per FU (g/FU) equals the inventory data of the refillable packaging system. Regarding the refill packaging, a concentrated powder refill from SophieGreen (multi-purpose cleaning detergent) was purchased in order to weigh the primary packaging. The secondary and tertiary packaging were derived from a product sold by ALDI in the Netherlands with similar measurements and mass (i.e. a toothbrush).

**Table 8** Inventory data of rf-home-powder and its single-use alternative

Packaging type	Packaging item	Material	Mass (g)	Mass per FU (g/FU)	Recycled content (%)	Production process	References
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<sup>11</sup> In the tool, the production impact of unbleached paper is included in the material selection itself.

Primary packaging (1.25 L)	Bottle	PET	48.00	4.80	50	Injection blow molding	Retrieved from supplier; OECD, 2021; KIDV, n.d.c
	Cap/closure	PP	6.60	0.66	0	Injection molding	Retrieved from supplier; OECD, 2021
	Label	Bleached paper	1.85	0.19	50	Calendaring	Retrieved from supplier; Deshwal et al., 2019
Secondary packaging (per bottle)	Boxes	Corrugated board	27.00	2.70	Industry average	Cardboard box folding	Retrieved from supplier
Tertiary packaging (per bottle)	Boxes & layer pads	Corrugated board	6.39	0.64	Industry average	Cardboard box folding	Retrieved from supplier
Refill packaging	Sachet	Bleached paper	11.00	11.00	50	Calendaring	Purchased packaging from SophieGreen
Refill - secondary packaging (per sachet)	Boxes	Corrugated board	10.50	10.50	Industry average	Cardboard box folding	Retrieved from supplier
Refill -tertiary packaging (per sachet)	Boxes & layer pads	Corrugated board	0.56	0.56	Industry average	Cardboard box folding	Retrieved from supplier
Refill -tertiary packaging (per sachet)	Stretch film	LLDPE	0.35	0.35	0	Film extrusion	Retrieved from supplier

#### 4.2.4 Rf-home-liquid: refill at home for liquid laundry detergent

In this refillable packaging system, consumers refill their laundry detergent by pouring non-concentrated liquid laundry detergent out of a pouch into their empty bottle at home. The inventory data is described in Table 9. The same data from section 4.2.1 applies to the bottle in the refillable and single-use packaging systems here. Next, the pouch containing the refill laundry detergent was assumed to be two times the volume of one bottle, so 2.2 L. This was decided based on desktop research on current pouch sizes in the market, which showed that larger pouches might be impractical. The largest pouch size for a similar product was found at Splosh, which sold 2.5 L washing liquid pouches (Splosh, n.d.). Given that ALDI in the Netherlands currently sells a pouch for hand soap, it was assumed that similar materials would be used in this refillable packaging system. The secondary and tertiary packaging of the pouch were also derived from ALDI in the Netherlands' current hand soap pouch.

**Table 9** Inventory data of rf-home-liquid and its single-use alternative

Packaging type	Packaging item	Material	Mass (g)	Mass per FU (g/FU)	Recycled content (%)	Production process	References
Primary/secondary /tertiary packaging	Same packaging items as in 4.2.1 (Table 5)						

Refill packaging (2.2 L)	Pouch	PET	44.18	22.09	0	Film extrusion	Retrieved from supplier; Polymer Data Services, n.d.
	Cap/closure	PP	1.20	0.60	0	Injection molding	Okada et al., 2021; OECD, 2021
Refill - secondary packaging (per pouch)	Boxes	Corrugated board	84.33	42.17	Industry average	Cardboard box folding	Retrieved from supplier
Refill - tertiary packaging (per pouch)	Stretch film	LLDPE	2.44	1.22	0	Film extrusion	Retrieved from supplier; Polymer Data Services, n.d.

### 4.3 Transport between facilities

Two types of transport were considered: transport between supplier location and all distribution centra (DC) of ALDI in the Netherlands, and between all DC's and all stores. Data on the first type of transport was collected through the product suppliers, where possible. Data on the second type of transport was collected internally at ALDI in the Netherlands. Some general assumptions apply to all packaging systems. First, all transport distances were calculated as average distances. Additionally, 95% of transport between DC's and stores is organized through trucks (> 32 tons). Since no significant impact is expected from the remaining 5% (smaller trucks), it was assumed that 100% of DC to stores transport was facilitated through trucks (> 32 tons). Moreover, only the laundry detergent supplier was able to share the type of truck used for transport from its facility to the DCs of ALDI in the Netherlands. It was assumed that the cleaning detergent supplier used a similar type of truck, since it is a similar product being shipped and since the annual sales data was comparable. Even though the annual sales data of pasta is twice as high as laundry detergent, the same truck types were assumed for the transport between the pasta supplier's facility and ALDI's DC's, since the product is lighter than laundry detergent and has no strict expiration date. This means that more units could be transported per trip (compared to laundry detergent), implying similar transport needs in terms of the type and size of truck. Finally, it is expected that the transport types and average distances do not differ between refillable and single-use packaging systems. Based on these assumptions, Table 10 summarizes the transport type and average distance for both transport between supplier and all DC's and transport between all DC's and all stores.

**Table 10** Overview of the four packaging systems (applies to both single-use and refillable alternative)

Packaging system	Supplier – DC		DC - store	
	Transport type	Avg. distance (km)	Transport type	Avg. distance (km)
Rf-go-liquid	Truck (16 – 32 tons)	194.00	Truck (> 32 tons)	48.59
Rf-go-pasta	Truck (16 – 32 tons)	166.14	Truck (> 32 tons)	48.59
Rf-home-powder	Truck (16 – 32 tons)	299.14	Truck (> 32 tons)	48.59
Rf-home-liquid	Truck (16 – 32 tons)	194.00	Truck (> 32 tons)	48.59

The mass of the packaging was expected to affect the impact of transport. In addition, the weight of the product itself was taken into account, even though the production of the products (e.g. laundry

detergent) was excluded from the LCA. In order to compare single-use with refillable packaging systems, the mass of the product should be included to account for the impact of transport. Moreover, the packaging and product mass were adjusted to the FU through formula (1).<sup>12</sup> The mass of all packaging items can be found in the previous sections; the product mass was gathered internally at ALDI in the Netherlands. Furthermore, the single-use packaging still used in the refillable packaging systems (e.g. laundry detergent bottle) was assumed to be transported empty. Table 11 illustrates the total mass per FU (i.e. the sum of the packaging and product mass). This mass per FU is equal across the two types of transport.

**Table 11** *Overview of the transported mass per FU (in g/FU)*

Packaging system	Single-use pack (full)	Single-use pack (empty)	Bulk packaging	Dispenser container	Refill packaging
Rf-go-liquid	1366.17	12.41	1302.62	0.19	/
Rf-go-pasta	527.15	/	522.64	0.12	/
Rf-home-powder	1273.39	8.98	/	/	37.40
Rf-home-liquid	1366.17	12.41	/	/	1308.20

#### 4.4 Use

Several packaging items in the four refillable packaging systems must be cleaned in some way. However, most packaging items would have to be rinsed with hot water to get rid of any soap residue left. Those packaging items are the bulk tank and dispenser container for laundry detergent, and the primary packaging (i.e. bottles) for laundry and cleaning detergent. Given that the KIDV tool doesn't allow for rinsing as a cleaning process, the cleaning of these packaging items was not included for now. Furthermore, the customer's container in rf-go-pasta was assumed to be washed by hand in 55% of the cases and washed in a consumer grade dishwasher in 45% of the cases (Miliutenko et al., 2020). Finally, it should be noted that with rf-home-powder water must be added at home to create new (liquid) cleaning detergent that is ready-to-use. However, given that this water would not be packaged and transported before use of the product, the potential impact of this step was considered negligible.

#### 4.5 Disposal

To account for the transport of disposed packaging items, the average distance a garbage truck travels was estimated. Given that there are a total of 3,457 garbage trucks in the Netherlands (RVO, 2022), covering a road network of approximately 140,000 km (Centraal Bureau voor de Statistiek [CBS], n.d.), it was assumed that every garbage truck covers an average of 40.5 km. Furthermore, it is known that 3,152 of the total amount of garbage trucks are heavy-weight trucks of more than 23 tons (RVO, 2022). Given that this group represents 91% of the total, it was assumed that transport to end-of-life is facilitated through the 16 to 32-ton truck. The mass of the disposed packaging items was derived from the data in Table 11.

<sup>12</sup> For the bulk packaging of laundry detergent (in the case of rf-go-liquid) the number of uses were not accounted for when adjusting to the FU. This was decided because the transport would need to happen for every use cycle of the HDPE tank and steel outer cage.

Table 12 summarizes the end-of-life treatments modeled for every different packaging type in all four refillable packaging systems. In order to determine which end-of-life treatment (i.e. incineration, recycling or a mix of both) applies to a packaging item, the “Recyclecheck” published by the Netherlands Institute for Sustainable Packaging was consulted (KIDV, n.d.b). If a packaging was not deemed as “good recyclable” in this check, it was assumed that the item would be incinerated. For packaging items that were attached to other packaging items (e.g. cap or label on a bottle), the whole would be incinerated as soon as one item was not deemed as “good recyclable”. The steel outer cage of the bulk packaging of laundry detergent was assumed to be recycled, since steel is one of the most recycled materials (EU-Metal, n.d.) Furthermore, it was considered whether proper disposal (and sorting) could be reassured (by ALDI in the Netherlands) or not. For instance, the refill paper sachet for cleaning detergent is theoretically recyclable if it has no PE coating, as seen at SophieGreen (SophieGreen, n.d.). However, if the consumer disposed this incorrectly, it would not be recycled, so it was assumed to be treated according to the average Dutch waste scenario (i.e. a mix of both incineration and recycling).

**Table 12** *Summary of end-of-life treatment per packaging type*

Packaging system	Packaging type	End-of-life treatment
Rf-go-liquid	Bulk packaging	Recycling
	In-store dispenser	Recycling
	Primary packaging – bottle	Incineration
	Secondary & tertiary packaging	Recycling
Single-use laundry detergent	Primary packaging – bottle	Incineration
	Secondary & tertiary packaging	Recycling
Rf-go-pasta	Bulk packaging	Recycling
	Secondary & tertiary packaging	Recycling
	In-store dispenser	Recycling
	Primary packaging – cellulose bag	Average Dutch waste scenario
	Primary packaging – container	Incineration
Single-use pasta	Primary packaging – flow pack	Incineration
	Secondary & tertiary packaging	Recycling
Rf-home-powder	Primary packaging – bottle	Recycling
	Secondary & tertiary packaging (bottle)	Recycling
	Primary packaging – refill sachet	Average Dutch waste scenario
	Secondary & tertiary packaging (refill sachet)	Recycling
Single-use cleaning detergent	Primary packaging – bottle	Recycling
	Secondary & tertiary packaging	Recycling
Rf-home-liquid	Primary packaging – bottle	Incineration
	Secondary & tertiary packaging (bottle)	Recycling
	Primary packaging – refill pouch	Incineration
	Secondary & tertiary packaging (refill pouch)	Recycling
Single-use laundry detergent	Primary packaging – bottle	Incineration
	Secondary & tertiary packaging (bottle)	Recycling

## 4.6 Costs

Three types of internal costs for ALDI in the Netherlands were included in the LCC: production costs, transport costs and end-of-life costs. The selection of cost types was based on the costs included in the KIDV tool. In addition, a retailer perspective was applied, implying that costs external to ALDI in the Netherlands were excluded. For instance, the cost of cleaning is included in the KIDV tool but only applies to the customer's container in rf-go-pasta, implying that it is not a cost for ALDI in the Netherlands. The production, transport and end-of-life costs of this container were also excluded because of this reasoning. Similarly to the LCA data, the costs were calculated relative to each packaging element's FU. For this, it was necessary to know how many units of packaging were transported per trip. For the transport between ALDI in the Netherlands DC's and stores, data was available on the number of units boxed and palletized. Knowing that the average truck at ALDI in the Netherlands can contain 30 pallets, this allowed to estimate the number of units transported, under the assumption that a truck only transports one type of product at once. The same assumption was made for the transport between the supplier's facilities and ALDI in the Netherlands DC's, except if the supplier mentioned otherwise. The latter was the case for the cleaning detergent supplier, who mentioned that the trucks were either fully loaded or half loaded. Therefore, this study assumed the average: 75% loaded trucks.

All packaging production costs were estimated based on the current market prices of materials (Indexmundi, n.d.; Plastic Portal, 2022; SteelOrbis, n.d.)<sup>13</sup>. This was decided because suppliers of ALDI in the Netherlands were not willing to share internal cost structures, i.e. the cost of producing/purchasing different packaging items. The cost of transport from the supplier's facilities to ALDI in the Netherlands DCs was provided by one supplier (the supplier of laundry detergent). The remaining transport costs for the other suppliers were then derived from this (by adjusting it to the average distance between the supplier's facilities and ALDI in the Netherlands DC's). Furthermore, the cost of transport between the DC's and stores, was calculated based on the average tariff per kilometer, 0.45 €/km. Both transport costs were adjusted to the number of units per trip, for which it was assumed that the truck was loaded with only one type of product. The costs were also adjusted to the FU, based on formula (1) in section 3.3.2. However, for the single-use packaging items and the bulk tank for rf-go-liquid, the transport would have to happen every use cycle, which implied that it was not necessary to adjust to the number of uses. Furthermore, given that the dispensers for both laundry detergent and pasta would be used 10 years, it was assumed that the cost of one trip per 10 years is negligible. Additionally, the relative transport cost of the paper bags was assumed to be negligible because of their relative low mass per FU. Finally, regarding the end-of-life treatment of the packaging items, internal costs to ALDI in the Netherlands were calculated based on the national tariffs for packaging waste (Afvalfonds Verpakkingen, n.d.). To determine which tariff was applicable to each packaging item, the "KIDV Recyclecheck" was guiding (KIDV, n.d.b). As the tool required one single disposal cost for all packaging items, the weighted average of the national waste tariffs was calculated based on each item's mass per FU. The resulting production, disposal and transport costs are summarized in Appendix E.

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<sup>13</sup> The sources differ in term of their reference year due to issues with accessibility to public data. Still, all data originates from within the timespan 2020 – 2022.

## 5 Qualitative results

The analysis of the conducted expert interviews lead to two types of findings. First, general findings on the suitability of refillable packaging for supermarkets. Second, a feasibility framework for refillable packaging systems is introduced, of which the most important considerations per refillable packaging system are discussed in more detail.

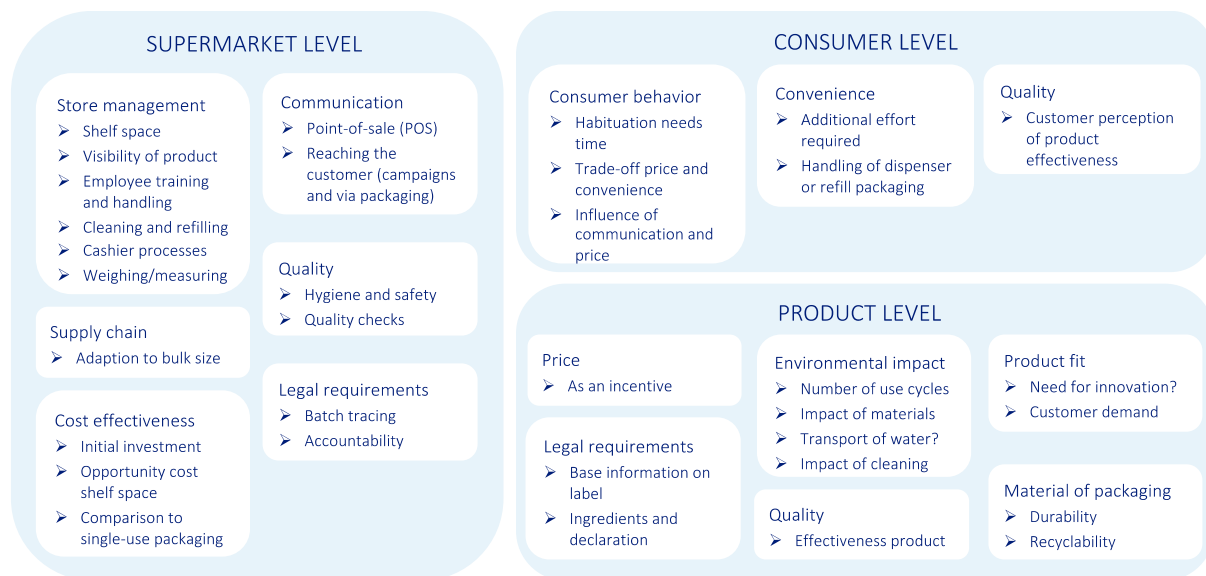
### 5.1 Feasibility of refillable packaging in general

First, some general insights on the feasibility of refillable packaging systems for Dutch supermarkets were discovered. Reasons for opting for refillable packaging systems include responsible use of resources, preventing packaging waste and helping consumers towards sustainable behavior. Refillable packaging represents both an opportunity for supermarkets to gain green credits and an opportunity for consumers to shop responsibly. However, successful implementation of refillable packaging systems requires to rethink packaging, as packaging cannot be solely understood as primary packaging. Supermarkets should apply zero waste principles to the entire supply chain and strive for an absolute reduction of packaging instead of a visible reduction of packaging. Similarly, supermarkets should not implement refillable packaging systems purely for green credits and publicity (i.e. extrinsic motivation). According to one interviewee "... supermarkets should take responsibility and commit to reuse and waste prevention because of intrinsic motivation." Furthermore, supermarkets play a key role in guiding behavioral change among their customers, since these need to get used to the new packaging systems. This guidance can be facilitated through clear and transparent communication as to why refillable packaging systems were implemented and how to interact with them. One interviewee for example pointed out that "you could add a symbol or text on the bottom of a laundry detergent bottle when it is empty. As such, you remind the customer to bring the empty bottle to the store next time." Another example consists of communicating how much single-use packaging, how much CO<sub>2</sub>-eq emissions or how much money consumers could save by buying refillable packaging instead of single-use. Finally, supermarkets should consider the role of convenience and price sensitivity for today's consumer.

Since ALDI in the Netherlands is a discounter supermarket, offering mostly private-label brands at competitive prices, refillable packaging systems could be particularly interesting for its consumers. One interviewee stated that "low-budget supermarkets, such as ALDI in the Netherlands, could focus on the perspective that bulk produce is cheaper in terms of price per kilo than packaged produce." However, some potential barriers were identified as well. In general, implementing refillable packaging systems has an interdisciplinary nature, which implies that numerous departments will be involved (e.g. marketing, sales, communication, logistics, purchasing). Secondly, the success of refillable packaging systems depends on the consumers' behavioral change, which is a rather long-term process. Most supermarkets evaluate the turnover of their products frequently and omit the products with a low turnover rate from their product offering. Finally, discounters tend to work with minimal staffing models in their stores (to cut costs), which means that there is little to no excess capacity to manage refill on the go stations.

## 5.2 Feasibility of the four refillable packaging systems

The coding process described in section 3.2.1 resulted in an understanding of feasibility with regards to three levels: product, consumer, and supermarket. Each level indicates to whom or what the themes and concepts matter or refer. Figure 4 represents the resulting feasibility framework, which serves to guide supermarkets in the assessment of refillable packaging systems. The sections below discuss the most important themes and concepts for each refillable packaging system. Appendix F contains a full systematic overview of the framework with an elaboration on each concept.



**Figure 4** Feasibility framework for refillable packaging systems

### 5.2.1 Rf-go-liquid: refill on the go for laundry detergent

A key component of the success of this packaging system is communication. There are two broad types of communication: point of sale communication and communication outside the store. As one interviewee described, it is important to “... reach the customer that is not standing in front of your shelves ... and think of e.g. an opening campaign besides your POS communication.” Besides the environmental gains, communication should also emphasize discount as an incentive. This is especially important since most interviewees agreed consumers trade-off effort and price. One interviewee concluded that he/she “... would mention in the communication how much discount you would receive as a customer. So, why should you as a customer bring back such an old packaging.” Besides the additional effort of bringing back the empty bottles, someone also stated that “if I can handle it easily and it is clean, it could work.” Cleaning the dispenser is therefore an important aspect of store management, since “... hygiene plays a key role here. ... the chance of having a contamination is quite big, so you will have to clean thoroughly every time.” Adjusting the cashier process is another important sub aspect of store management, as there are three possible scenarios. One interviewee summarized it as follows: “is it a previously bought refillable bottle with new laundry detergent or is it a completely new (single use) article or is it a new refillable bottle plus the refill?” Labelling was identified as possible solution to this issue. Labelling is also a key sub aspect of the legal requirements as it must contain all the base information (e.g. supplier information, EAN code), as well as the ingredient list of the laundry

detergent. The latter is to avoid "... having to sell new bottles to clients when the recipe of your laundry detergent changes." Finally, a key link between consumer behavior and environmental impact was identified by some interviewees: "... it is important you guide behavioral change. In the end, rotation determines the success, so how many times the consumer will reuse [the bottle]." However, a critical note regarding the environmental impact of this packaging system is that "... liquid laundry detergent still contains a lot of water and as such [requires] the transport of water."

### 5.2.2 Rf-go-pasta: refill on the go for pasta

Similarly to the previous packaging system, communication is a key aspect here. The POS communication is especially important because "... the [weighing of the] container might be difficult to explain to the customer. Communication needs to be really good there." Indeed, the consumer is again expected to make the trade-off between the required effort and the price. One interviewee wondered "why the consumer will do it [refilling], if we say you have to pay 75 cents instead of 80 cents, but you still have to refill it yourself." This also relates to the product fit of this packaging system as the price discount supermarkets would have to offer endangers its cost effectiveness. Besides good communication, offering cellulose bags could reduce the effort for some consumers and increase the likelihood of consumers getting used to this new system. However, some interviewees questioned "... what the [environmental] advantage is over very thin PP bags. We could get in trouble with this with greenwashing." Furthermore, choosing an automated dispenser type that facilitates easier weighing (including taring) could also reduce the additional effort required from consumers. Such dispenser types will also affect store management, as it is likely that less customer assistance will be needed. Additionally, with manual dispensers it could for example be that "... the customer is not really honest and manipulates the tare weight." An especially important sub aspect of store management is cleaning since food products are more heavily regulated. One interviewee pointed out that "we will maybe need some type of dishwasher in the backroom of the store to clean all this stuff regularly." Besides the base requirements for the label and ensuring batch traceability, accountability is another important legal aspect for supermarkets to consider. Multiple interviewees expressed their concern that "if I use, for example, a container that is not completely clean, and then I take the product from ALDI home and I get sick afterwards, then who is responsible for this?"

### 5.2.3 Rf-home-powder: refill at home for cleaning detergent

Given that the significantly smaller size of the refill packaging, which reduces its visibility in the shelves, strong communication will again be essential to draw the attention of consumers and inform them on this new packaging system. Especially with POS communication, one interviewee suggested to "... go big on this, through for example a display separated from other brands, and clearly motivate why you are doing this and what you win as a consumer." Furthermore, interviewees had mixed opinions on the consumer behavior, with some stating that "if the price is right, this could work." Others suggested that increased ease-of-use could push the consumer towards this new packaging systems since "... it saves you a lot of dragging if you do not have to carry a 1.5 L bottle home." However, some mentioned that "it could be that the consumer associates powder with lower product quality." Ensuring the quality of the product is thus an important aspect for this packaging system and it is also related to the material and the environmental impact of the refill packaging. Indeed, as one interviewee pointed out: "... the concentrate should be soluble in water and if you package this in paper, [the powder] will seek out

water because it is hydrophile. ... Then you will not have a powder, but a lump of concentrate.” Opting for coated paper then raises the question whether it is more sustainable than simple plastic packaging. However, all interviewees still expected that the total environmental impact would significantly improve because of the reduced impact of transport. One interviewee explained that “everyone who is in the business knows how much water and air we transport in those trucks, especially for this type of product.” Going back to the refill packaging, one interviewee expressed concerns about the look and feel of the packaging since various information elements (e.g. supplier name, article code, ingredients, instructions) are still legally required on the packaging.

#### 5.2.4 Rf-home-liquid: refill at home for laundry detergent

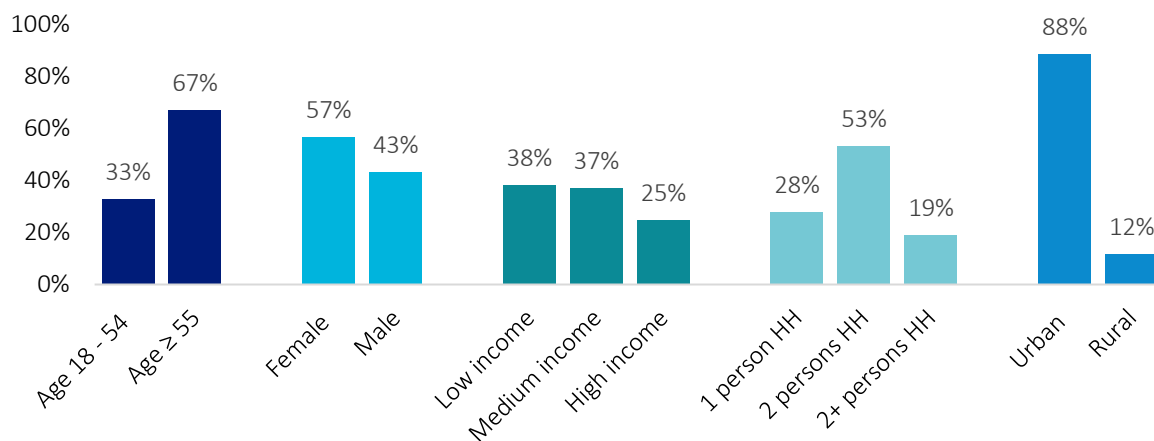
Even though some interviewees emphasized the importance of communication again, it was interestingly more focused on what could go wrong. Customers and the press could be skeptical about rf-home-liquid since it is still liquid laundry detergent, and it is still packaged in plastic. Therefore, one interviewee suggested to “... communicate in the media that you are trying to reduce the impact of your packaging [instead of eliminating packaging].” The concerns regarding the environmental impact were stemming from the material selection and the product fit. Regarding the latter, interviewees wondered whether this could not “... be packaged in a different type of packaging? For example, a small PET bottle with a PET cap.” This refers to the fact that pouches are usually not produced from a mono-material and as such “... go straight into the incinerator.” By contrast, one interviewee foresaw environmental benefits, because “... if you replace 10 single-use bottles that you used to throw away with 1 [refillable] bottle and 9 refill pouches, then you save a considerable amount of packaging waste and as such CO<sub>2</sub>.” It is thus important to convince consumers with the right price and minimal required effort. However, some concerns were voiced regarding the latter since “you still have to bring 1.5 L [of laundry detergent] home and you might prefer doing this with an easy-to-handle bottle than with a pouch that might slip out of your hands or leak in your grocery bag.” Additionally, these pouches tend to have difficulty standing up, which is an issue for both the perceived ease-of-use and the visibility of the product in the store’s shelves. On the other hand, the product requires minimal alterations to store management, as it was the also the case with rf-home-powder. One interviewee stated that “you do not need more space, you do not have to invest in an entire machine, which you would have to install and maintain, and you do not have to train employees [how to handle the new packaging system].”

## 6 Quantitative results: consumer survey

The first section describes the data collected from the respondents, whereas the second section dives into the relationships between different variables.

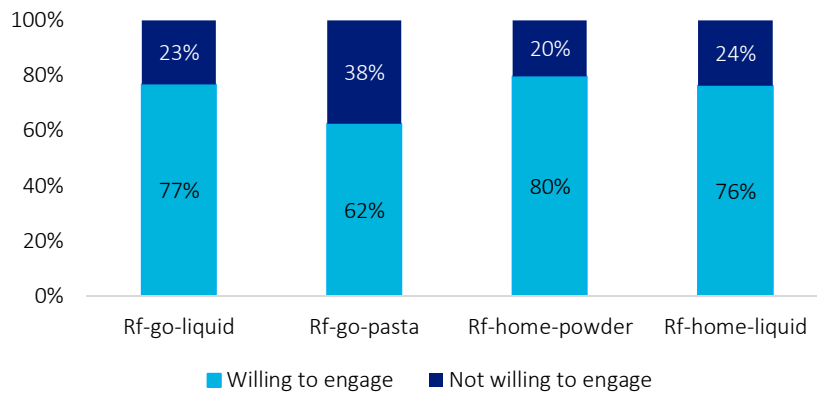
### 6.1 Description of the data

Figure 5 provides a summary of the demographic variables. It can be seen from the figure that 67% of the respondents were aged 55 and above. Furthermore, more women filled in the survey than men, with 57% of the respondents being female. Regarding the level of income, most respondents had a low income (corresponding to a monthly wage below 1499€), given that 37% of respondents had a medium income (1500€ - 2499€) and 25% had a high income (over 2500€). Finally, most of the respondents reported to do their groceries for a 2 persons household (53%) and 12% of the respondents lived in provinces categorized under the rural part of the Netherlands.



**Figure 5** Distribution of respondents across socio-demographic variables

Figure 6 summarizes the dependent variables, which indicate whether a respondent would be willing to engage (1) or not engage (0) with a certain packaging system. As such, the average value of these variables gives an indication of the adoption rate of the four refillable packaging system included in this study. Notably, all four packaging systems are characterized by considerably high adoption rates, with 17 percentage points difference between the packaging system with the lowest adoption rate, *rf-go-pasta* (62%), and the one with the highest adoption rate, *rf-home-powder* (80%). Regarding the remaining packaging systems, 77% of the respondents would engage with *rf-go-liquid* and 76% would engage with *rf-home-liquid*.



**Figure 6** Adoption rates of the four refillable packaging systems

## 6.2 Variables affecting the willingness to engage

As discussed in section 3.2.2, both Chi-square tests and linear regression analyses were performed. The Chi-square tests (Appendix G) showed that there is no significant effect between each socio-demographic variable and each willingness to engage variable. Furthermore, significant relationships were found between each willingness to engage variable and price, environment, and quality. However, the relationship between both price and environment and the willingness to engage variables was stronger than the quality relationships. The Chi-square tests were most suitable for the type of data, but they did not consider the effect of multiple independent variables on the willingness to engage. Therefore, this section further focuses on the results of the linear regression analyses. Table 13 summarizes the linear regression findings for each packaging system. The adjusted R-squared indicates how much variance in the dependent variable is explained by all the independent variables included in the regression model. As such, it serves as an indicator of the goodness-of-fit of that regression model. The goodness-of-fit varies between the four regression models: 68.21% of the variance in *rf-go-liquid* can be explained by the independent variables, as opposed to 37.30% of the variance in *rf-home-liquid*. This implies that *rf-go-liquid* is best predicted by the regression model. The coefficients of the independent variables in the models are interpreted as follows: if an independent variable increases from 0 to 1, then the likelihood of a respondent adopting a packaging system increases/decreases by a percentage equal to the coefficient. For instance, the results show that if a consumer values *convenience* in its choice for *rf-go-liquid* (i.e. value of *convenience* becomes 1), then the likelihood of adopting *rf-go-liquid* decreases by 10.22% (as indicated by the related negative coefficient of -0.1022, see Table 13). In other words, this finding suggests that *rf-go-liquid* was perceived as inconvenient. Moreover, this finding is significant at 0.05 significance level, which implies that it can be concluded that *convenience* has this effect on *rf-go-liquid* with 95% certainty.

Besides *convenience*, the variables *environment*, *price*, *gender\_male*, and *household\_2* also have a significant effect on the adoption of *rf-go-liquid*. If a respondent values the *environment* and *price*, the likelihood of adopting *rf-go-liquid* increases by respectively 38.26% and 12.66%. This indicates that respondents perceived *rf-go-liquid* as a cheaper and more environmental-friendly option than its single-use variant. If the respondent is male, the likelihood of adopting *rf-go-liquid* decreases by 10.04% indicating that this refillable packaging system might appeal relatively more to women. For bigger

households, the likelihood of adopting *rf-go-liquid* also decreases, which could be because of a higher required purchase frequency and the perceived inconvenience (-0.1022).

For *rf-go-pasta*, the regression model shows a significant effect for *convenience*, *environment*, and *price*. If a consumer values *convenience*, the likelihood of adopting *rf-go-pasta* decreases with 19.24%. This implies that *rf-go-pasta* was generally perceived as inconvenient by those consumers that value convenience. For both *environment* and *price* there is again a positive effect. When the environmental impact matters to a consumer, the likelihood of adopting *rf-go-pasta* increases by 46.75%. When the *price* matters to a consumer, the likelihood increases by 34.02%, implying that *rf-go-pasta* was perceived as cheaper than its single-use variant.

Furthermore, the regression model for *rf-home-powder* only displays a significant effect for *environment* and *price*. As with the previous two packaging systems, both variables have a positive effect on the adoption of *rf-home-powder*. This implies that *rf-home-powder* is perceived as having a positive impact on the environment (30.47% increase in adoption likelihood) and as being less expensive than its single-use variant (22.61% increase in adoption likelihood).

Finally, *environment*, *price*, and *income\_high* appear to have a significant effect on the adoption of *rf-home-liquid*. Again, both *environment* and *price* display a positive effect on the adoption of *rf-home-liquid*: 26.90% and 24.19% respectively. The income level of a consumer seems to have a negative impact on the likelihood of adopting *rf-home-liquid*: if *income\_high* is 1, then the likelihood decreases with 15.97%. This implies that *rf-home-liquid* is more interesting to consumers in low and medium level income categories, for whom price is assumingly more decisive.

**Table 13** Results of the regression analyses for the willingness to engage with each packaging system: coefficients, adjusted R-squared and the number of observations

Variable	Rf-go-liquid	Rf-go-pasta	Rf-home-powder	Rf-home-liquid
Convenience	-0.1022*	-0.1924*	-0.0653	-0.0251
Environment	0.3826*	0.4675*	0.3047*	0.2690*
Price	0.1266*	0.3402*	0.2261*	0.2419*
Quality	-0.0106	-0.0446	-0.0343	0.0501
Other	-0.4866*	-0.2392*	-0.3187*	-0.3375*
Aged_55	0.0173	-0.0562	-0.0328	0.0533
Gender_male	-0.1004*	-0.0028	-0.0170	0.0227
Income_medium	-0.0088	-0.0858	-0.0732	-0.0940
Income_high	-0.0252	0.0215	-0.0960	-0.1597*
Household_2	-0.9010*	-0.0306	0.0686	0.0465
Household_2more	-0.1801*	-0.1510	0.0450	0.0757
Province_rural	-0.0632	-0.0043	0.0717	0.0214
Adjusted R-squared	0.6821	0.5786	0.3923	0.3730
Observations	178	178	178	178

Note: \* denotes significance at a  $\leq 0.05$  significance level

### 6.3 Insights from the consumer survey

Overall, both *environment* and *price* are significant variables in all four regression models. Both always have a positive effect on the adoption of a packaging system, implying that when a consumer values *price* and *environment*, refillable packaging in general is more likely to be adopted. In other words, refillable packaging is perceived as both good for the environment and as an economically viable choice. In terms of magnitude, it can be concluded that *environment* has a stronger (positive) influence on the likelihood of adoption than *price* has.

On the other hand, *convenience* and *other* negatively affect the likelihood of consumers adopting refillable packaging. In terms of magnitude, *other* seems to affect the likelihood of not adopting more than *convenience* does. More specifically, *convenience* has a significant effect on the refill on the go packaging systems (*rf-go-liquid* and *rf-go-pasta*). This implies that when consumers value *convenience*, it only has a significant (negative) effect on that type of refillable packaging systems, which are deemed as rather inconvenient. Although the variable *other* doesn't have an underlying meaning ("other" reasons differ between respondents), it can be concluded that when a consumer has another reason in their decision to engage or not with a refillable packaging system, it is more often a reason to not engage. These negative other reasons can be classified in three main categories: product fit, hygiene and environmental doubt. Product fit relates to personal reasons as to why a customer might not be interested in a certain product. For instance, a customer might not eat pasta or prefer to use powder laundry detergent or pods. Examples of hygiene reasons are customers being worried about spillages (both in stores and at home) or other people touching their food (pasta). Environmental doubt refers to (relatively less) customers expressing concerns regarding the environmental benefit of the packaging system. For instance, customers wondered if the refillable packaging systems were necessary since plastics are being recycled already.

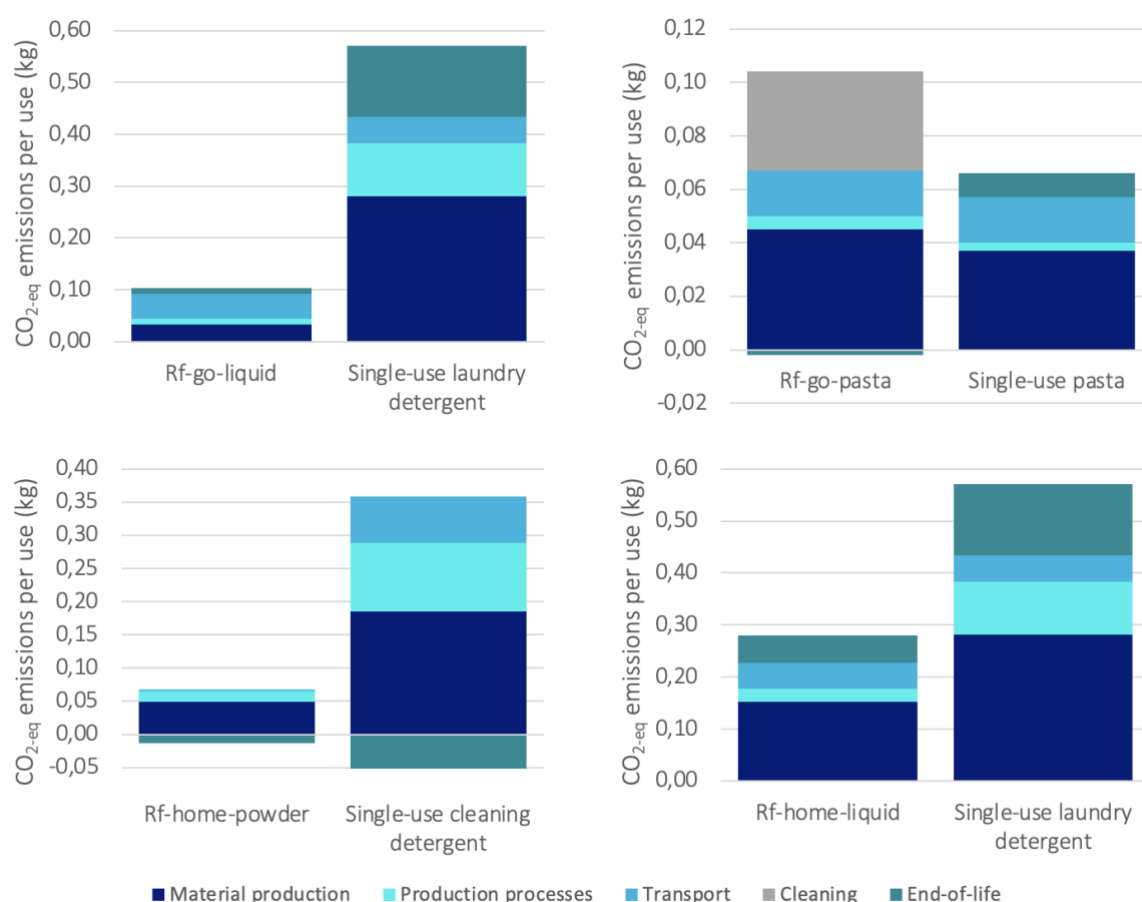
Finally, it is worth mentioning that these regression models align with the Chi square results (Appendix G), as well as further complement it. They capture additional effects that could not be captured in the Chi square tests, such as the influence of convenience on the refill on the go packaging systems and the influence of some socio-demographic variables. The Chi square tests also showed significant relationships of price and environment on all four willingness to engage variables. They also showed a significant relationship for quality, but this was a considerably weaker relationship compared to price and environment. The linear regression models then confirmed that quality is not a significant influential variable.

## 7 Quantitative results: LCA

First the environmental impact of the baseline scenario is described in section 7.1, after which the results of the sensitivity analyses are discussed.

### 7.1 Results baseline

Figure 7 illustrates the total environmental impact in kg CO<sub>2-eq</sub> emissions per FU, i.e. per use, for each packaging system, as well as the contribution of each life cycle stage to the total impact of a packaging system. For every refillable packaging system, its single-use alternative is shown for comparison. Table 14 gives a quantitative overview of the impact in terms of CO<sub>2-eq</sub> emissions for each packaging system.



**Figure 7** Contribution of different life cycle stages to the total environmental impact of each refillable and single-use packaging system

**Table 14** Break-down of total environmental impact (in kg CO<sub>2-eq</sub> emissions per use) per packaging system

Packaging system	Material production	Production processes	Transport	Cleaning	End-of-life	Total impact per use	Potential CO <sub>2-eq</sub> difference
Rf-go-liquid	0.033	0.012	0.047	0	0.011	0.103	-82%
Single-use laundry detergent	0.281	0.102	0.051	0	0.136	0.570	

Rf-go-pasta	0.045	0.005	0.017	0.037	-0.002	0.102	+55%
Single-use pasta	0.037	0.003	0.017	0	0.009	0.066	
Rf-home-powder	0.049	0.016	0.003	0	-0.013	0.054	-82%
Single-use cleaning detergent	0.185	0.104	0.070	0	-0.052	0.306	
Rf-home-liquid	0.153	0.025	0.049	0	0.052	0.279	-51%
Single-use laundry detergent	0.281	0.102	0.051	0	0.136	0.570	

Rf-go-liquid has a total environmental impact of 0.103 kg CO<sub>2-eq</sub> emissions per use, which implies an 82% reduction compared to its single-use alternative. Given that the (absolute) contribution of the transport stage remains equal, the main reason for this significantly lower impact is the contribution of material production (and consequently end-of-life). More precisely, it was assumed that the laundry detergent bottle would be used 10 times, implying that the environmental impact of material production (in CO<sub>2-eq</sub> emissions per use) was divided over 10 uses, instead of 1 use as with the single-use bottle. As such, material production has an environmental impact of 0.033 kg CO<sub>2-eq</sub> emissions per use for rf-go-liquid, compared to 0.281 kg for single-use laundry detergent, which is roughly 8.5 times higher.

Rf-go-pasta is the only packaging system that performs worse than its single-use alternative, with a total impact of 0.102 kg CO<sub>2-eq</sub> emissions per use compared to 0.066 kg. This increase of 55% in CO<sub>2-eq</sub> emissions per use is partly due to the impact of cleaning the customer's container, which constitutes 36% of the total impact of the refillable packaging system. As mentioned in section 4.4, it was assumed that 55% of customers would clean their container by hand, whereas 45% of customer would clean it with a consumer-grade dishwasher. Second, rf-go-pasta is the only packaging system for which the contribution of material production increases compared to single-use pasta. This can be explained by the fact that the pasta is still transported in plastic flow packs to the store. Still, it is worth noting that its single-use alternative has a low environmental impact to begin with (0.066 kg).

On the other hand, the best performing refillable packaging system is rf-home-powder with a total impact of 0.054 kg CO<sub>2-eq</sub> emissions per use and a corresponding 82% reduction compared to its single-use alternative. It is worth noting here that the contribution of the transport stage is similar across all refillable and single-use packaging systems, except for rf-home-powder. This refillable packaging has a significantly lower impact of transport (compared to the other refillable packaging systems), because the powder concentrate implies a significantly lower mass of transport. In fact, the omission of water in the cleaning detergent decreases the (absolute) contribution of the transport stage by 96%.

Finally, rf-home-liquid emits 0.279 kg CO<sub>2-eq</sub> per use, which constitutes a 51% CO<sub>2-eq</sub> reduction compared to its single-use alternative. The difference in performance between rf-go-liquid and rf-home-liquid, i.e. 0.033 kg CO<sub>2-eq</sub> emissions for rf-go-liquid compared to 0.153 kg for rf-home-liquid, is mainly due to the contribution of material production. With refill on the go, a 600 L HDPE tank, which can be reused 50 times, is used to hold the liquid laundry detergent until it is inside the customer's refillable bottle. By contrast, a pouch is used with refill at home, which contains merely twice the volume of one refillable bottle and cannot be reused in itself. As a result, the material production of rf-go-liquid is allocated over significantly more uses than in the case of rf-home-liquid. Given that the refillable bottles are the same

in both packaging systems, the impact of material production is roughly 4.5 times higher for rf-home-liquid.

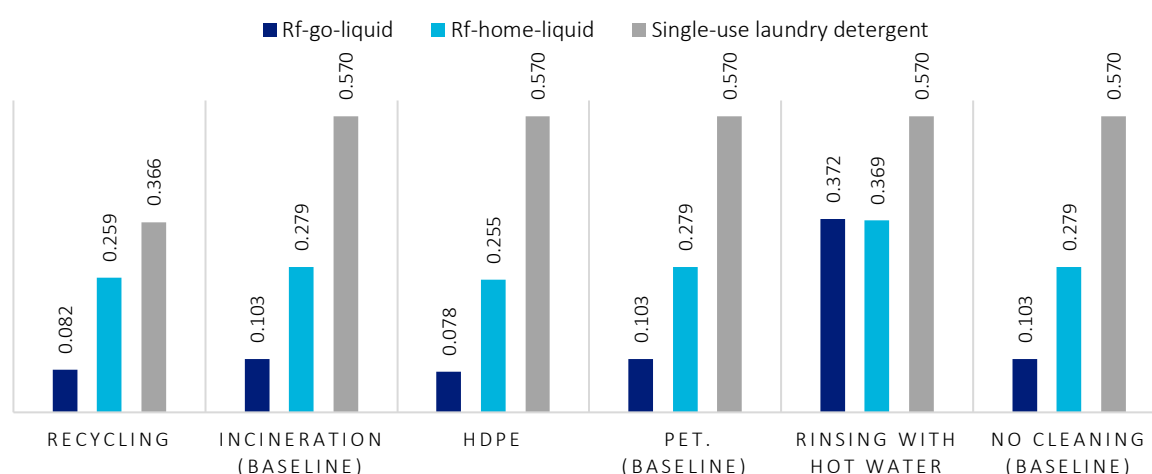
## 7.2 Results sensitivity analyses

The following sections discuss the results of the sensitivity analyses, grouped per product type. See section 3.3.3 for a discussion of the assumptions that were challenged. All quantitative data is included in Appendix H.

### 7.2.1 Rf-go-liquid and rf-home-liquid

#### 7.2.1.1 Scenarios: end-of-life treatment of opaque PET, material choice refillable bottle, and cleaning of packaging items that were in contact with detergent

Figure 8 summarizes the results of modelling these different scenarios. These results are ceteris paribus, with the most important assumption that the refillable bottles are still used 10 times (as in the baseline).



**Figure 8** Total environmental impact in kg CO<sub>2-eq</sub> emissions per use for every scenario tested

Regarding the end-of-life treatment of opaque PET, Figure 8 shows that both rf-go-liquid and rf-home-liquid still perform better than the single-use alternative when assuming recycling instead of incineration (baseline). However, the degree to which they perform better than the single-use alternative decreases. For instance, the impact of single-use laundry detergent is approximately 5.5 times higher than the rf-go-liquid in the baseline scenario (i.e. incineration). This decreases to an impact of 4.5 times the impact of rf-go-liquid when recycling of opaque PET is assumed. Thus, assuming that opaque PET would be recycled, negatively affects how much better the refillable packaging system performs than the single-use one.

Next, Figure 8 illustrates how assuming HDPE as the material for the refillable bottles decreases the total CO<sub>2-eq</sub> emissions (kg) per use of both refillable packaging systems. In the baseline scenario (i.e. PET), both rf-go-liquid and rf-home-liquid perform better than their single-use alternative. Since the impact of rf-go-liquid and rf-home-liquid decreases when assuming HDPE bottles, this material choice increases the degree to which the refillable packaging systems perform better than the single-use one.

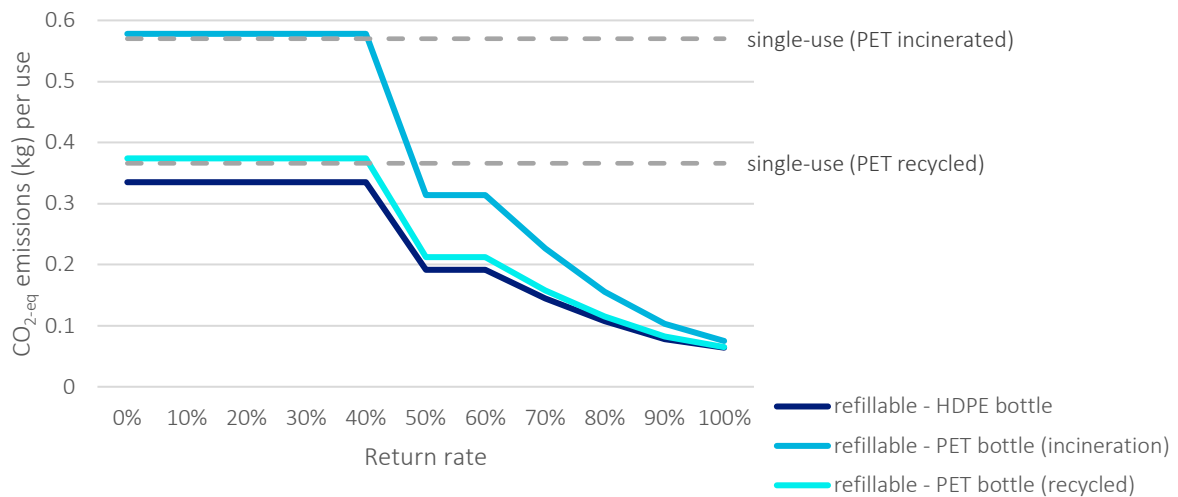
For instance, the single-use bottle has a 5.5 higher impact than rf-go-liquid when the bottle is PET, whereas it has a 7.3 higher impact when the refillable bottle is HDPE. This result can mainly be explained by the fact that HDPE is assumed to be recycled, whereas the opaque PET single-use bottles are assumed to be incinerated. The impact of material production, however, is higher for HDPE than for PET. Still, HDPE laundry detergent bottles would be favorable, both in terms of total environmental impact and in terms of relative performance compared to the single-use alternative.

Regarding the cleaning of packaging items that were in contact with detergent, Figure 8 illustrates that the total environmental impact of rf-go-liquid and rf-home-liquid increases. For rf-go-liquid, if the dispenser container, tank (bulk packaging) and detergent bottle would be rinsed with hot water, the total environmental impact would increase by 261%. For rf-home-liquid, the environmental impact would increase by merely 32% since only the refillable bottle would be rinsed with hot water. However, even though the impact of both refillable packaging systems increases when including cleaning, they still perform better than the single-use alternative. The degree to which they perform better merely decreases.

#### *7.2.1.2 Sensitivity analysis: return rate of detergent bottle*

The results above are valid *ceteris paribus* and do not account for the possibility that the refillable bottles might be used less or more than 10 times by the consumer. For instance, the end-of-life treatment of opaque PET could imply that HDPE is less favorable compared to PET (as concluded above). Therefore, the effect of both assumptions (i.e. end-of-life treatment and material choice) were combined with a varying return rate of detergent bottles. Figure 9 illustrates the results of this analysis for rf-go-liquid, and Figure 10 for rf-home-liquid. In the baseline scenario, with PET refillable bottles and opaque PET assumed to be incinerated, both rf-go-liquid and rf-home-liquid perform better than the single-use alternative as soon as the bottle is used at least 2 times (i.e. a minimum return rate of 50%). This is the break-even point for those packaging systems. At that point, rf-g-liquid emits 86% less CO<sub>2-eq</sub> emissions per use than the single-use alternative, and rf-home-liquid emits 55% less CO<sub>2-eq</sub> emissions per use.

Assuming opaque PET would be recycled, does not change the break-even point of rf-go-liquid (Figure 9). The refillable bottle needs to be used minimum twice before the rf-go-liquid performs better. By contrast, assuming that the refillable bottle is HDPE, changes the break-even point of rf-go-liquid. Compared to single-use bottles (PET incinerated), the refillable HDPE bottle must only be used once to perform better (i.e. have a lower impact). This corresponds to a return rate of 0% to 40%. However, if it is simultaneously also assumed that opaque PET would be recycled, the degree to which rf-go-liquid (HDPE) performs better than its single-use alternative decreases, since the impact of the single-use bottle also decreases. Therefore, assuming opaque PET would be recycled, decreases the attractiveness of choosing HDPE over PET for the refillable bottle (in terms of less CO<sub>2-eq</sub> emissions per use).



**Figure 9** Break-even point (in terms of the return rate of the refillable bottle) for the different scenarios affecting rf-go-liquid

Assuming opaque PET would be recycled, does change the break-even point of rf-home-liquid (Figure 10). The refillable bottle would have to be used a minimum of three times in order to perform better than the single-use alternative. This corresponds to a return rate of 70%. The packaging would thus have to be used one more time compared to when opaque PET would be incinerated. Even when the refillable bottle is assumed to be HDPE (i.e. a lower environmental impact), the break-even point remains 3 uses when opaque PET is assumed to be recycled (as opposed to merely 1 use when opaque PET is assumed to be incinerated).



**Figure 10** Break-even point (in terms of the return rate of the refillable bottle) for the different scenarios affecting rf-home-liquid

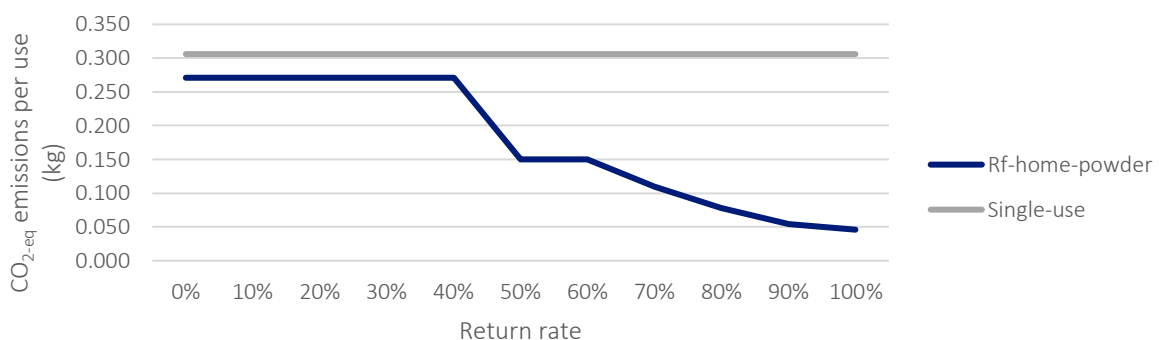
## 7.2.2 Rf-home-powder

### 7.2.2.1 Scenario: cleaning packaging items that were in contact with detergent

As just discussed for rf-go-liquid and rf-home-liquid, the total environmental impact of rf-home-powder increases when cleaning is modelled. The same conclusion thus holds: including cleaning of packaging items that were in contact with detergents significantly increases the total environmental impact of the refillable packaging system and as such decreases the degree to which the refillable packaging system performs better than the single-use one. In this case, the impact of a single-use bottle is 5.5 times higher than the impact of rf-home-powder when no cleaning is modelled, whereas it is merely 2 times higher than the impact of rf-home-powder when cleaning is accounted for.

### 7.2.2.2 Sensitivity analysis: return rate of detergent bottle

Figure 11 shows that rf-powder-home always performs better than its single-use alternative, independently of the return rate of the cleaning detergent bottle. This implies that it always has a lower total environmental impact in terms of CO<sub>2</sub>-eq emissions per use, compared to the single-use alternative. Indeed, at a 0% return rate (i.e. 1 use of the bottle), rf-home-powder has a 89% lower total impact than a single-use bottle of cleaning detergent. This is mainly due to the impact of transport since empty bottles and significantly lighter (powder) detergents are transported with rf-home-powder. In fact, even when the refillable bottle is only used once, transport of refillable packaging accounts for 0.007 kg CO<sub>2</sub>-eq emissions per use, whereas transport of (full) single-use bottles accounts for 0.070 kg (i.e. 100 times more).



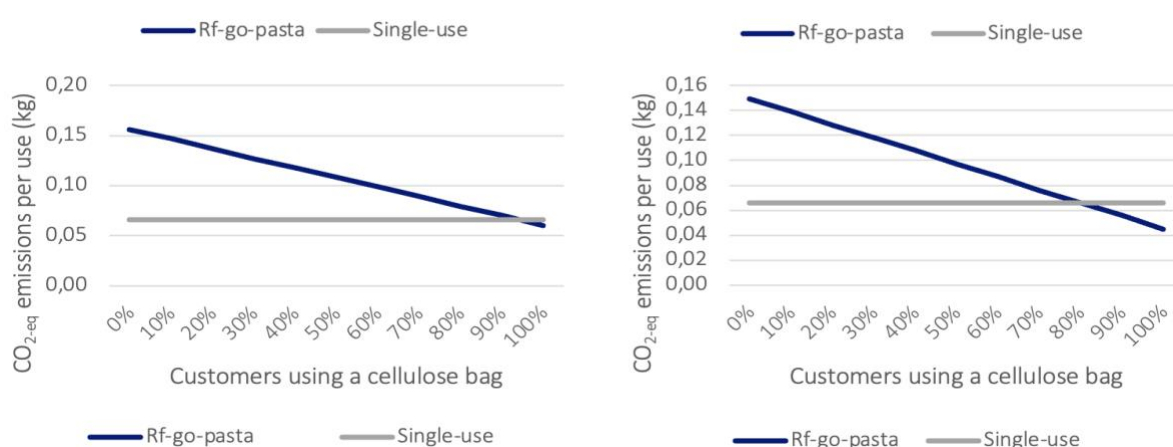
**Figure 11** Break-even point (in terms of the return rate of the refillable bottle) for rf-home-powder

### 7.2.3 Rf-go-pasta: % container use, cleaning frequency, and bulk size

It was assumed in the baseline scenario that 40 % of the customers would use their own container to dispense pasta, whereas 60% would use a cellulose bag offered in the store. Figure 12a illustrates how the performance of rf-go-pasta changes when this ratio varies. Surprisingly, rf-go-pasta is only expected to have a lower total environmental impact than its single-use alternative when 0% of the customers bring their own container (i.e. 100% use a cellulose bag offered in-store). This can mainly be explained by the fact that no cleaning of the customer's container is required when using cellulose bags and by the fact that the cellulose bags would be recycled. However, when accounting for a varying cleaning

frequency for the customer's container (Table 15a), the break-even point (in terms of % cellulose bag use) changes. Rf-go-pasta performs better than single-use pasta when 40% or 30% of customers use a container and (in theory) never wash it. When 20% of customers use a container and only wash it every 5 uses, the refillable system also performs better than its single-use alternative, as well as when 10% of customers use a container and wash it every 2 times. It can thus be concluded that accounting for a varying cleaning frequency can positively influence the performance of rf-go-pasta compared to its single-use alternative.

Furthermore, it was also analyzed whether a different size of bulk packaging would significantly affect the performance of rf-go-pasta. As can be seen in Figure 12b, opting for 10kg bulk packaging (instead of 5kg) to transport the pasta to the stores, entailed that rf-go-pasta performs better than single-use pasta as soon as 80% of the customers use a cellulose bag (and 20% bring their own container). This implies that larger bulk packaging decreases the total environmental impact of rf-go-pasta. Table 15b then illustrates how other bulk sizes affect this break-even point. It shows that the baseline assumption of 60% cellulose bag use and 40% container use only results in a better performance for rf-go-pasta (compared to single-use pasta) when the pasta is transported per 20kg.



**Figure 12** Break-even points when (a) the ratio % cellulose bag/% container varies, and (b) the pasta is transported in 10kg bulk packaging

**Table 15** Break-even points (in terms of the ratio % cellulose bag/% container that equals the impact of refillable over the impact of single-use) for rf-go-pasta when (a) the cleaning frequency varies, and (b) the size of the bulk packaging varies

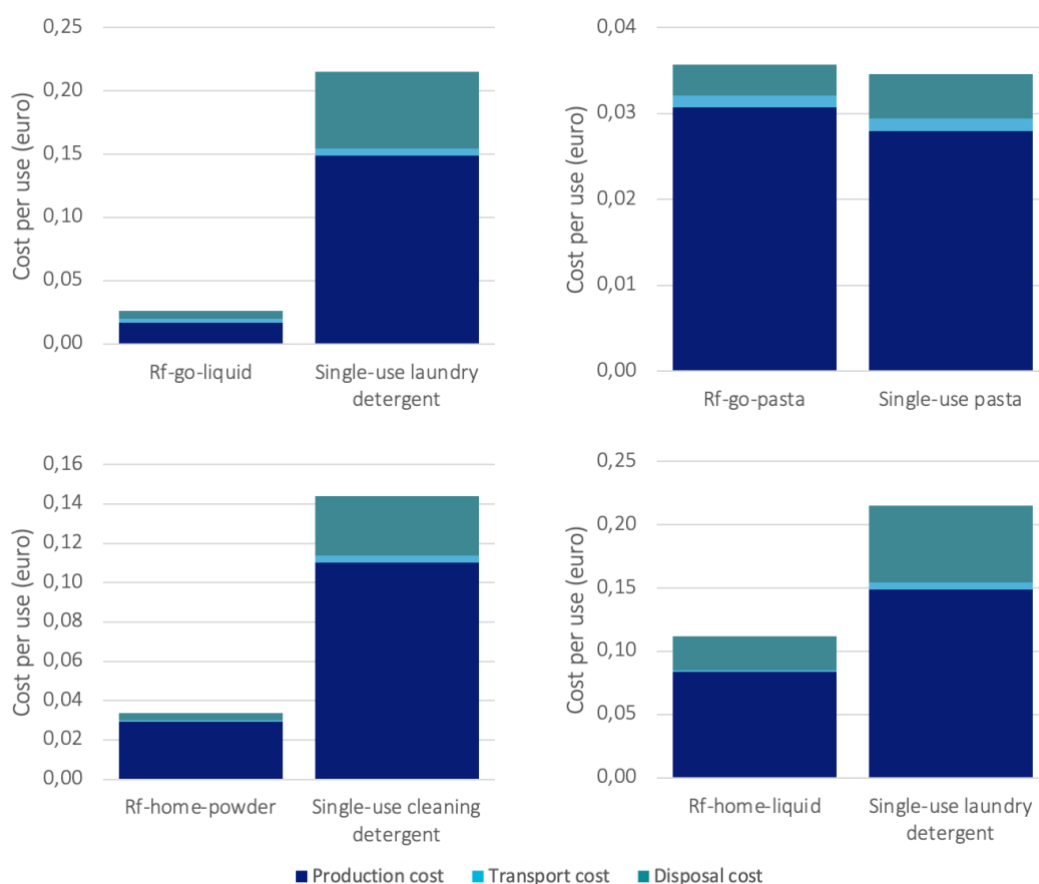
Cleaning frequency	Break-even point		Size bulk packaging	Break-even point	
	% cellulose bag use	% container use		% cellulose bag use	% container use
Every use (baseline)	100%	0%	3 kg	/	/
Every 2 uses	90%	10%	5 kg (baseline)	100%	0%
Every 3 uses	90%	10%	10 kg	80%	20%
Every 4 uses	90%	10%	15 kg	70%	30%
Every 5 uses	80%	20%	20 kg	60%	40%
...	...	...			
Every 50 uses (never cleaned)	60%	40%			

## 8 Quantitative results: LCC

The total cost per use is estimated for every packaging system according to the baseline scenario first. After, the break-even point is calculated based on the return rate of the refillable bottle.

### 8.1 Results baseline

Figure 13 shows an estimation of the costs per use, from a supermarket perspective, related to the refillable packaging systems and their single-use alternatives. Additionally, it illustrates how each cost component contributes to the total estimated cost per use. The quantitative data is listed in Table 16.



**Figure 13** Comparative overview of the estimated total cost per use per refillable packaging system and its single-use alternative

The figure shows that all refillable packaging systems are expected to have a lower total cost per use than their single-use alternative except for rf-go pasta. The largest cost component is the production cost, as it is for the single-use packaging systems. As shown in the table, the cost per use is expected to increase by 4% for rf-go-pasta. This can be explained by the fact that the bulk packaging does not significantly differ from the single-use primary packaging. With the other three refillable packaging systems, the primary packaging (bottle) is reused 10 times in the baseline scenario, thus spreading the cost of production and end-of-life over those uses. For rf-go-liquid, this results in potential cost reduction of 88%: from approximately 21 cents per use (single-use) to approximately 3 cents per use (refillable). For rf-home-powder and rf-home-liquid this results in a potential cost reduction of respectively 76% and 48%. Still, it is worth noting that the total cost of single-use pasta is relatively low

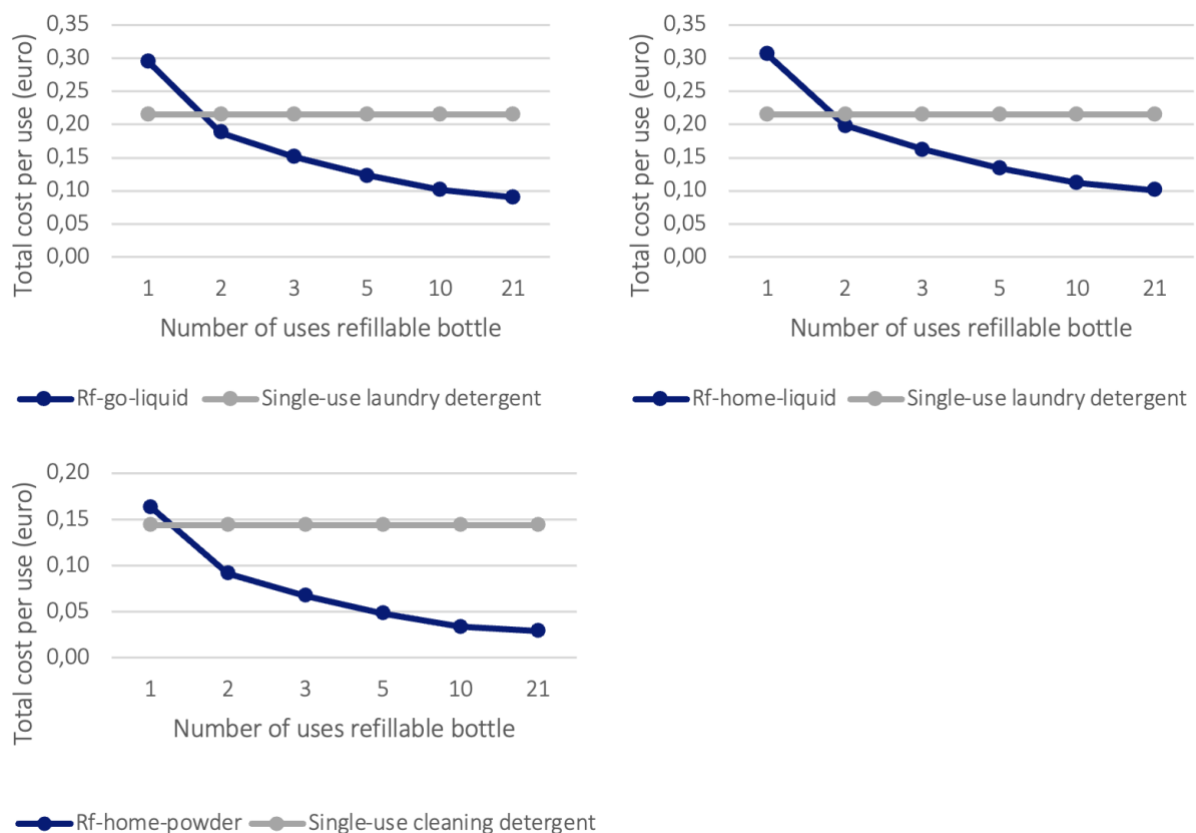
to begin with: around 3.5 cents compared to 22 cents for single-use laundry detergent and 14 cents single-use cleaning detergent.

**Table 16** Breakdown of total cost per use (in euro) per refillable and single-use packaging system

Packaging system	Production cost	Transport cost	Disposal cost	Total cost per use	Cost difference
Rf-go-liquid	0.01672	0.00318	0.00655	0.02645	-88%
Single-use laundry detergent	0.14877	0.00588	0.06029	0.21494	
Rf-go-pasta	0.03074	0.00137	0.00361	0.03571	4%
Single-use pasta	0.02798	0.00147	0.00512	0.03448	
Rf-home-powder	0.02913	0.00101	0.00377	0.03392	-76%
Single-use cleaning detergent	0.11007	0.00395	0.03001	0.14403	
Rf-home-liquid	0.08360	0.00157	0.02702	0.11219	-48%
Single-use laundry detergent	0.14877	0.00588	0.06029	0.21494	

## 8.2 Break-even point for rf-go-liquid, rf-home-powder and rf-home-liquid

Figure 14 shows the results of the sensitivity analyses for the three refillable packaging systems. The quantitative data is included in Appendix I. Interestingly, all three refillable packaging systems reach their break-even point after 2 uses of the refillable bottle. This implies that as soon as the customer uses the refillable laundry/cleaning detergent bottle at least twice, the refillable packaging would become an economically viable option compared to its single-use alternative.



**Figure 14** Break-even points (in terms of number of uses of the refillable bottle) for (a) rf-go-liquid, (b) rf-home-powder, and (c) rf-home-liquid

## 9 Discussion

There are two main theory contributions: (1) providing a holistic comparative approach to analyze the transition from single use to refillable packaging systems, and (2) aggregating and extending existing concepts and considerations regarding refillable packaging systems into one feasibility framework. Moreover, this study makes one main practical contribution: offering a comprehensive analysis on the suitability of the four most-implemented refillable packaging systems.

### 9.1 Theoretical implication

First, existing studies have either focused on how consumers perceive refillable packaging systems (Costa, 2018; Kobayashi & Benassi, 2015), or on the drivers and barriers (or so-called design considerations) for businesses to implement refillable packaging systems (Lofthouse & Bhamra, 2006; Lofthouse et al., 2009). Another (relatively unexplored) research avenue has been LCAs that aim to compare the impact of single-use to refillable packaging systems (Coelho et al., 2020b; Dolci et al., 2016; Nessi et al., 2012; Nessi et al., 2014; Potting & van der Harst, 2015; Woods & Bakshi, 2014). Therefore, this study provides a unique approach to comparatively analyze the transition to refillable packaging systems by combining different methods, both qualitative and quantitative. By conducting the expert interviews first, these results helped to make assumptions during the Life Cycle Inventory (LCI) phase, as well as to determine interesting sensitivity analyses. For instance, it was suggested by some interviewees that the feasibility of rf-go-pasta would increase by offering cellulose bags as a potential alternative to the customer's container. Others doubted whether offering such bags would be beneficial in terms of environmental impact. Therefore, it was chosen during the LCI to model cellulose bags and include them in the sensitivity analysis. Another example entails the modelling of refillable bottles in rf-go-liquid and rf-home-liquid equal to the single-use laundry detergent bottles (in terms of material and weight). This was decided based on the interview finding that this would allow for a smoother transition. However, since another interviewee doubted whether the currently used material (PET) is durable enough, a sensitivity analysis on HDPE refillable bottles was opted for.

Using expert interviews, a consumer survey, a LCA and a LCC allowed for data triangulation in two ways: (1) reinforcing findings, and (2) nuancing or even contradicting findings. For instance, interviewees questioned whether rf-go-pasta would have a positive environmental impact (compared to the single-use plastic flow packs). This finding was later confirmed in the LCA: in the baseline scenario, rf-go-pasta does not perform better than the single-use alternative (due to the impact of cleaning the customer's container). Another example concerns the *trade-off between price and effort* that consumers are expected to make according to the interviewed experts. This was confirmed in the consumer survey results for the refill on the go packaging systems, in which *convenience* and *price* both had a significant effect on the willingness to engage of consumers (respectively a negative and positive effect). For refill at home packaging systems, however, this finding was nuanced in the sense that only *price* displayed a significant effect on the willingness to engage. This relates to the second type of data triangulation, in which findings are nuanced or contradicted. Another example regards the interview finding that cellulose bags might increase the environmental impact for rf-go-pasta. However, the sensitivity analysis (section 7.2.3) shows that the environmental impact rf-go-pasta in fact decreases when more customers use a cellulose bag. Only when 100% of the consumers use a cellulose bag (as opposed to 60% in the baseline), rf-go-pasta performs better than single-use pasta. Even if the frequency of

cleaning the container is checked for, rf-go-pasta generally performs better when consumers do not use containers. A final example constitutes the interview finding regarding the importance of (the customer perception of) quality for refill at home packaging systems. The consumer survey results, however, showed no significant effect for *quality* in the linear regression models.<sup>14</sup>

Second, this study provides a framework that could be employed by various stakeholders to assess the feasibility of refillable packaging systems. Thus far, refillable packaging systems have mainly been approached from a classification and terminology point of view (Coelho et al., 2020a; Lofthouse & Bhamra, 2006; Muranko et al., 2021). On the other hand, business barriers and drivers of refillable packaging systems have been discussed by some authors (EMF, 2019; Lofthouse et al., 2009). By contrast, this study took a supply chain perspective to allow for a holistic comparison between refillable and single-use packaging systems. As such, the theory framework (Figure 1) represents an aggregation of relevant drivers and barriers from various research papers. Through expert interviews this study aimed to confirm and/or extend the concepts aggregated in section 2.3. The resulting feasibility framework (Figure 4) serves as a guide for supermarkets and other interested stakeholders to assess and ensure successful implementation of refillable packaging systems. The framework distinguishes between three levels, indicating which entity (i.e. consumer, supermarket or product) is relevant for the respective themes and concepts. These levels create an additional layer of structure to assess refillable packaging systems, which is currently missing in existing literature. Many concepts in the feasibility framework reflect what was aggregated from existing literature. For instance, *price as an incentive* was also recognized by Minami et al. (2010). Kobayashi and Benassi (2015) concluded that lower prices positively influence the purchase intention towards refillable coffee packs. The importance of selecting the right material in terms of *durability* and *recyclability* was recognized in the literature as well (Coelho et al., 2020a; Lofthouse et al., 2017; Scharpenberg et al., 2021). By contrast, the challenge of brand attachment and customer attraction with refillable packaging systems did not surface during the expert interviews (EMF, 2019; Lofthouse & Bhamra, 2006). A possible explanation for the latter could be that ALDI in the Netherlands is a discounter retailer, which primarily sells in-house brands. Furthermore, the feasibility framework includes concepts that extend current literature. For instance, *impact on cashier processes*, in the theme *store management*, was identified as an important aspect to the feasibility of refill on the go packaging systems. The issue of *accountability*, in theme *legal requirements*, raised the question who would be responsible for food or product contamination when customers refill potentially unclean containers in a store. As a final example, the *point-of-sales*, in the theme *communication*, was identified as a vital enabler of successful implementation as it ensures visibility, story-telling and proper customer guidance.

## 9.2 Practical implication

As mentioned above, this study aimed to provide a holistic comparative analysis of the four most-implemented refillable packaging systems. The results of this analysis are summarized in Table 17. This table provides a pragmatic overview of the suitability of these refillable packaging systems for both ALDI in the Netherlands and Dutch supermarkets in general to implement. An interesting insight from the table is that customers generally are willing to engage with all four packaging systems (ranging from

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<sup>14</sup> Rf-go-liquid, rf-go-pasta and rf-home-liquid displayed significant relationships in the Chi-square tests for *quality*, but these were relatively weak relationships compared to other variables (such as *environment* and *price*).

62% to 80%). This is in line with a recent study in the Netherlands that found that 73% of customers had a rather positive attitude towards refill on the go, and 79% towards refill at home (Kramer et al., 2021). In addition, the findings in both Kramer et al. (2021) and this study imply that refill at home is slightly more preferred than refill on the go packaging systems. As also shown in the table, the report found that convenience negatively influences the intention to participate, whereas environment positively influences it. Still, convenience was only significant for refill on the go packaging systems in this research. A possible explanation for this could be the specific nature of packaging systems under study (i.e. laundry and cleaning detergent), whereas the report by Kramer et al. (2021) had a more general focus. In other words, convenience and ease-of-use could be less important for refill at home packaging systems than some authors have claimed (Beitzen-Heineke et al., 2017; EMF, 2019; Lofthouse & Bhamra, 2006; Lofthouse et al., 2017). Furthermore, Kramer et al. (2021) did not find that price was an influential factor for either type of refillable packaging. A possible explanation could be that the respondents in this study were discounter customers, who are generally more price sensitive. Still, other authors recognized the importance of price to the success of refillable packaging systems (Costa, 2018; Lofthouse & Bhamra, 2006; Lofthouse et al., 2017).

Based on this overview, rf-go-pasta has the worst environmental and economic performance, showing an 55% increase of CO<sub>2-eq</sub> emissions per use and an 4% increase of costs per use, with respect to the single-use alternative.<sup>15</sup> The results showed that this is mainly due to the cleaning of the container and the fact that the pasta is still transported in plastic flow packs to the store. Dolci et al. (2016) also found that transport packaging is a considerable contributor to all impact categories. In addition, this refillable packaging system displayed the lowest consumer willingness to engage and relatively more risk elements than success elements in terms of feasibility considerations. As with rf-go-liquid, the consumer willingness to engage of rf-go-pasta is negatively affected if consumers value *convenience*. With rf-go-liquid, however, it was found that some socio-demographic variables also (negatively) influence the consumer willingness to engage, namely being male and shopping for 2 persons (household size). Still, both rf-go-liquid and rf-home-powder achieved the largest baseline CO<sub>2-eq</sub> reduction. Although similar, the sensitivity CO<sub>2-eq</sub> difference interval is more attractive for rf-home-powder than for rf-go-liquid since it remained negative throughout all the analyses. Both rf-go-liquid and rf-home-powder also have the highest potential cost reduction. It is important to note again that this reflects the cost per use, excluding initial investment costs. At 80%, the consumer willingness to engage is slightly higher for rf-home-powder (compared to rf-go-liquid). On top of that, no significant predictor variables with a negative effect on the willingness to engage with rf-home-powder were uncovered. Finally, rf-home-liquid scores good in terms of CO<sub>2-eq</sub> difference, with a decrease of 51% in the baseline. The uncertainty displayed in the CO<sub>2-eq</sub> difference interval (+49% to -58%) is also reflected in the relatively more risk elements identified during the interviews. However, there is still a potential cost reduction of 48%, implying that it could be an interesting option if carefully implemented (by considering the risk elements).

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<sup>15</sup> It is worth noting that cleaning the dispensers, which was deemed essential in the interviews, has not been modeled. Therefore, the baseline CO<sub>2-eq</sub> difference is underestimated and will be even higher.

**Table 17** *Comparative analysis of the four most-implemented refillable packaging systems*

Refillable packaging system	Baseline CO <sub>2</sub> -eq difference*	CO <sub>2</sub> -eq difference interval*	Baseline cost difference*	Consumer willingness to engage	Significant predictor variables	Most important feasibility considerations
Rf-go-liquid	-82%	+2% to -89%	-88%	77%	Convenience (-) Environment (+) Price (+) Gender_male(-) Household_2 (-)	<b>Success elements:</b> price as an incentive, communication <b>Risk elements:</b> cleaning and refilling, cashier processes, labelling, required effort, handling of dispenser
Rf-go-pasta	+55%	+742% to -32%	+4%	62%	Convenience (-) Environment (+) Price (+)	<b>Success elements:</b> price as an incentive, communication <b>Risk elements:</b> cleaning and refilling, cashier processes, weighing, batch tracing, accountability, labelling, impact material, impact cleaning
Rf-home-powder	-82%	-11% to -85%	-76%	80%	Environment (+) Price (+)	<b>Success elements:</b> impact of material, transport of water, communication, price as an incentive, required effort <b>Risk elements:</b> perceived product effectiveness, visibility of product
Rf-home-liquid	-51%	+49% to -58%	-48%	76%	Environment (+) Price (+) Income_high (-)	<b>Success elements:</b> price as an incentive <b>Risk elements:</b> visibility of product, communication, handling of refill pack, impact of material, durability, recyclability

\* With respect to each single-use alternative

### 9.3 Limitations

Given that a supply chain perspective was guiding throughout this research, one important limitation is that the stakeholder selection was not fully covering all supply chain stakeholders. For instance, packaging designers and manufacturers, managers of waste facilities or transport organizers could have been interviewed as well. Nevertheless, it was assumed that the selected experts possess extensive enough knowledge to at least cover some aspects related to different supply chain steps. These experts were also the most willing to share their knowledge and expertise on refillable packaging systems. Moreover, consumers (i.e. important stakeholders in refillable packaging systems) were incorporated in the study by conducting a consumer survey.

A limitation regarding the consumer survey entails the self-selection bias encountered through the distribution channel of the survey (weekly online newsletter of ALDI in the Netherlands). Since consumers selected themselves to participate in the survey, this implied that there might be a bias towards consumers generally interested in sustainability and/or new packaging systems. To avoid such a bias, it was opted to offer a monetary incentive to the survey participants. Another limitation regards the structure of the consumer survey data. Due to the nature of the questions, all data was categorical and coded with dummy variables. This implies that the linear regression analysis was theoretically not the best fit for the data. However, it does allow to include the effect of multiple independent variables on one dependent variable. By contrast, the Chi-square test, which was appropriate for such categorical data, did not allow to include multiple independent variables. Since the results of the linear regression models differed from the Chi-square tests, it can be concluded that some effect was not captured yet by the Chi-square tests alone.

Finally, this study aimed to use the KIDV tool to perform the LCA. The tool was developed to compare single-use to reusable packaging, which would entail both returnable and refillable packaging systems. In practice, however, the tool did not allow to properly model refillable packaging systems. For instance, merely five input lines existed to model the different materials used in the packaging, whereas refillable packaging systems often contain multiple packaging items, such as bulk packaging, dispensers, and refill packaging. In addition, the tool was built to calculate impact with one single return rate, whereas the above-mentioned different packaging items in refillable packaging systems were often characterized by different return rates. As a solution, the tool was adapted by the researcher to fit the scope of this study. Even though this was an iterative process with multiple checks for inconsistencies and other faults, the alterations were not verified by the tool programmers or another third party.

## 9.4 Future research

This study identifies two main future research directions. First, ALDI in the Netherlands customers were sampled for the consumer survey, since ALDI in the Netherlands was the case study of this research. However, to further substantiate the findings of the consumer survey, another survey, sampling customers from different types of Dutch supermarkets, could be conducted. Attention should also be paid to ensuring population representativeness since the sample in this study contained a large proportion of elderly people (67% aged above 55). Second, this study conducted an LCA using a tool developed by the KIDV, which only compares packaging systems based on one impact category, namely climate change (CO<sub>2</sub>-eq emissions per use). As it more common to include a variety of impact categories in LCA, the LCI data of this study could be used to model the LCA in a different tool, which allows for multiple impact categories. It would be interesting to see how this affects the general suitability of the refillable packaging systems to Dutch supermarkets. However, for rf-go-liquid for instance, the results are not expected to significantly change since a similar study found that HDPE refillable bottles must be used merely once to perform better than PET single-use bottles when more impact categories are considered (Nessi et al., 2014).<sup>16</sup> This is in line with results in this study. Moreover, Dolci et al. (2016)

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<sup>16</sup> Only if all single-use baseline scenarios are accounted for (including a 5000 ml HDPE bottle), the refillable bottle must be used at least 10 times (mainly due to the impact category human toxicity non-cancer effects) (Nessi et al., 2014).

found that when pasta is distributed in 5kg flow packs (i.e. the baseline in this study), 10 out of 14 impact categories increased compared to single-use pasta, including climate change. This is an indication that the LCA results in this study are representative of a full-scale LCA. Still, it could be relevant to include all impact categories for increased accuracy and validity.

## 10 Conclusion

The aim of this study was to assess how suitable the four most-implemented refillable packaging systems are for Dutch supermarkets. ALDI in the Netherlands was chosen as a case study and source of data to approach this question. The packaging systems were selected based on a market analysis and input from ALDI in the Netherlands. As such, refill on the go laundry detergent (rf-go-liquid), refill on the go pasta (rf-go-pasta), refill at home cleaning detergent powder (rf-home-powder), and refill at home laundry detergent (rf-home-liquid) were selected. These were analyzed through a combination of qualitative and quantitative methods. First, five expert interviews were conducted based on feasibility concepts aggregated from existing literature. Second, the willingness to engage with every refillable packaging system was tested on the ALDI in the Netherlands customers through an online survey. The goal of this survey was to 1) find the average willingness to engage among ALDI in the Netherlands consumers, and 2) discover which factors influence this. Third, a LCA and LCC were conducted to compare the environmental impact (in CO<sub>2-eq</sub> emissions per use) and costs per use (from a supermarket perspective) between refillable and single-use packaging systems. By using a simple tool developed by the KIDV, climate change was used as the impact category for the LCA. Sensitivity analyses were subsequently conducted. This allowed to check the impact of the relatively weaker assumptions made during the LCI phase, as well as doubts or questions raised during the interviews.

The results showed that rf-home-powder represents the most suitable refillable packaging system for both ALDI in the Netherlands and Dutch supermarkets to implement. It had the highest baseline CO<sub>2-eq</sub> reduction (-82%), its sensitivity CO<sub>2-eq</sub> difference interval remained negative (-11% to -85%), it had the highest willingness to engage (79.77%), and it had a considerable potential cost reduction (76%). Next, rf-go-liquid also shows great potential if the risk elements, such as required effort, cleaning, and cashier processes, are tackled. Rf-home-liquid presents more uncertainty in terms of CO<sub>2-eq</sub> reduction, given that its sensitivity CO<sub>2-eq</sub> difference interval ranges from +49% to -58%. It should thus be carefully implemented to ensure optimal environmental impact while taking into account potential risk elements, such as communication (greenwashing) and shelf visibility. The fourth packaging system, rf-go-pasta, is the least suitable refillable packaging system for Dutch supermarkets to implement, with a baseline CO<sub>2-eq</sub> difference of +55%, a highly uncertain sensitivity interval (+742% to -32%), and a potential increased cost per use (+4%). Moreover, Dutch supermarkets and other invested stakeholders should consider the significant role of *price*, *environment* and *convenience* when designing and marketing refillable packaging systems. The results showed that the former two positively influence the willingness to engage with all four refillable packaging systems. The latter negatively influences the willingness to engage for refill on the go packaging systems, indicating that those were deemed as inconvenient. Thus, as also mentioned in the interviews, successful implementation will rely on clear and transparent communication to the consumer on the environmental impact and pricing of these packaging systems, as well as efficient store management to increase convenience to the customer (e.g. cashier processes, cleaning, handling etc).

Overall, the refillable packaging systems included in this study show potential for CO<sub>2-eq</sub> reduction compared to their single-use alternatives. However, it is essential to take a holistic perspective considering the transition along the entire supply chain and involving all stakeholders, such as packaging manufacturers, store managers and consumers.

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## Appendix A

### Interview guide and consent form

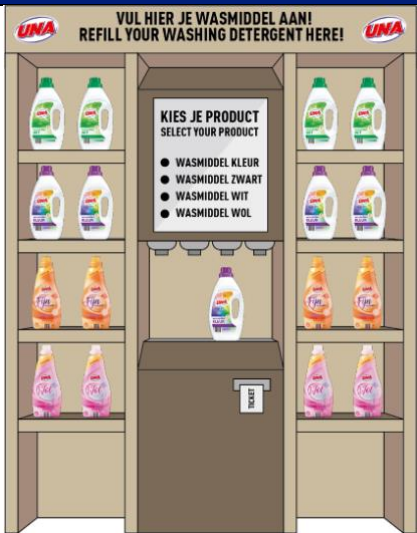
#### Use of the interview guide

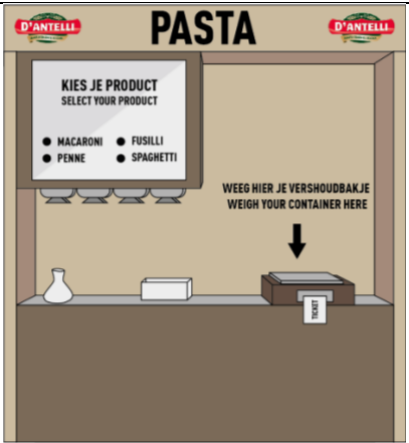


This interview guide elaborates on the research aim and set-up, provides an overview of the questions to be asked as well as the refillable packaging systems that will be the subject of the interview. The interviewee receives the interview guide (opening and questionnaire) and consent form beforehand to allow for preparation. During the interview, the interview guide will serve to guide the researcher in asking questions. However, given that it is semi-structured, the expertise of each interviewee will determine the direction of the interview, i.e. which feasibility dimensions to focus on. The guiding topics are solely to guide the interviewer in asking follow-up questions and will therefore not be sent to the interviewee.

#### Opening

This interview is conducted in light of my Master's Thesis at Utrecht University in collaboration with ALDI in the Netherlands. **The aim is to assess the suitability of refillable packaging systems for Dutch supermarkets.** Two refillable packaging types are considered in this study: 1) refill at home, and 2) refill on the go. Together with ALDI in the Netherlands, 4 refillable packaging systems were selected based on a market analysis (see table below). The purpose of this interview is to assess the **feasibility** of these 4 refillable packaging systems. This would help gaining an understanding of which refillable packaging systems are most suitable for Dutch supermarkets in the end. Feasibility is understood as assessing whether implementation would be possible, for which five dimensions are guiding: stakeholder, market, primary production, structure and enabling environment (see questions below). This interview will take approximately 45min and will be recorded for research purposes with your consent (see consent form).

#### Description of refillable packaging systems

No.	Description refillable packaging system	Single-use alternative	Picture
1	<b>Refill on the go for laundry detergent</b> The customer either brings a bottle of laundry detergent from home or gets a new and empty one at the dispenser. The customer then selects which type of laundry detergent he/she wishes to purchase on the touch screen. While holding the bottle underneath the spout, the customer waits for the machine to fill the bottle. The machine will then print a ticket with the price and necessary information. This ticket can be scanned at check-out. The customer will only pay for the content of the bottle if he/she brought a bottle from home.	Single-use bottle of laundry detergent (1.1 L)	

2	<p><b>Refill on the go for pasta</b></p> <p>The customer either brings a container from home or gets a paper bag at the dispenser. A container needs to be weighed on the build-in weighing scale that remembers the tare weight. After pressing the button/touch screen, the customer dispenses the produce and weighs it. The weighing scale prints a ticket with weight, price and necessary information of the produce. This ticket can be scanned at check-out. Given that the weighing scale automatically subtracts the tare weight, the customer will only pay for the produce if he/she brought their own container.</p>	<p>Single-use flow pack of pasta (500gr)</p>	
3	<p><b>Refill at home for powder cleaning detergent</b></p> <p>The customer buys a bottle of cleaning detergent, including the actual cleaning detergent, in a store. When the bottle is (almost) empty, the customer returns to the store to buy a refill sachet containing concentrated detergent. At home, the customer pours the (loose or compressed) powder in the bottle and adds water. The product can now be used again.</p>	<p>Single-use bottle of liquid cleaning detergent (1.25 L)</p>	
4	<p><b>Refill at home for liquid laundry detergent</b></p> <p>The customer buys a bottle of laundry detergent, including the actual laundry detergent, in a store. When the bottle is (almost) empty, the customer returns to the store to buy a refill pouch containing the liquid laundry detergent. At home, the customer can refill the laundry detergent bottle 2 times with this refill pouch.</p>	<p>Single-use bottle of liquid laundry detergent (1.1 L)</p>	

## Questionnaire

### 1. Refillable packaging in general

- What is your opinion in general on refillable packaging? Do you think it is a direction worth pursuing for Dutch supermarkets and why?

- b. Which refillable packaging type (i.e. refill at home or refill on the go) do you deem most feasible for Dutch supermarkets and why?

2. *Feasibility of the selected refillable packaging systems (repeat questions for each refillable packaging system)*

- a. Which stakeholders do you identify as important actors when deciding whether to implement this refillable packaging system and why?

(Guiding topics: suppliers, consumer willingness to engage)

- b. How would the market and the minimum requirements of packaging influence the decision whether to implement this refillable packaging system and why?

(Guiding topics: price, quality, communication through packaging, brand loyalty, ease of use)

- c. Which aspects of the production of packaging might influence the decision whether to implement this refillable packaging system?

(Guiding topics: material choice, durability)

- d. How do structural aspects (such as store management, knowledge and expertise, supply chains, ...) affect the decision whether to implement this refillable packaging system?

(Guiding topics: employee handling time, storage, shelf space, distribution)

- e. How does the enabling environment (e.g. policies, regulations, institutions) potentially affect the implementation of this refillable packaging system?

(Guiding topics: health and safety regulations)

3. *Closing questions*

- a. Are there any important aspects to the feasibility of these refillable packaging systems we have not discussed yet according to you?
- b. Based on what we have discussed today, which refillable packaging systems would you deem most suitable for Dutch supermarkets to implement?
- c. Do you have any recommendations for Dutch supermarkets to overcome the barriers to implementation discussed today?



**Assessing the potential of refillable packaging systems for Dutch supermarkets: a case study of ALDI in the Netherlands**

To be completed by the participant:

I confirm that:

- I am satisfied with the received information about the research;
- I have been given opportunity to ask questions about the research and that any questions that have been risen have been answered satisfactorily;
- I had the opportunity to think carefully about participating in the study;
- I will give an honest answer to the questions asked.

I agree that:

- the data to be collected will be obtained and stored for scientific purposes;
- video and/or audio recordings may also be used for scientific purposes.

I understand that:

- I have the right to withdraw my consent to use the data;
- I have the right to see the research report afterwards

Name of participant: \_\_\_\_\_

Signature: \_\_\_\_\_ Date, place: \_\_\_\_/\_\_\_\_/\_\_\_\_,

To be completed by the investigator:

Name: \_\_\_\_\_

I declare that I have explained the above mentioned participant what participation means and the reasons for data collection. I guarantee the privacy of the data.

Date: \_\_\_\_/\_\_\_\_/\_\_\_\_(dd/mm/yyyy)

Signature: \_\_\_\_\_

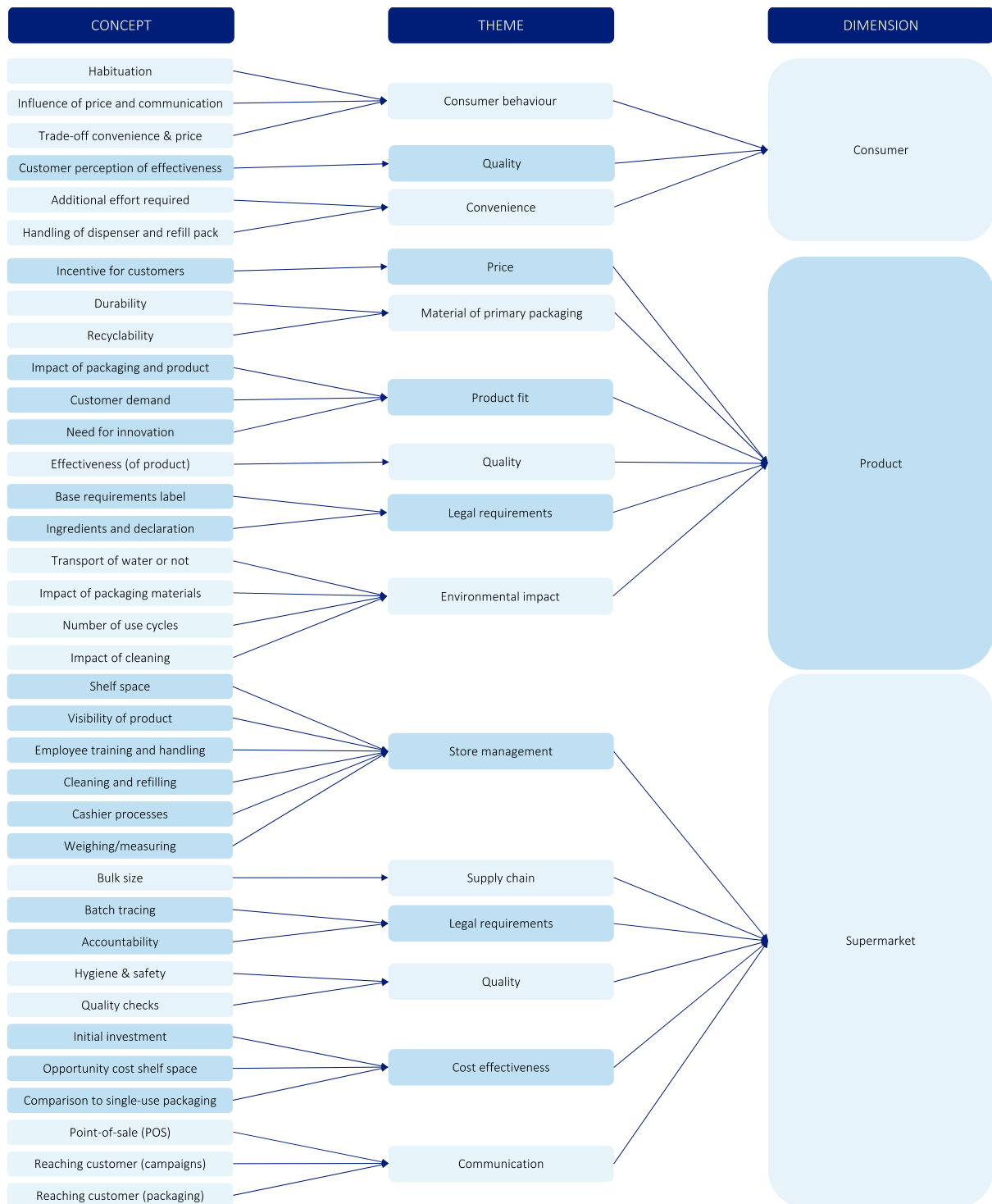
## Appendix B

### Summary of sampled experts

Interviewee	Internal/external	Expertise	Duration
1	External	Zero waste and circular solutions for businesses, with a focus on marketing and story telling	42 min
2	External/internal	Member of the international packaging team at ALDI Nord, previous experience with packaging at a detergent manufacturer	37 min
3	External	Packaging expert at the Netherlands Institute for Sustainable Packaging (KIDV), key member in the development of the KIDV Reusable packaging calculation tool applied in this study	1 h 9 min
4	Internal	Quality manager for non-food articles within ALDI in the Netherlands, focusing both on quality and compliance	25 min
5	Internal	Sales manager within ALDI in the Netherlands, focusing on innovative project implementation	44 min

## Appendix C

### NVivo coding scheme



## Appendix D

### List of main assumptions in the KIDV tool

The following assumptions are listed in the tool developed by the Netherlands Institute for Sustainable Packaging (KIDV, n.d.a):

- This tool works with average LCA data (sources listed in Data tab) and is based on assumptions by the user. So the results can only give a rough indication of the CO<sub>2</sub> impact of the packaging systems.
- The return rate does not only determine the number of average use cycles, but it also influences the impact of cleaning, impact of return transport, and end-of-life scenario.
- It is assumed that the unreturned reusable packaging will enter the Dutch municipal waste stream and is taken into account accordingly.
- Transport is calculated based on mass, not volume. When you have a very voluminous packaging with low density, this will distort the accuracy of the calculation.
- The impact of the used energy is based on the average impact of electric energy consumption in the Netherlands.
- Road transport is calculated by using vehicles with the highest EU standard (Euro6).
- Aluminum is used as virgin material, and this will be recycled to other products but not in packaging applications.
- Impact of bioplastics is based on calculation with values from Chen and Patel (2012). This study did not include the effects of land use change, i.e. it is not taken into account that forest is cleared to grow the crops

## Appendix E

### Cost inventory data

**Table 1** *Overview of production and disposal costs rf-go-liquid*

Packaging type	Packaging item	Material	Material price (€/kg)	Production cost per FU (€/FU)	Waste tariff, incl. VAT (€/kg)	Disposal cost per FU (€/FU)
Bulk packaging (600 L)	Tank	HDPE	1.77000	0.00084	0.53240	0.00025
	Outer cage	Stainless steel	0.90000	0.00066	0.23000	0.00017
In-store dispenser (80 L)	Container	HDPE	1.77000	0.00034	0.53240	0.00010
Primary packaging (1.1 L)	Bottle	Single-use: PET	1.44000	0.08640	0.84700	0.05082
		Refill: PET	1.44000	0.00864	0.84700	0.00508
	Cap/closure	Single-use: PP	1.98000	0.01742	0.84700	0.00745
		Refill: PP	1.98000	0.00174	0.84700	0.00075
	Label	Single-use: paper	0.79000	0.00070	0.02662	0.00002
		Refill: paper	0.79000	0.00007	0.02662	0.00000
Secondary packaging	Boxes	Single-use: corrugated board	0.79000	0.03995	0.02662	0.00134
		Refill: corrugated board	0.79000	0.00400	0.02662	0.00013
Tertiary packaging	Boxes & layer pads	Single-use: corrugated board	0.79000	0.00222	0.02662	0.00007
		Refill: corrugated board	0.79000	0.00022	0.02662	0.00001
	Stretch film	Single-use: LLDPE	1.94000	0.00208	0.53240	0.00057
		Refill: LLDPE	1.94000	0.00021	0.53240	0.00006

**Table 2** *Overview of production and disposal of rf-go-pasta*

Packaging type	Packaging item	Material	Material price (€/kg)	Production cost per FU (€/FU)	Waste tariff, incl. VAT (€/kg)	Disposal cost per FU (€/FU)
Bulk packaging (5 kg)	Pouch	LDPE	1.96000	0.00906	0.53240	0.00246
	Boxes	Corrugated board	0.79000	0.01392	0.02662	0.00047
	Stretch film	LLDPE	1.94000	0.00081	0.53240	0.00022
In-store dispenser (10.6 kg)	Container	HDPE	1.77000	0.00021	0.53240	0.00006
Primary packaging – refill	Bag (250 g)	Unbleached paper	0.79000	0.00674	0.02662	0.00023
Primary packaging – single-use	Flow pack (500 g)	PP	1.98000	0.01026	0.84700	0.00439
Secondary packaging	Boxes	Corrugated board	0.79000	0.01714	0.02662	0.00058
Tertiary packaging	Stretch film	LLDPE	1.94000	0.00058	0.53240	0.00016

**Table 3** Overview of production and disposal costs of rf-home-powder

Packaging type	Packaging item	Material	Material price (€/kg)	Production cost per FU (€/FU)	Waste tariff, incl. VAT (€/kg)	Disposal cost per FU (€/FU)
Primary packaging (1.25 L)	Bottle	Single-use: PET	1.44000	0.06912	0.53240	0.02556
		Refill: PET	1.44000	0.00691	0.53240	0.00256
	Cap/closure	Single-use: PP	1.98000	0.01307	0.53240	0.00351
		Refill: PP	1.98000	0.00131	0.53240	0.00035
	Label	Single-use: paper	0.79000	0.00147	0.02662	0.00005
		Refill: paper	0.79000	0.00015	0.02662	0.00000
Secondary packaging	Boxes	Single-use: corrugated board	0.79000	0.02136	0.02662	0.00072
		Refill: corrugated board	0.79000	0.00214	0.02662	0.00007
Tertiary packaging	Boxes & layer pads	Single-use: corrugated board	0.79000	0.00505	0.02662	0.00017
		Refill: corrugated board	0.79000	0.00051	0.02662	0.00002
Refill packaging	Sachet	Bleached paper	0.79000	0.00870	0.02662	0.00029
Refill - secondary packaging	Boxes	Corrugated board	0.79000	0.00831	0.02662	0.00028
Refill – tertiary packaging	Boxes & layer pads	Corrugated board	0.79000	0.00044	0.02662	0.00001
Refill -tertiary packaging	Stretch film	LLDPE	1.94000	0.00067	0.53240	0.00018

**Table 4** Overview of production and disposal costs of rf-home-liquid

Packaging type	Packaging item	Material	Material price (€/kg)	Production cost per FU (€/FU)	Waste tariff, incl. VAT (€/kg)	Disposal cost per FU (€/FU)
Primary/secondary /tertiary packaging	Same packaging items as in Table 1					
Refill packaging (2.2 L)	Pouch	PET	1.44000	0.03181	0.84700	0.01871
	Cap/closure	PP	1.98000	0.00119	0.84700	0.00051
Refill -secondary packaging	Boxes	Corrugated board	0.79000	0.03336	0.02662	0.00122
Refill -tertiary packaging	Stretch film	LLDPE	1.94000	0.00247	0.53240	0.00065

**Table 5** Overview of transport costs across different packaging types in the four packaging systems

Packaging system	Packaging type	Supplier – DC			DC - store		
		Nr of units	Cost per trip (€)	Cost per FU (€/FU)	Nr of units	Cost per trip (€)	Cost per FU (€/FU)
Rf-go-liquid	Bulk packaging (tank)	30	20.48	0.00125	30	21.87	0.00134
	Refill primary packaging (bottle)	7200	20.48	0.00028	7200	21.87	0.00030

	Single-use primary packaging (bottle)	7200	20.48	0.00284	7200	21.87	0.00304
Rf-go-pasta	Bulk packaging	2880	17.54	0.00061	2880	21.87	0.00076
	Single-use primary packaging	28800	17.54	0.00061	28800	21.87	0.00076
Rf-home-powder	Refill packaging (sachet)	86400	31.85	0.00037	86400	21.87	0.00025
	Refill primary packaging (bottle)	12150	31.85	0.00026	16200	21.87	0.00014
	Single-use primary packaging (bottle)	12150	31.85	0.00260	16200	21.87	0.00135
Rf-home-liquid	Refill packaging (pouch)	21600	20.48	0.00047	21600	21.87	0.00051
	Refill primary packaging (bottle)	7200	20.48	0.00028	7200	21.87	0.00030
	Single-use primary packaging (bottle)	7200	20.48	0.00284	7200	21.87	0.00304

## Appendix F

### Qualitative results interviews: systematic overview feasibility framework

Level	Theme	Concept	Elaboration
Supermarket	Store management	Shelf space	Either shelf space will be sacrificed (refill on the go) or it will be gained (refill at home)
		Visibility of product	Concerns the questions whether the product is still visible to the consumer's eye compared to other products on the shelves
		Employee training and handling	Concerns the questions whether the packaging requires new process to be implemented by the store employees
		Cleaning and refilling	Additional tasks for store employees in the case of refill on the go
		Weighing/measuring	Importance of facilitating straightforward and efficient weighing/measuring processes, which also protect from misuse
	Supply chain	Adaption to bulk size	Suppliers, transport, and warehouse management must be adapted to bulk sizes in the case of refill on the go
	Cost effectiveness	Initial investment	Concerns the investment in (automated) dispensers, but also the design of new packaging and/or product (refill at home)
		Opportunity cost shelf space	The revenues from shelf space lost or gained by introducing a refillable packaging
		Comparison to single-use packaging	Concerns the question whether the refillable packaging is economically viable for the supermarket
	Communication	Point-of-sale (POS)	Importance of attracting and guiding customers in the process of behavioral change
		Reaching the customer	Introducing campaigns and communicating on the packaging to advertise the benefits
	Quality	Hygiene and safety	Ensuring that the dispenser is clean, and that no contamination happens with other products/consumers
	Legal requirements	Batch tracing	Tracking which batch is sold in which dispenser to be able to organize call-backs when necessary
		Accountability	Concerns the question who is accountable when a customers falls ill from eating produce which was dispensed with his/her own container
Consumer	Consumer behavior	Habituation	It will take time for consumers to adapt their behavior and become familiar with the new packaging

		Trade-off price and convenience	Consumers are expected to trade-off the price and the required effort when choosing a packaging system
		Influence communication and price	Consumers are influence by price (incentives) and communication (marketing)
	Convenience	Additional effort required	Concerns the question how (in)convenient the process is deemed by the consumers
		Handling of dispenser or refill packaging	Concerns the question whether a packaging item is easy to use
	Quality	Customer perception of product effectiveness	Concerns the question whether the refillable packaging negatively influences the perception of product quality
Product	Price	As an incentive	Importance of offering a price incentive to persuade consumers
	Legal requirements	Base information label	The new packaging should contain all base information, such as supplier information, EAN code, ...
		Ingredients and declaration	The new packaging should contain the ingredients list
	Environmental impact	Number of use cycles	Concerns the question when (after how many uses) the refillable packaging has a lower environmental impact than the single-use one
		Impact of materials	Supermarkets should consider the best material for the new packaging in terms of environmental impact
		Transport of water?	Concerns the question whether the new packaging entails that water is not transported anymore (relevant for refill at home packaging systems)
		Impact of cleaning	Concerns the question whether the impact of cleaning the packaging items outweighs the environmental benefits or not
	Quality	Effectiveness product	Concerns the questions whether the concentrated refill product can maintain quality or effectiveness standards
	Product fit	Need for innovation?	Concerns the questions whether the refillable packaging entails some form of product innovation (e.g. concentrated refill)
		Customer demand	Are customers actually interested in such refillable packaging systems?
	Material of packaging	Durability	Can the material of the packaging withstand frequent reuse?
		Recyclability	Is the material of the packaging recyclable?

## Appendix G

### Quantitative results consumer survey: Chi-square tests

Chi-square tests of Independence were performed for every pair of 1) willingness to engage and 2) each demographic and influential factor variable. The results are shown in Table 1, which only lists the Pearson Chi2 values<sup>17</sup> and not the individual cell frequencies of each test. Additionally, only those values that were significant (at 0.05 significance level) are shown to increase relevance. It is noticeable that approximately all demographic variables have no effect on either of the four willingness to engage variables. Only for *rf-go-liquid*, *province\_rural* has a significant effect, which in this case implies that urban consumers are more likely to be willing to engage with *rf-go-liquid*. Moreover, the willingness to engage with all four packaging systems is not affected by *convenience*. On the other hand, *environment* seems to have a considerable impact on all four packaging systems, with the biggest effect on *rf-go-liquid* and *rf-go-pasta*. This implies that, for instance, when the environment is valued in the decision to engage or not, more consumers will be willing to engage with *rf-go-liquid* and *rf-go-pasta*. *Price* has a similar effect on each packaging system's willingness to engage, with *rf-go-pasta* being the one that is most influenced by it. *Quality* affects every packaging system relatively less than the other influential factor variables, but it is still a significant effect. In the case of *rf-go-pasta* for instance, it indicates that when quality is valued, more consumers will be willing to engage, compared to when it is not valued. This also links to the finding that some customers valued the different options offered in refill on the go packaging systems (e.g. bio pasta). Finally, *other* also has a relatively high effect on *rf-go-liquid* and a relatively medium effect on the other three packaging systems. For instance, consumers who value other reasons in their decision to engage or not tend to not engage with *rf-home-liquid*, whereas consumers who don't have other reasons tend to engage with it. This implies that a consumer's other reasons are more likely to negatively affect its willingness to engage with *rf-home-liquid*.

**Table 1** Summary of the results of the Chi-square tests for the willingness to engage of each packaging system: Pearson Chi2 values

Variable	Rf-go-liquid	Rf-go-pasta	Rf-home-powder	Rf-home-liquid
convenience	NS	NS	NS	NS
environment	86.2667	78.4887	42.3710	34.1978
price	24.3190	37.8327	28.0814	32.7528
quality	5.2256	4.0044	NS	7.9752
other	86.7654	42.0117	33.2649	37.7019
aged_55	NS	NS	NS	NS
gender_male	NS	NS	NS	NS
income_medium	NS	NS	NS	NS
income_high	NS	NS	NS	NS
household_2	NS	NS	NS	NS
household_2more	NS	NS	NS	NS
province_rural	6.0898	NS	NS	NS

Note: NS denotes "not significant" (at a 0.05 significance level)

<sup>17</sup> The Pearson Chi2 value indicates the strength of the effect a demographic or influential factor variable has on the willingness to engage.

## Appendix H

### Quantitative results of the LCA sensitivity analysis

In the tables below, the quantitative results of the sensitivity analyses are shown. Every refillable packaging system is compared with its single-use alternative. Some analyses investigate the impact of changing a parameter to one (new) value, while other check for varying values of a parameter (e.g. return rate of detergent bottles). In case of the latter, the blue cells indicate the values of that parameter where the refillable packaging system performs better (i.e. has a lower total environmental impact in kg CO<sub>2</sub>-eq emissions per use) than its single-use alternative.

**Table 1** Overview of the environmental impact of rf-go-liquid and rf-home-liquid, per EoL treatment

EoL treatment	Total impact of CO <sub>2</sub> -eq emissions (kg) per use			
	Rf-go-liquid	Single-use	Rf-home-liquid	Single-use
recycling	0,082	0,366	0,259	0,366
Incineration (BL)	0,103	0,570	0,279	0,570

Note: BL stands for baseline

**Table 2** Overview of the environmental impact of rf-go-liquid and rf-home-liquid, per material (of the bottle)

Material	Total impact of CO <sub>2</sub> -eq emissions (kg) per use			
	Rf-go-liquid	Single-use	Rf-home-liquid	Single-use
HDPE	0,078	0,570	0,255	0,570
PET (BL)	0,103	0,570	0,279	0,570

Note: BL stands for baseline

**Table 3** Overview of the environmental impact of rf-home-powder, per return rate of the bottle

Return rate (%)	Nr of uses	Total impact of CO <sub>2</sub> -eq emissions (kg) per use	
		Rf-home-powder	Single-use
0,00	1	0,271	0,306
0,10	1	0,271	0,306
0,20	1	0,271	0,306
0,30	1	0,271	0,306
0,40	1	0,271	0,306
0,50	2	0,150	0,306
0,60	2	0,150	0,306
0,70	3	0,11	0,306
0,80	5	0,078	0,306
0,90 (BL)	10	0,054	0,306
1,00	TS	0,046	0,306

Note: TS stands for technical lifespan, BL stands for baseline

**Table 4** Overview of the environmental impact of rf-go-liquid and rf-home-liquid, per return rate of the bottle (as well as material and EoL treatment)

	Return rate (%)	Nr of uses	Total impact of CO <sub>2</sub> -eq emissions (kg) per use							
			PET bottle is incinerated (BL)				PET bottle is recycled			
			Rf-go-liquid	Single-use	Rf-home-liquid	Single-use	Rf-go-liquid	Single-use	Rf-home-liquid	Single-use
HDPE	0,00	1	0,335	0,570	0,507	0,570	0,335	0,366	0,507	0,366
	0,10	1	0,335	0,570	0,507	0,570	0,335	0,366	0,507	0,366
	0,20	1	0,335	0,570	0,507	0,570	0,335	0,366	0,507	0,366
	0,30	1	0,335	0,570	0,507	0,570	0,335	0,366	0,507	0,366
	0,40	1	0,335	0,570	0,507	0,570	0,335	0,366	0,507	0,366
	0,50	2	0,192	0,570	0,367	0,570	0,192	0,366	0,367	0,366
	0,60	2	0,192	0,570	0,367	0,570	0,192	0,366	0,367	0,366
	0,70	3	0,145	0,570	0,320	0,570	0,145	0,366	0,320	0,366
	0,80	5	0,107	0,570	0,283	0,570	0,107	0,366	0,283	0,366
	0,90	10	0,078	0,570	0,255	0,570	0,078	0,366	0,255	0,366
	1,00	TS	0,064	0,570	0,240	0,570	0,064	0,366	0,240	0,366
PET (BL)	0,00	1	0,578	0,570	0,750	0,570	0,374	0,366	0,547	0,366
	0,10	1	0,578	0,570	0,750	0,570	0,374	0,366	0,547	0,366
	0,20	1	0,578	0,570	0,750	0,570	0,374	0,366	0,547	0,366
	0,30	1	0,578	0,570	0,750	0,570	0,374	0,366	0,547	0,366
	0,40	1	0,578	0,570	0,750	0,570	0,374	0,366	0,547	0,366
	0,50	2	0,314	0,570	0,489	0,570	0,212	0,366	0,387	0,366
	0,60	2	0,314	0,570	0,489	0,570	0,212	0,366	0,387	0,366
	0,70	3	0,226	0,570	0,401	0,570	0,158	0,366	0,333	0,366
	0,80	5	0,156	0,570	0,331	0,570	0,115	0,366	0,291	0,366
	0,90 (BL)	10	0,103	0,570	0,279	0,570	0,082	0,366	0,259	0,366
	1,00	TS	0,075	0,570	0,252	0,570	0,065	0,366	0,242	0,366

Note: TS stands for technical lifespan, BL stands for baseline

**Table 5** Overview of the environmental impact of rf-go-liquid, rf-home-powder and rf-home-liquid, with and without a cleaning process for packaging items that were in contact with detergent

Cleaning process	Total impact of CO <sub>2</sub> -eq emissions (kg) per use					
	Rf-go-liquid	Single-use	Rf-home-powder	Single-use	Rf-home-liquid	Single-use
no cleaning (BL)	0,103	0,570	0,054	0,306	0,279	0,570
rinsing with hot water	0,372	0,570	0,155	0,306	0,369	0,570

Note: BL stands for baseline

**Table 6** Overview of the environmental impact of rf-go-pasta, per return rate of the customer's container

Return rate (%)	Total impact of CO <sub>2</sub> -eq emissions (kg) per use	
	Rf-go-pasta	Single-use
0,00	0,556	0,066
0,10	0,556	0,066
0,20	0,556	0,066
0,30	0,556	0,066
0,40	0,556	0,066
0,50	0,323	0,066
0,60	0,323	0,066
0,70	0,245	0,066
0,80	0,183	0,066
0,90	0,136	0,066
1,00 (BL)	0,099	0,066

Note: BL stands for baseline

**Table 7** Overview of the environmental impact of rf-go-pasta, per cellulose bag – customer's container ratio

% cellulose bag	% container	Total impact of CO <sub>2</sub> -eq emissions (kg) per use	
		Rf-go-pasta	Single-use
0,00	1,00	0,156	0,066
0,10	0,90	0,147	0,066
0,20	0,80	0,137	0,066
0,30	0,70	0,127	0,066
0,40	0,60	0,118	0,066
0,50	0,50	0,108	0,066
0,60 (BL)	0,40 (BL)	0,099	0,066
0,70	0,30	0,089	0,066
0,80	0,20	0,079	0,066
0,90	0,10	0,070	0,066
1,00	0,00	0,060	0,066

Note: BL stands for baseline

**Table 8** Overview of the environmental impact of rf-go-pasta, for a varying cleaning frequency and a varying customer's container-cellulose bag ratio

% cellulose bag	% container	Total environmental impact in CO <sub>2</sub> -eq emissions per use (kg)						
		rf-go-pasta - per cleaning frequency (nr of uses per clean)						Single-use
		1	2	3	4	5	..50	
0%	100%	0,164	0,117	0,102	0,094	0,090	0,073	0,066
10%	90%	0,154	0,112	0,098	0,091	0,087	0,072	0,066

20%	80%	0,143	0,106	0,094	0,087	0,084	0,070	0,066
30%	70%	0,133	0,100	0,089	0,084	0,081	0,069	0,066
40%	60%	0,122	0,095	0,085	0,081	0,078	0,068	0,066
50%	50%	0,112	0,089	0,081	0,077	0,075	0,067	0,066
60% (BL)	40% (BL)	0,102	0,083	0,077	0,074	0,072	0,065	0,066
70%	30%	0,091	0,077	0,073	0,070	0,069	0,064	0,066
80%	20%	0,081	0,072	0,069	0,067	0,066	0,063	0,066
90%	10%	0,071	0,066	0,064	0,064	0,063	0,062	0,066
100%	0%	0,060	0,060	0,060	0,060	0,060	0,060	0,066

Note: BL stands for baseline

## Appendix I

### Quantitative results of the LCC sensitivity analysis

**Table 1** Total cost per use for rf-go-liquid, rf-home-powder, rf-home-liquid and their single-use alternatives, for a varying return rate of the refillable bottle

Return rate	Nr of uses	Total cost per use (euro)					
		Rf-go-liquid	Single-use laundry detergent	Rf-home-powder	Single-use cleaning detergent	Rf-home-liquid	Single-use laundry detergent
0%	1	0,29495	0,21494	0,16354	0,14403	0,30564	0,21494
10%	1	0,29495	0,21494	0,16354	0,14403	0,30564	0,21494
20%	1	0,29495	0,21494	0,16354	0,14403	0,30564	0,21494
30%	1	0,29495	0,21494	0,16354	0,14403	0,30564	0,21494
40%	1	0,29495	0,21494	0,16354	0,14403	0,30564	0,21494
50%	2	0,18748	0,21494	0,09153	0,14403	0,19817	0,21494
60%	2	0,18748	0,21494	0,09153	0,14403	0,19817	0,21494
70%	3	0,15165	0,21494	0,06752	0,14403	0,16234	0,21494
80%	5	0,12299	0,21494	0,04832	0,14403	0,13369	0,21494
90% (BL)	10	0,10150	0,21494	0,03392	0,14403	0,11219	0,21494
100%	21	0,09024	0,21494	0,02912	0,14403	0,10093	0,21494

Note: BL stands for baseline