THE FUTURE OF PLASTIC PACKAGING FOR THE FRESH FOOD INDUSTRY.

Master thesis researching the future of PET packages for fresh food, based on the opinion of the consumer and results of Life Cycle assessments.

Emma Horsthuis | S1853104

UNIVERSITY OF TWENTE.

KONINKLIJKE hordijk

THE FUTURE OF
PLASTIC PACKAGING FOR
THE FRESH FOOD INDUSTRY

Emma Mariet Silvia Horsthuis
Student number | S1853104

Education

Faculty | Faculty of Engineering Technology
Department | Design, Production and Management
Master program | Industrial Design Engineering
Master track | Management of Product Development

Educational institution

University of Twente
Drienerlolaan 5, 7500 AE Enschede

Offering organization

Hordijk Verpakkingsindustrie Zaandam B.V.
Daalderweg 17 , 1507 DS Zaandam

Examination Date

March 9, 2023

Examination board

Supervisor Hordijk | Fons Groenen
Supervisor UT | Ir. M.E. Toxopeus
Prof. Dr. Ir. D. Lutters
Prof. Dr. Ir. R. Ten Klooster

Pages

1-79 | Report
1-53 (Document 2) | Appendix

PREFACE

Plastic is all around us and the public opinion about plastic packaging is here and now. But how is it possible that people are willing to put on a fleece jacket (i.e. "plastic") to be able to turn down the heating a degree or so. And on the same time, the same people are against plastic because it "contributes to global warming". People are shocked by the 'plastic soup' in the ocean, but it is actually the people that throw away those plastics into the environment. People want less and less plastic packaging, but Hordijk makes an increasing amount of plastic packaging for the Dutch industry every year.

Luckily it is not rocket science. Indeed, plastic is polluting and we should use it as little as possible. But, imagine walking out of the supermarket with a hand full of vegetable spread in it. It almost sound ironically. And then I did not even start about the expanded shelf life, the possibility to see the product and the light weight. It is not a popular opinion, but for the fresh food industry plastic may be a blessing in disguise.

"PLASTIC MAY BE
A BLESSING IN DISGUISE".

Within this research I was given the opportunity to fully dive into this world of plastic. To actually research if plastic offers opportunities, or if other solutions should be used, as they are truly better for the environment and accepted by the consumer.

A research about the paradox that exists between the opinion of the consumer and real data, performed in order to find a solution that unites. All information is researched from the perspective of the plastic industry, while being open to new innovations and other technologies or materials.

I appreciated the determination and belief of my temporary colleagues at Hordijk when talking about the possibilities of plastic. Plastic is indeed flowing through their veins. I especially want to thank Fons Groenen (the Technical director and internal guidance) and Marten Toxopeus (Life Cycle Specialist and guidance from the UT) for all the support throughout the entire project.
Business-to-Business

LIST OF ABBREVIATIONS

B2B Business-to-Business
EFSA European Food Safety Authority
FCM Food contact materials
GMP Good Manufacturing Practice
HDPE High Density Polyethylene
IAM Impact Assessment Method
KIDV Kennisinstituut Duurzaam Verpakken (Netherlands Institute for Sustainable Packaging)
LC Life Cycle
LCA Life Cycle Assessment
LDPE Low Density Polyethylene
NIR Near Infra Red
PB Paper and Board
PCR Post-Consumer Recycled
PET Polyethylene Terephthalate
PLC Product Life Cycle
RPET Recycled Polyethylene Terephthalate
SKU Stock Keeping Unit
SML Specific Migration Limit
SUP Single Use Plastic


1
Introduction


2
Current
state of
affairs


Product
3
Consumer
analysis


4
Life
Cycle
Assessment


5
Proposal
for
designing


6
Evaluation

CONTENTS

1.INTRODUCTION

Currently, the presence of plastics in our daily life has become indispensable. Plastics are strong, stiff, flexible, lightweight and depending on the design (non) shape-retaining [1], [10]. Hence, plastic offers great possibilities in the use of packaging. But what about the fossil fuels? Litter, microplastics and the plastic soup in the ocean... All buzz-words in today's society asking for clarity and a fair view towards the use of plastic.

To emphasize, the amount of packaging materials generated per person is expected to increase from 174 kilograms per person in 2018, to respectively 209 and 245 kilograms per person in 2030 and 2040 [17]. And as plastic packaging accounts for almost half of this increase, according to the same source, it has to be ensured that the use of this specific packaging material is sustained in more ways than one. Promoting a circular economy could be one direction, where packaging waste is not only reduced, but is brought back into the loop when creating new packages. At first, this report aims to research the use of plastic being a packaging material at all. Moreover, it dives into the possibilities within the plastic solutions and looks further towards other existing materials and the comparison between them. Lastly, the customer perspective is taken into account as well. What are the wishes and demands of stakeholders? In conclusion: a fair and transparent view on the future of plastics as packaging material by means of a Life Cycle Assessment (LCA) and consumer analysis.

1.1. THE PROJECTS BACKGROUND

The presence of plastic in the design of food containers has grown rapidly the past few years [1]. First of all, it offers great possibilities in terms of functionality [2] due to the unique material properties and the financially attractive status of fossil fuels [1]. Also, the results in terms of sustainability, in theory, do not disappoint: for example, the reduction of carbon emissions via plastic-produced applications as declared by Ministerie I&W & Ministerie van EZK (2018).

However, the affection of the customer against the use of plastic has become stronger as well, mainly seen in the reporting about litter, plastic soup and microplastics in the ocean and even our blood [3]. Although there are many other packaging materials available, it is not immediately clear what truly is the most sustainable option. Even more importantly, what is desired or at least accepted by the customer as well. Many brand owners redesign their packaging (materials) and claim to be more sustainable and the customer believes it [4]–[6]. However, greenwashing is not rare in the industry [7] and it is difficult to conclude what truly is sustainable. This can also be concluded from decisions of brand owners to return to previous packaging solutions, which were banned by the same brand owners in the first place [8].

IF COMPANIES ALREADY STRUGGLE, HOW CAN IT BE EXPECTED THAT THE CUSTOMER HAS A FAIR VIEW OF WHAT TRULY IS SUSTAINABLE?

The offering organization, Hordijk, also deals with this dilemma. Being a manufacturer for major players in the market (e.g. brand owners and supermarkets), questions regarding the sustainability of the material keep arising. Is the use of plastic, especially with regards to their commonly used PET, still a wise choice and which aspects should be taken into account?
This research aims to find an answer to both sides of the problem. This is done by providing a LCA in order to see what truly is the most sustainable option and by performing a consumer analysis in order to check what is preferred, or at least accepted, among the public.

1.2. THE OFFERING ORGANIZATION

The assignment is conducted for Hordijk, "a prominent supplier of products and services for the food and agriculture sector" [9]. The business started in 1922 and has been a family business ever since. Nowadays, about 500 people work at Hordijk in four prominent and specialized subsidiaries: "Hordijk Verpakkingen", "Hordijk Spuitgiet Verpakkingen", "Hordijk EPS Verpakkingen en Isolatie" and "Alcomij" at multiple offices and manufacturing locations in the Netherlands.

This assignment will focus on the first subsidiary "Hordijk Verpakkingen", located in Zaandam with an office and brand new factory for extrusion and thermoform processes. The business exists over a hundred years and has adapted to the times. As the wishes of Hordijks customers are currently gaining towards a sustainable packaging solution for food containers, Hordijk is curious about the possibilities and is open-minded in researching alternatives.

Although Hordijk is a prominent player in the industry, they are not alone and hence they are willing to use information from and share information with other players in the packaging industry. Although plastic flows through the veins of Hordijks employees, it should be said that this research will be conducted unbiased. Indeed, the focus will be on plastics – what is its true position – but Hordijk purely offers a facilitating role in this assignment.

"WITHOUT DATA YOU'RE JUST A PERSON WITH AN OPINION"

W. Edwards Deming [7]

Hundred years ago the business started selling wooden crates and from that perspective, Hordijk is open-minded in (re)considering other materials. As plastics are currently in place, it will have a specific focus in this assignment. Hordijk is a member or support of various, independent commissions and boards (i.e. NVC Netherlands, Petcore Europe, Plastic Pact) and is hence, able to provide scientific data. For other material types, scientific data will be searched and verified. Only this way, the facts can be checked and eventually identify the true problem for crafting an effective solution.

1.3. STAKEHOLDERS

As described, the goal of the research is to gain information in choosing a proper packaging solution for future food packages. Hordijk is no independent player: it is not possible to extrude foils without suppliers of plastic flakes or granulate for example. Moreover, Hordijk cannot design the product without the wishes or demands of the customer and they cannot take each packaging bought by the consumer to the recycler themselve. Hence, for more reasons than one, the company has an open mind in sharing and retrieving information. These stakeholders depend the in- and output of the products leaving Hordijks manufacturing plant. Hence, they are of importance in this assignment and will be discussed in the remainder of this section.

Hordijk

First of all, Hordijk will act as the main stakeholder in this assignment as the research is conducted on their request. This way, they can either empower their current belief to customers that plastic is the right decision or they can head towards another packaging material when necessary. Hordijk wants to convince customers by telling a true story about sustainability and it is not possible to do that without data, as stated above within the quote of W. Edwards Deming.

Supplier

Before Hordijk can manufacture, (raw) materials need to be supplied to the manufacturing plant. It is important to know where this material comes from: if differences exists between one supplier and another in terms of sustainability and if so, what these differences are. Research should demonstrate important factors in buying and supplying materials needed to produce packaging.

Client and end-users

Actually, there are two kinds of purchasers to discuss: the *client* of Hordijk, which will come along to represent the wishes of their customers, which will be referred to as the *end-users (i.e. customers)*. To illustrate, the client is a company in the food industry, for example (the representative of) Albert Heijn B.V. The end-user is anyone who buys the products in one of the supermarkets of Albert Heijn B.V. It is important that Hordijk can present a true story to their clients, so they are giving pause for thought and make decisions based on demonstrated results. Since, they can decide which packages are brought to the supermarket and purchased by the end-users.

Though, the end-user in this assignment can also be seen as an 'individual' stakeholder. Since, the end-user actually depends what the client purchases from Hordijk, instead of the reverse. To illustrate: when the end-user will not buy the packaging, it will not be brought to the shelfs by the client and they will not buy it at Hordijk. Hence, it is the second part of the research to investigate what the actual wishes and demands of the end-user are and to see if a balance can be found between what is truly sustainable and what the customer accepts.

Waste processor and Recycler

Lastly, there is an end-of-life stage in the chain: at the *waste processor* and *recycler*.

Although it is beyond the power of Hordijk to recycle or process waste, it is desired to close the loop and take responsibility if necessary. As stated before: Hordijk is no individual player and they are willing to use and share information with other players in the industry. Within the Plastic Pact [10] Hordijk and 74 other businesses promised, amongst others, to design packaging solutions that can be recycled. Thus, it is a must to take the end-of-life scenario into account when designing. Hordijk has collaborations with recycling plants to retrieve information and in line with the desires: buy recycled plastic flakes to create foils and close the loop [10]. Thus, not only waste processors but also recycling systems will be taken into account in this research.

1.4. RESEARCH QUESTIONS

As described, the assignment has the desire to expand knowledge in the field of food packaging (i.e. containers), with a special focus on the use of plastics. The aim is to research the different materials that can be used, especially in terms of sustainability and the wishes of the end-user. All in order to eventually define a realistic view of the possibilities in creating a true sustainable food container. To do so, one main research question is defined, supported by five sub research questions. The framework in Figure 1 provides a graphical illustration of how the sub research questions are tackled throughout the assignment and together lead to a final answer to the main question:

"How can packaging solutions for the fresh food industry be designed in the future, according to the product life cycles of different material types and the wishes of the customer and what is the place of PET as packaging material in this perspective?"

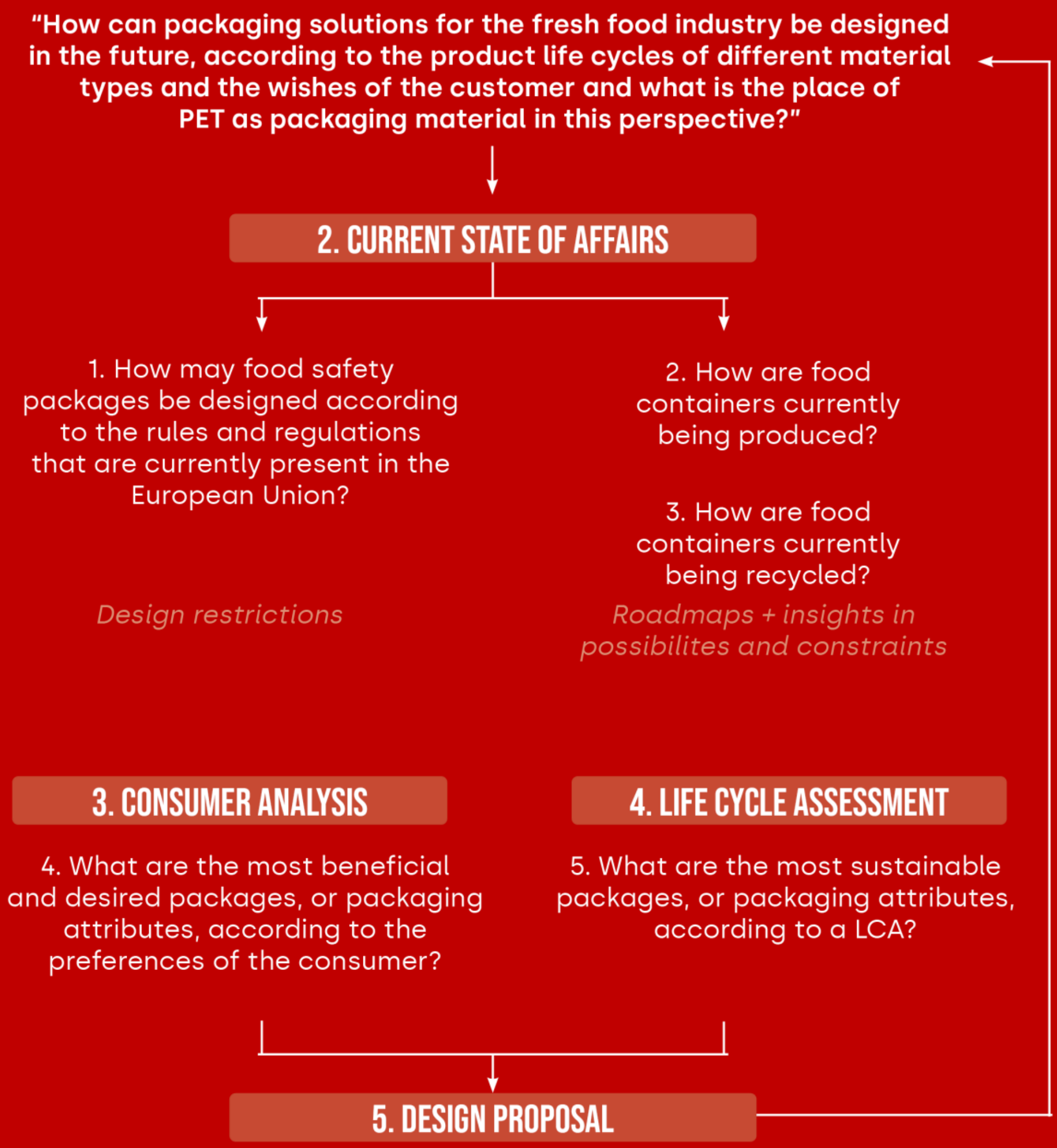

Figure 1: Schematic illustration of research approach

1.5. PROJECT SCOPE

Since this assignment is carried out during a limited amount of time and a proper depth is desired, a few restrictions will define the scope.

Geographical validity

First of all this assignment focuses on the environmental performance of food packaging for *the Dutch market*. As the legislation is regulated by the European Union, numbers and facts within European resources will be accounted for. All information found in sources of countries beyond the European Union will be mentioned on beforehand and verified using European literature.

Material selection

It would be too time consuming to evaluate all possible materials known in packaging solutions. This research aims to find an answer in what is the most desired solution in terms of the environmental impact and according to the wishes of the customer. Hence, a selection has been made based upon (1) what the customer nowadays demands (and thus prefers in terms of sustainability) and (2) what current scientific literature presents to be sustainable. From these insights four material solutions (PET, RPET, Paper and Board (PB) and glass) have been chosen to be of focus in this assignment. The sources influencing the decision in selecting the material solutions will be discussed in Chapter 2.1.

Plastic and PET

As can be concluded from opinions of end-users: consumers all around us (at supermarkets, in online responses at social media [11] and even in politics [12]) do most commonly not differentiate between plastic types. From this perspective, it will be assumed in this research that the end-user does not prefer one polymer type over another. PET has proven to be an unique packaging material, due to the excellent material properties (i.e. high strength, lightweight and transparent) [13], [14] [14] and recycling possibilities [14], [15] and impact to the environment [7] compared to other materials. According to Franz & Welle (2022) there are strong indicators that PET is even the most promising packaging polymer for closed-loop recycling. Lastly, Hordijk in Zaandam is specialized in creating food containers using PET, resulting in a high availability of information. Based upon these reasons, PET will have the focus when discussing plastics in this report.

Food contact packages

Within the assignment, packages will be researched that come into contact with food. When performing a LCA, one specific type of product (thus food) should be chosen, which will be discussed in Chapter 4. For the other parts of the research any arbitrary fresh food type can be imagined, that is processed, has a limited expiration date and relatively high moisture share. Examples are (vegetable) spreads, salads, meat or appetizers.

1.6. LIST OF REQUIREMENTS

As with any design (to be), a list of requirements is desired. Although this is in a very early stage of designing, the requirements that state the boundaries of this assignment will be presented below. As there are multiple stages within this assignment that can be interpret as design stages, such as the creation of the LCA, the creation of the conjoint analysis and the creation of the design proposal, multiple lists of requirements will be presented throughout this report.

The list of requirements that can already be presented in the beginning of this assignment is based upon the vision of and demands that can be derived from the stakeholders, as declared in Chapter 1.3. Please note that this list of requirements will be asserted throughout the entire assignment, but will be expanded when creating the consumer- and life cycle analysis. The design(s) to be proposed should ...

1. Be a result of independent and scientific based research to the best of the knowledge of the author.
2. Comply with the rules and regulations stated by the European government and the specific demands that are defined by the Dutch government.
3. Comply with the agreements made in the Plastic Pact [10].
4. Present a realist view on the future of packaging design, that is achievable for manufacturers of packaging solutions at high scale.
5. At least be accepted by – but preferably be a balance between the desires of – the wishes of the customer and the results of the LCA.
6. Be possible to implement in a current situation of producing food containers, within ten years.
7. Comply with the recycling system that is currently present in the Netherlands, or expected within the coming ten years.
8. Be expected by experts to be marketable among similar circumstances as current designs.

1.7. NOTES

For consistency throughout the report, declarations of the terminology, as used in this report, will be declared. Please note that this terminology is the perspective chosen for this assignment and cannot be generalized for all purposes.

Recyclability

In this report recyclability is meant in the context of packaging that has been in contact with food, after being consumed by the end-user. This fraction can also be referred to as Post-Consumer Recycled (PCR) content. One of the descriptions of recyclable packaging is: "that which can be effectively and efficiently separated from the waste stream, collected, sorted and aggregated into defined streams for recycling processes, and recycled at scale through relevant industrial processes such that it is tuned into a secondary raw material [17].

With recycling in this report any mechanical, physical or chemical technique is meant, that processes waste products into new products, materials, flakes or granulates for the initial or another purpose. Techniques that result purely in energy recovery, or the processing of materials meant to be used as fuel or filling materials are not covered within the scope of 'recycling'. To illustrate, field research [S2, S3, S4] demonstrated that often foils are too thin or light to be detected or sorted in the recycling system. Other examples are found in black-colored plastic packages and the use of multiple layers from different plastics in one packaging [18, S2, S3, S4]. In reality, these packages will end-up in the incineration process and will therefore be considered as non-recyclable in this research.

Recyclate: Material (in flakes, granulate or shards) that results from a mechanical, physical or chemical recycling technique and can be used as input for new products. Within the assignment, purely PCR materials corresponding with this description are denoted as recyclate. Hence, excess material that is reused in the production process (i.e. pre consumer recycled content or trim) is not considered as recyclate.

Recyclable packaging: Packaging that can be recycled, according to the description of 'recyclability' that has been provided. Meaning that the packaging can be 'recycled' into new products, materials, flakes or granulate for the initial or another purpose by a mechanical, physical or chemical technique. Packaging that is designed to end up in an incineration process is not considered as recyclable packaging.

Recycled content: the weight of one specific recycled material (i.e. RPET) towards the weight of the same material in the virgin option (i.e. virgin PET).

There is quite some debate about what can be accounted as recycled content. To illustrate, in a thermoform process packages will be 'pressed' and 'punched' out of the foil. This results in a rest-material of foil, called 'trim'. This trim can be used as new input material for extrusion. Within this report trim will not be included in the calculation of recycled content as it is not post-consumer recyclate and has not been in contact with food yet.

Plastic versus Polymers

The words plastics and polymers are used interchangeably, however there is a clear distinction which will be discussed here. Plastics are a specific types of very large molecules called polymers. In daily life, many other types of polymers can be found, such as cellulose, silk, cotton and even our DNA [7]. Decades ago a way has been found to actually recreate polymers, these will be referred to as plastics.

Sustainability

In terms of sustainability the entire lifespan and all choices made to create (and dispose) the product are considered. When referred to as being 'sustainable' in this report, it will mean that the environmental impact of the to be discussed application is (acceptable) low. A popular definition of sustainability that is still applicable today, is presented by the United Nations in 1987, in combination with an explanation given by Rosenbaum and Vieira in 1993:

"Sustainable developments are those which fulfil present and future needs [19] while [only] using and not harming renewable resources and unique human-environmental systems of a site: [air], water, land, energy, and human ecology and/or those of other [off-site] sustainable systems [20]".

From this definition, three pillars of sustainability can be derived: people, planet and profit. These three pillars combined are also referred to as the Triple Bottom Line, a concept that should motivate businesses to considerate the social and environmental dimensions, besides the changing their economic goals [21]. Figure 2 presents the concept of these three pillars.

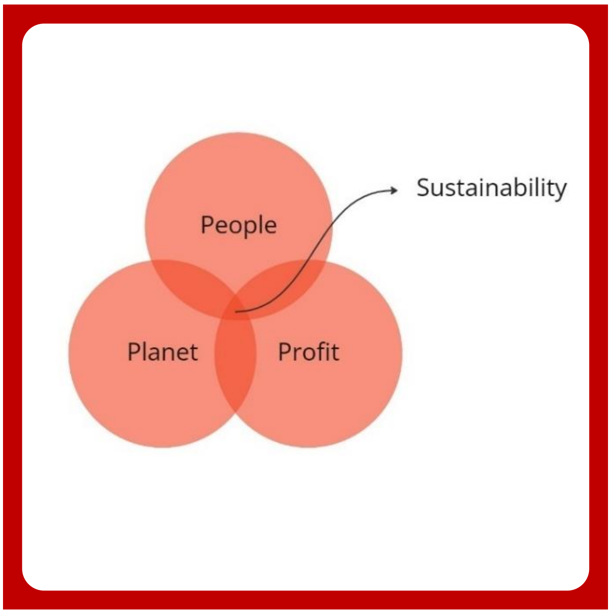

Figure 2: The three pillars of sustainability

Within this assignment the focus will be on the 'P' of Planet, in terms of sustainability. However, as the Figure 2 clearly illustrates: the People and Profit should also be taken into account when 'true' sustainability is desired.

Single-use plastics

The term single-use plastics brings up a lot of discussions nowadays, as can also be concluded from the Directive that has been conducted by the European Union [22]. With single-use plastics in this report, consumer goods are meant that are partly or completely made from plastic and are not designed or brought to the market with the intention to be used multiple times for its initial purpose. This does not mean that the products can truly be used one single time.

Industry

A major share of the thermoformed PET packages of Hordijk can be found in supermarkets since Hordijk supplies different food manufacturing companies. Therefore, all to-be discussed packaging solutions and information regarding food- and recycling systems will be checked upon this scope. It will be made sure that packaging solutions are discussed that can be found in supermarkets, in high shares and most commonly end up in consumer households and subsequently municipality waste streams.

Influence of the data due to Covid-19

Within the report data retrieved in the time frame of 2020-2022 will, amongst others, be discussed. It should be noted that within the same time frame the corona pandemic was present in the Netherlands. Logically, the pandemic resulted in a high(er) share of at-home consumption and corresponding collection rates of household waste. This reflects in the data used for this report and should hence be taken into account.

2.CURRENT STATE OF AFFAIRS

Within this section the current situation of food-contact packaging will be discussed. This will be done according to the scope, discussed in Chapter 1. As with any topic, checking the facts first allows to identify the true problem, something that is vital for crafting an effective solution in the end.

The current state of affairs covers the middle part of the framework (Figure 1) covering the first three research questions:

1. How may food safety packages be designed according to the rules and regulations that are currently present in the European Union?
    - *What should be taken into account when designing for food safety packages / which design restrictions result from this?*
2. How are food containers currently being produced?
    - *Which insights does this give in terms of possibilities and constraints?*
3. How are food containers currently being recycled?
    - *Which insights does this give in terms of possibilities and constraints in the design of (new) packaging solutions?*

The goal is to conclude design restrictions in order to create some boundaries for further research. Moreover, insights and constraints from current practice are desired, to create a blueprint for the LCA. Lastly, the trends and possibilities in the market should be made clear in order to retrieve guidelines for the consumer analysis

2. CURRENT STATE OF AFFAIRS

2.1. PACKAGING

Packaging has become indispensable in todays society, especially with regard to the convenience of containing and preserving food. Though, food packaging is nothing new. Historically, examples can already be found in mother nature, such as the peel of an orange. Also, very early packages were made using herbal or feral sources, such as preserving food in the skin, intestine or bladder of an animal or the creation of a basket made out of twigs or stems, smeared with loam to make it water resistant [23]. The consumer of today has been spoiled with a wide portfolio of food packages in all types of materials, ranging from purely functional packaging to packaging solutions that emphasize product characteristics. Packaging is no longer just a functional additive, it is part of a bigger technical and commercial system in which all kinds of machines, traffic and marketing attributes create a complete industry.

Within the nineteenth century the first packaging solutions, using paper and board were brought to the market [23]. The use of glass in packaging solutions was at that time already quite common for expensive, small unities such as fragrant oils and creams [23]. According to the same source, the use of plastics was not emerging until the twentieth century.

Functions of packaging

A modern packaging solution can consist of multiple (loose) pieces, made from different materials. Most commonly, the main compartment is needed up till the moment the content has run out [23]. It is often seen in current practice, that the packaging outlasts its contents and becomes redundant after usage [24]. After usage, the disposal process starts, including steps as waste collection, sorting and preferable: recycling. For each material this disposal process differs, which will further be discussed in Chapter 2.4.

Within 'Zakboek verpakkingen' a total of five packaging functions is described [25]:

1. To contain: the content, the packed product
2. To facilitate transport: the packaging-product combination
3. To protect (the product or packaging-product combination) from environmental influences
4. To inform
5. To facilitate end-use and disposal

The importance of one function over another can vary in each packaging solution and commonly more functions are in place. When analyzing, designing, innovating or optimizing a specific packaging-product combination the right balance should be found between the functions. The latter also held for comparing different packaging solutions in terms of sustainability, as will be done in this assignment. In the case of packaging for (fresh) food, specifically function two, three and five, should be weighted.

Function one covers the essence of packaging, in which (according to the scope) food is accommodated by an enclosing material. It is assumed that all to-be discussed packaging solutions will accommodate the food properly as they are already brought to the market. Function two, should be weighted among packaging solutions as sustainability is affected by transport. The same held for the end-use and disposal phase of packaging, covered by function five. The influence of function three, to protect, is variable depending on the material and is hence, also important to take into account during the assignment. Lastly, function four in spite of the scope, is about the information accompanying the packaging, found in examples such as labels, wrapping or sleeves. As this is not the business of packaging manufactures, such as Hordijk, but rather lies within the focus of the brand owners, the 'to inform' function will not thoroughly be discussed or weighted.

Numbers and facts

From all the packages brought to the market, around 60% [23] is used for the packaging of food. Other sources provide different percentages: according to KIDV the share of packaging for the food industry is about 30% [26]. Of course, some variation can be declared by the scope of the research. For example; within one research secondary and tertiary packaging that accompany the primary packaging in for example transport can be taken into account, where in other researches these packages belong to a different industry. Anyhow, the share of packages belonging to the food industry is present and when discussing sustainability, important to look into. Especially when keeping in mind that packages do have a real impact to the environment. Since, (fossil) fuels and energy are used in the production and packaging covers 20% [27] of the total waste that is created.

Ten Klooster et al. (2008a) provides readers with a set of descriptions commonly used in the packaging industry. This source also describes the differences in primary, secondary and tertiary packaging. Primary packaging refers to the "first" packaging, such as the packaging visible in the supermarket shelves. The secondary packaging covers the consolidation of products and tertiary packaging is referred to when the packaging can only be transported with systems such as a forklift. Within this report the same terminology is in practice. It is claimed that 10% [27] of the total environmental impact is caused by packaging. According to the Dutch source "Samen tegen voedselverspilling (freely translated: "Together against food waste) a third of the worldwide emissions of greenhouse gasses originates from food systems. Both sources concede that much higher percentages are due to categories that are polluting even before the product is consumed (i.e. 15% as food waste [27], 39% agricultural production [29] and 32 % land use [29]). Thus, packaging offers potential with regards to the environmental impact, when compared to other influences of the food industry.

Packaging materials

Within the food industry, different packaging materials are available that typically all have their own focus area due to the corresponding material properties. Paper, plastics and glass are – whether or not combined – the most commonly used materials in food packaging [26]. Moreover, according to research performed by 'Two Sides' [30] paper and glass are the most preferred packaging solutions among the end-user, in terms of sustainability. Within the research of "ING Economisch Bureau" [31] this is confirmed: when asking the end-customer which packaging material is the least sustainable, 64%of the respondents answered plastic, where only twelve and 8% respectively answered carton and glass. Although this research is not conducted within the Netherlands, it gives a generalized view of Europe, which presents perspective for Dutch consumer behavior. However, in other scientific literature and LCA studies, plastics are demonstrated to be the most sustainable solution [16]. In supermarkets plastics are, both in numbers and weight, the most common packaging material, followed by glass and paper [31]. Hence, within this paper the decision has been made to discuss packaging solutions made from plastics (as declared in the introduction; purely PET), paper and board and glass:

Paper and board

A general definition of paper and (paper)board is provided by the Confederation of European Paper Industries (CEPI) and is quoted and maintained in this report [32]:

Paper: *"A range of materials in the form of a coherent sheet or web […] made by deposition of vegetable, mineral, animal or synthetic fibers, or their mixtures, from a fluid suspension onto a suitable forming device, with or without the addition of other substances. Papers may be coated, impregnated or otherwise converted, during or after their manufacture, without necessarily losing their identity as paper […]".*

(Paper) Board: *"Certain types of paper frequently characterized by their relative high rigidity. The primary distinction between paper and board is normally based upon thickness or grammage, though in some instances the distinction will be based on the characteristics and/or end-use […]".*

In the Netherlands around 3 million tons of paper and board was produced in 2019, of which 2,2 million tons is intended for the production of packaging [33]. This comes down to 73%. According to the same source, 86% of all produced paper and board in the Netherlands, is made from the recycling of a separate "old paper" waste stream (85% 2022 [34]). This relatively high number is a result of the high collection and recycling rates of old paper and board in the Netherlands (84-87% [31, 32]). However, paper fibers are fibrous and break easily, especially after many times of reuse. Hence, in many cases a specific amount of recycled fibers are used, accompanied by new fibers (around 15% to create a strong material for the production of new packaging solutions [33]).

The most beneficial characteristics of paper are [35]:

- Well printable with all kinds of printing techniques
- Well foldable, ability to tightly fold all kinds of packages
- Good to glue, with all kinds of glues
- Stiff, so that it can be transported easily through machines in the production process
- Easy to tear, for easy opening of packages
- Resistant to warmth and cold

Often PB are perceived as sustainable packaging materials, with high recycling rates. However, it is important to mention that exposure to light and moisture will reduce the life span of paper packaging as the material has limited barrier-properties [35]. Especially in the case of fresh food, paper itself cannot comply with the boundaries necessary for the packed product and hence, more complex packaging materials are being developed [33]. Examples can be found in multilayers, or paper supported by additives or coatings. Similarly to paper, cardboard is also consisting of cellulosic fibers most commonly originating from wood [35]. Where paper most commonly consist of one layer, cardboard is created by merging multiple layers. Each layer can consist of a different or equal type of paper mass. Anyhow, this consistency together creates the base of both folding- as well as solid board and is denoted as 'board' when grammages are found upward of 200 to 250 gram per squared meter [33]. When the grammage is below this boundary, it will be denoted as paper.

In the case of PB packaging for fresh food, a few difficulties are in place. According to the recycle check of KIDV [36], to be discussed more thoroughly later in the report, PB packages are only accepted in the separate 'old paper' waste stream when 'clean and dry'. Similarly to the pollution in the separated plastic waste stream, it cannot be expected that the users will dispose PB packages according to this condition, if even possible. Within the recycling of PB no extreme heat is used and food can cause deposits, odor nuisance and an overload of the water treatment [33] which should be prohibited.

Glass

Within the Netherlands a wide range of food products are packed in glass. Of all products made from glass in the Netherlands, almost 86% finds it function in packaging [37].

Glass is a non-crystalline solid of mineral origin [35] which can be shaped under high temperatures. Together with some unique material properties, glass is a perfect material for the use of food containers which will be discussed in Chapter 2.3.2. The mineral origin, accompanied by the embedded recycling system for glass in the Netherlands, creates circular opportunities that benefit glass materials in terms of sustainability. This will further be discussed and supported by references in Chapter 2.4.

As stated, the use of glass as a packaging material offers great potential, due to the beneficial characteristics, declared by Stichting Duurzaam Verpakkingsglas (n.d.):

- Natural preserving function; extends the shelf life of food
- Does not change the taste, quality or vitamins of the content.
- Preserves the freshness, taste, aromatics, texture, color, vitamins and quality of the content.
- Taste- and odorless
- Inert material; impregnatable to gasses and moisture.
- Circularity: in theory 100% recyclable without loss of quality
- Reusable, even in the case of food packaging
- When using colored glass, barriers against UV emission can be created.

For the creation of packaging glass, silicon dioxide (the main component of sand, commonly referred to as quartz), boron oxide, sodium, potassium, calcium, barium, lead and aluminum are used [35]. In short, this comes down to the three core materials: sand, soda and chalk [37]. The composition of the components can variate based upon the design, but is most commonly around: 72% silicon dioxide, 13% soda (for the introduction of sodium oxide), 11% limestone (for the introduction of calcium oxide) and around 1.7% aluminum oxide and diverse metal oxides such as potassium oxide and magnesium oxide [35].

Not only the material of properties of glass offer great potential. Also in terms of recycling, glass offers great possibilities, as it can be recycled endlessly without the loss of quality [37]–[39].

Plastics – PET

The share of plastic food packages in the Dutch market is substantial. Since, on average, 26 billion plastic food packages are used in the Netherlands [31].

With plastics, a group of organic materials with a high-molecular mass is meant that are synthetically build from monomers or less commonly; high-molecular products such as cellulosic, protein, starches or rubber [40]. Plastics have been known for their interchangeable material properties. Namely, the type, length and direction of the molecule can be manipulated within different steps of the production and eventually influence the properties of the packaging [40]. Also the corresponding manufacturing techniques offers possibilities in creating complex features that are not easily to recreate with any other material. The advantages of using plastics in general, for the application of packaging can be summarized by the following [40]:

- Good oxidation resistance
- Many processing capabilities and easy to process and deform
- Efficient material use
- Sustainable
- Cheap
- Easy accessible
- Possibility to compose in various kinds and qualities for multiple purposes

Disadvantages of using plastics for food-contact packages are for example, the sensitivity to temperature, an extensive need for energy in some purposes when compared to other materials and the possibility of crazing (small cracks). Moreover, societal affection is present against plastics as can be seen in discussions about litter and the plastic soup.

The main resource of the most common plastic types is crude oil [40]. By means of fractional distillation, crude oil can be separated and eventually 'cracked' resulting in a fission of the chains into unsaturated hydrocarbons. These are the building blocks for the specific polymers. Each individual polymer is in need for its own production and recycling technique and has its own specific earning and application of use. A distinction can be made into three categories, separating the plastics by their molecular structure into thermoplastics, thermosets or elastomers. With regards to the scope, most commonly thermoplastics are in use for the application of food containers of which examples can be found in PE, PP and PET [40]. Thermoplastics consists of high molecular materials that are primarily linearly constructed. Originally the material is entwined, but can be reshaped when heated as it initially gets weak and will consolidate when cooled off. While extending the chains, specific molecular properties, such as tensile strength, can be interchanged [40] resulting in material properties that also benefit the recycling.

One of this thermoplastic materials is PET (polyethylene terephthalate) [14]. The application of PET can, amongst the use of food containers, be found in clothing or industrial application, bottles and films. From a chemical point of view, PET is manufactured from terephthalic acid and ethylene glycol, that together react as a long polymer chain with water as a by-product [14].

The most important characteristics of PET are [35]:

- Transparency
- Good tensile strength
- Dimensionally stable
- High melting point
- Good fat and oil barrier
- When reinforced, the material has good barrier properties.

2.2. RULES AND REGULATIONS IN FOOD PACKAGING

As described, the use of plastic in designing packaging offers potential, due to the unique material properties. Moreover, it has become indispensable for the end-user, due to the possibility of buying pre-packed, precooked or sliced food, with or without an extended shelf life. However, that same end-user is demanding other packaging materials as the identity of plastics has been called into question.

Before new possibilities can be looked into, it should become clear at first where those possibilities should comply with. This section will therefore be devoted to rules and regulations in food packaging and aims to find an answer to the first sub research question:

How may food safety packages be designed according to the rules and regulations that are currently present in the European Union?
What should be taken into account when designing for food safety packages?
Which design restrictions results from this?

2.2.1. European legislations concerning food safety packages

The Netherlands is one of the Member States of the European Union and should therefore comply with rules and regulations assigned by the European Union.

Materials and articles (complying with the scope of this assignment) may only be placed to the market if they comply with Article 3, 15 and 17 of Regulation (EC) No 1935/2004 [41], are manufactured as declared by Regulation (EC) No 2023/2006 [42] and for plastic specifically, comply with the compositional and declaration requirements set out in Chapters 2, 3 and 4 of Regulation (EC) No 10/2011 [43]. Moreover, when recycled plastic materials and articles are used that (are intended to) come into contact with foods, Regulation (EC) No 2022/1616 [44] also applies. Lastly, Directive (EU) 2019/904 is specifically devoted to the reduction of single-use plastics that also applies to the use of food containers and will hence, be discussed. Each regulation has been translated into an illustrative figure, representing how the Regulation can be tackled within the scope of this research. For more detailed information behind each figure, Appendix A will be referred to. Within the remainder of this section all these Regulations will be discussed individually

Regulation (EC) No 1935/2004

The "Framework" Regulation (EC) 1935/2004, illustrated in Figure 3, approaches the general safety aspects of food packaging materials. The Regulation covers a set of articles specifying that all materials intended, are or can reasonably be expected to be brought into contact with food, with or without the use of recycled content, have to comply with some essential requirements. Namely, " *All materials* [...] *do not transfer their constituents to food in quantities which could:*

1. *Endanger human health;*
2. *Bring about an unacceptable change in the composition of the food; or*
3. *Bring about a deterioration in the organoleptic characteristics thereof."*

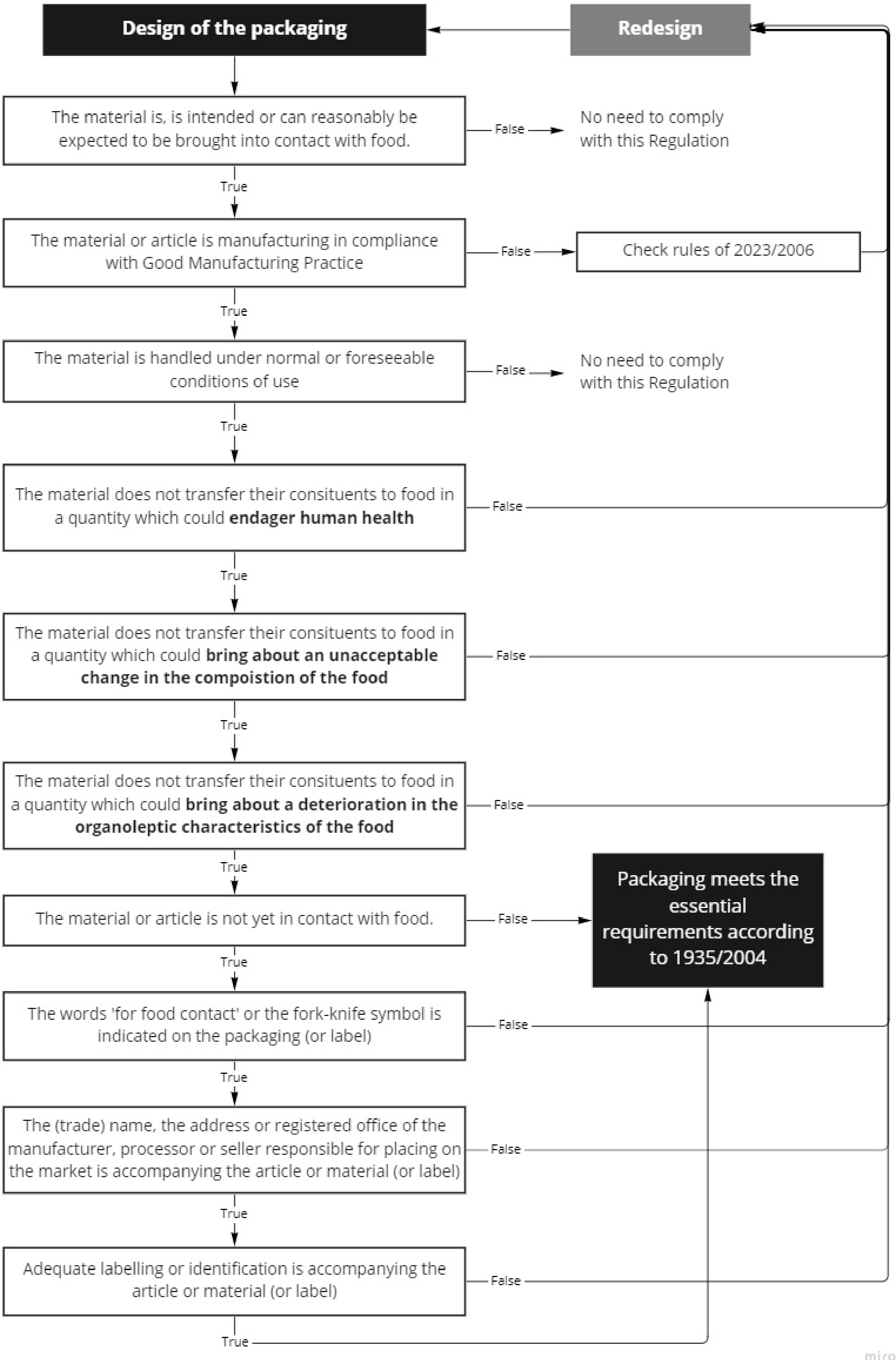

Figure 3: Requirements to comply with according to Regulation (EC) No 1935/2004

Also, a set of labelling attributes should accompany the materials and articles which are not yet in contact with food. The commonly used symbol is illustrated in Figure 4.

Figure 4: Symbol used as a labelling attribute, according to Regulation (EC) No 1935/2004

Regulation (EC) No 2023/2006

Regulation (EC) No 2023/2006, lays down rules on good manufacturing practices for materials and articles intended to come into contact with food, according to the specifications of Regulation (EC) No 1935/2004. When complying with the regulation as illustrated in Figure 5, it can be assured that the materials and articles are consistently produced and controlled to ensure conformity.

Regulation (EC) No 10/2011

The 'Plastics' Regulation (EC) No 10/2011 provides the Member States with a list of substances that is approved under the given restrictions, on plastic materials and articles intended to come into contact with food. When manufacturing plastic materials and articles, or the layers in those, only the substances mentioned in this "*Union list of authorized substances*" may intentionally be used. Moreover, the rules, as described in Figure 6 should be complied with.

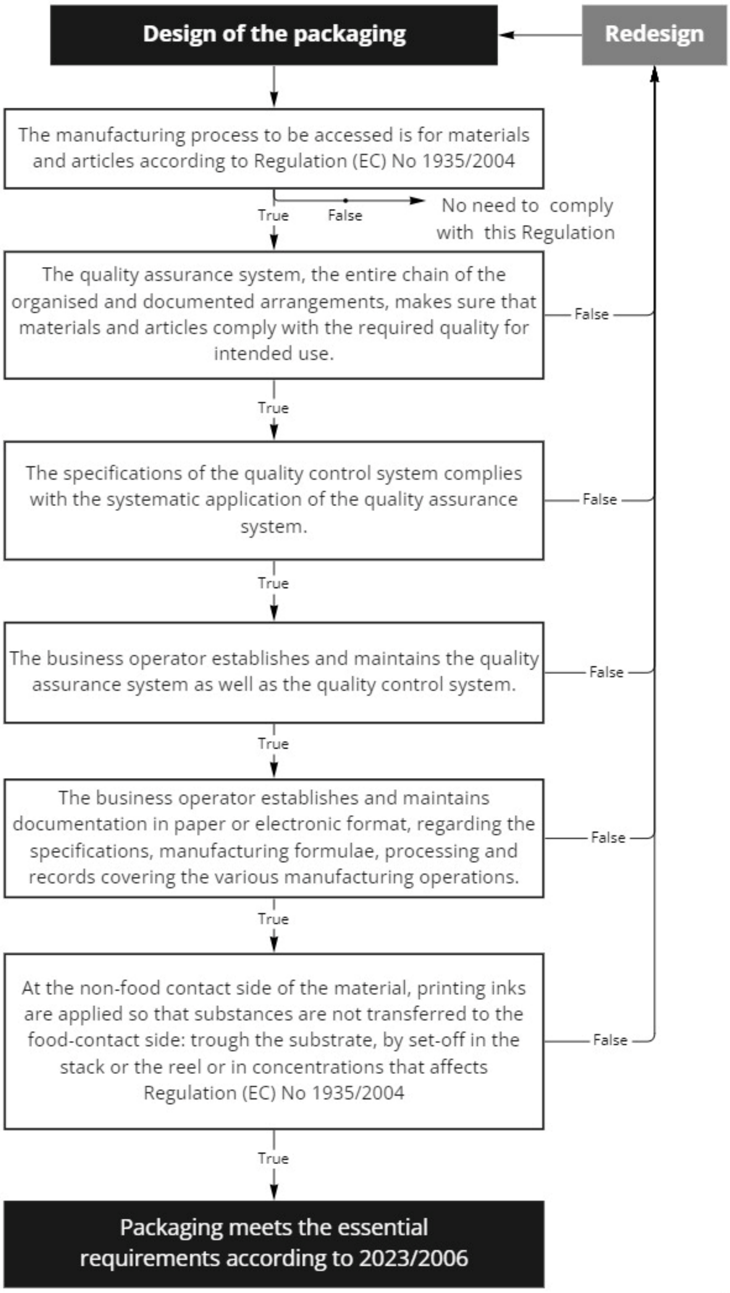

Figure 5: Requirements to comply with according to Regulation (EC) No 2023/2006

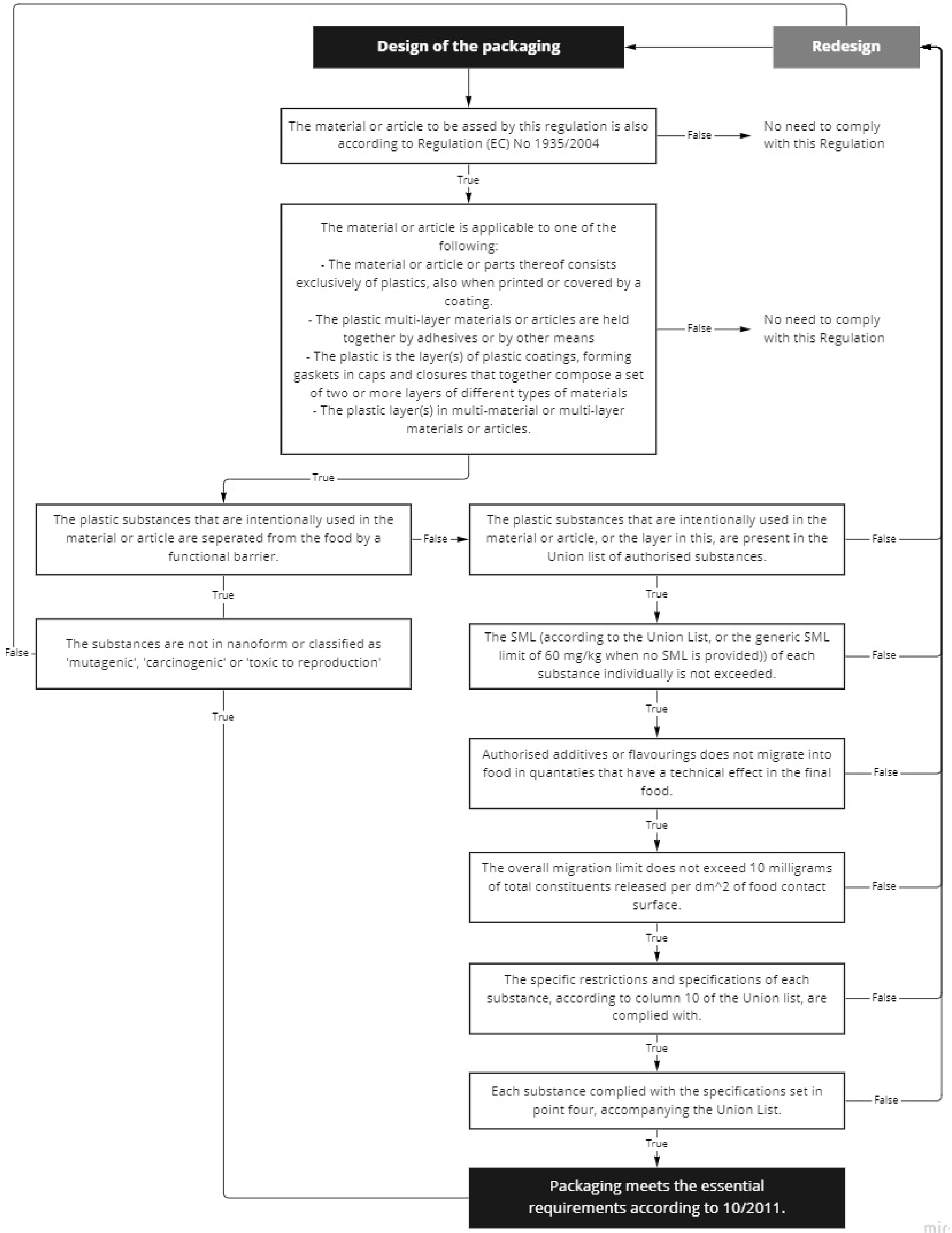

Figure 6: Requirements to comply with according to Regulation (EC) No 10/2011

Regulation No 2022/1616

Within the time frame of this research, Regulation (EC) No 282/2008 has been repealed and replaced by Regulation (EC) No 2022/1616 which is currently in force. The former regulation provided the Member States with the restrictions on (post consumer) recycled plastic materials and articles intended to come into contact with food. The new regulation serves as the legal basis for the authorization decisions for the recycling processes and focuses on decontamination. Within the regulation 'recycled plastic' is defined as "plastic resulting from the decontamination process of a recycling process and plastic resulting from subsequent post-processing operations and that is not yet transformed into recycled plastic materials and articles".

The discussed definitions laid down in Regulation (EC) No 1935/2004, 10/2011 and 2023/2006 also apply to the restrictions of this Regulation. To comply with the regulation safety should be demonstrated at three levels: recycling technology, process and installation. As this research focusses on the ability to recycle packaging solutions and implementation of recyclate into packaging, the specific rules laid down on the installation and technologies in this regulation will not be discussed. For further information, the official Regulation No 2022/1616 will be referred to [44].

According to the regulation, a recycling technology is considered "suitable" if it is *"shown to be capable of recycling waste into recycled plastic materials and articles that comply with Article 3 of Regulation (EC) No 1935/2004 and are microbiologically safe*". A list of approved technologies is added to Annex 1 of the Regulation. Another direction is using recycled plastic which is recycled via a "novel technology". Using such a technology, the material will be allowed on the European market, without prior approval. However, it is subject to certain limitations and specific data should be reported. The rules laid down in the regulation that comply with the scope are illustrated in Figure 7.

Next to the rules as declared in Figure 7, the regulation provides requirements for the collection and processing of plastic waste. The plastic waste should originate from municipal waste, or from food retail or other food businesses if it was only intended and used for contact with food. Moreover, the plastic waste should be subject to separate collection which is the case if the collection only consists of plastic materials and articles that are indeed intended and used for contact with food. It can be collected with other packaging waste fractions (for example, metal), but the collection system must only collect non-hazardous waste and should be designed to minimize contamination of collected plastic waste from any plastic waste that is not intended for contact with food. Moreover, the plastic waste should be controlled throughout collection and pre-processing via a quality assurance system. Amongst others, this system should ensure traceability of each batch up to the point of the first sorting of collected plastic waste. Although it is beyond the scope of this assignment to research the collection and pre-processing of waste, it should be noted that these requirements affect the creation of recyclate.

Although the new Regulation (EC) No 2022/1616 provides clear rules and boundaries in creating and using recycled content, only few recycling technologies are currently denoted as 'suitable' and can immediately be used. New technologies should apply as 'novel' and many requirements should be attained in order to actually create and use recyclate into new food containers. Especially in an uncontrolled and polluted disposal system of plastic waste many difficulties can be imagined. For example, the requirement of ensuring the traceability of each batch can be challenging. Despite these challenges and time- and effort consuming activities, the new Regulation does provide opportunities for new recycling technologies to enter the market.

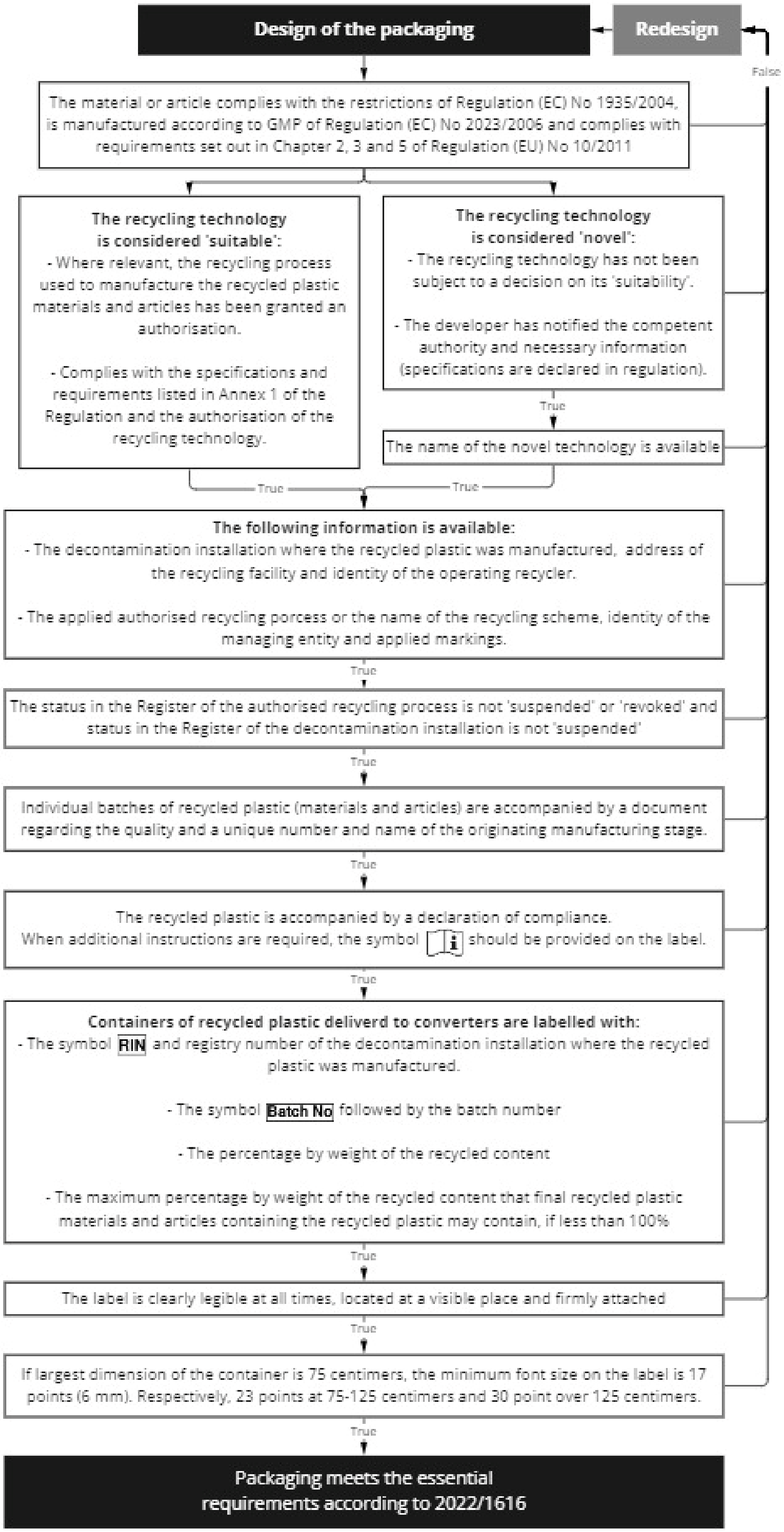

***Figure 7**: Requirements to comply with according to Directive (EU) No 2022/1616*

Directive (EU) No 2019/904

Directive (EU) No 2019/904, commonly known as the Single Use Plastic (SUP) Directive, promotes the reduction of the impact of certain plastic products on the environment. The Directive promotes circular approaches that prioritizes sustainable or re-usable products or systems in a wide context, of which packaging is only one. Only these complying with the scope are discussed in Figure 8.

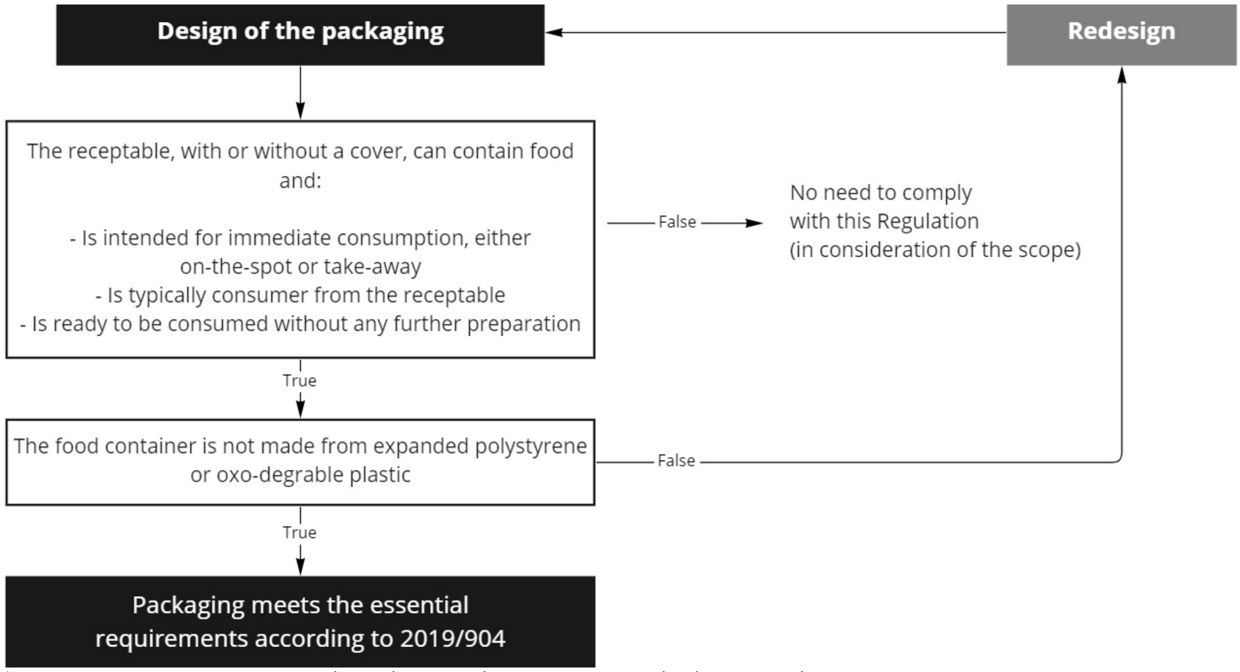

***Figure 8**: Requirements to comply with according to Directive (EU) No 2019/904*

National law: commodities act

Within the Netherlands, rules and regulations regarding food safety are registered in the 'commodities act packaging and consumables' (in Dutch: "*Warenwet*"). It is stated that the product cannot affect the health and safety of the consumers, referring to the food itself but also to the raw materials, production (site) and sales locations. Most rules are derived from the European Regulations and Directives discussed, but some differentiations exists.

Interestingly, within the European law no specific Regulations are found regulating the use of (recycled) PB or glass packaging materials. Within the commodities act, some specific measures are presented for these type of materials, amongst the use of plastics that is in line with the discussed 'plastic law' Regulation (EC) No 10/2011.

Within Article 2 of the commodities act, a list of materials is presented of which the fabrication (of the corresponding raw materials) must comply with the rules presented in Article 3. Similarly to Regulation (EC) 1935/2004 the materials cannot affect the content, exceeding specific migration limits. Specifically for the use of PB and glass materials, a list of accepted raw materials is presented, including specific quantities and origins - similarly to the regulations for plastics in No 10/2011. Thus, when creating a packaging solution for the Dutch market, this commodities act should also be checked.

2.2.2. Legislations concerning recycling

There is one important Directive concerning the recycling of (packaging) waste, which is important to discuss. Since, this assignment aims to present an honest view on the future of packaging materials and end of life scenarios comply with the scope. Hence, Directive 94/62/EC [45], amended by Directive 2004/12/EC [46] and Directive 2005/20/EC [47] will be discussed.

Directive 94/62/EC

Directive 94/62/EC lays down measures aimed to (a) prevent the production of packaging waste; (b) reuse packaging; (c) recycle and recover packaging waste; and (d) reducing the final disposal of such waste. From the Directive a set of essential requirements can be derived that packaging designs should comply with, which is illustrated in Figure 9. Moreover, Article 6 illustrates targets where Member States should attain to: a minimum of 60% of the weight of the packaging waste should be recovered or incinerated at waste incineration plants with energy recovery and 55-80 percent of the total weight of packaging materials should be recycled. Lastly, the following minimum recycling targets for materials should be attained:

- Glass 60%
- PB: 60%
- Plastics 22,5%

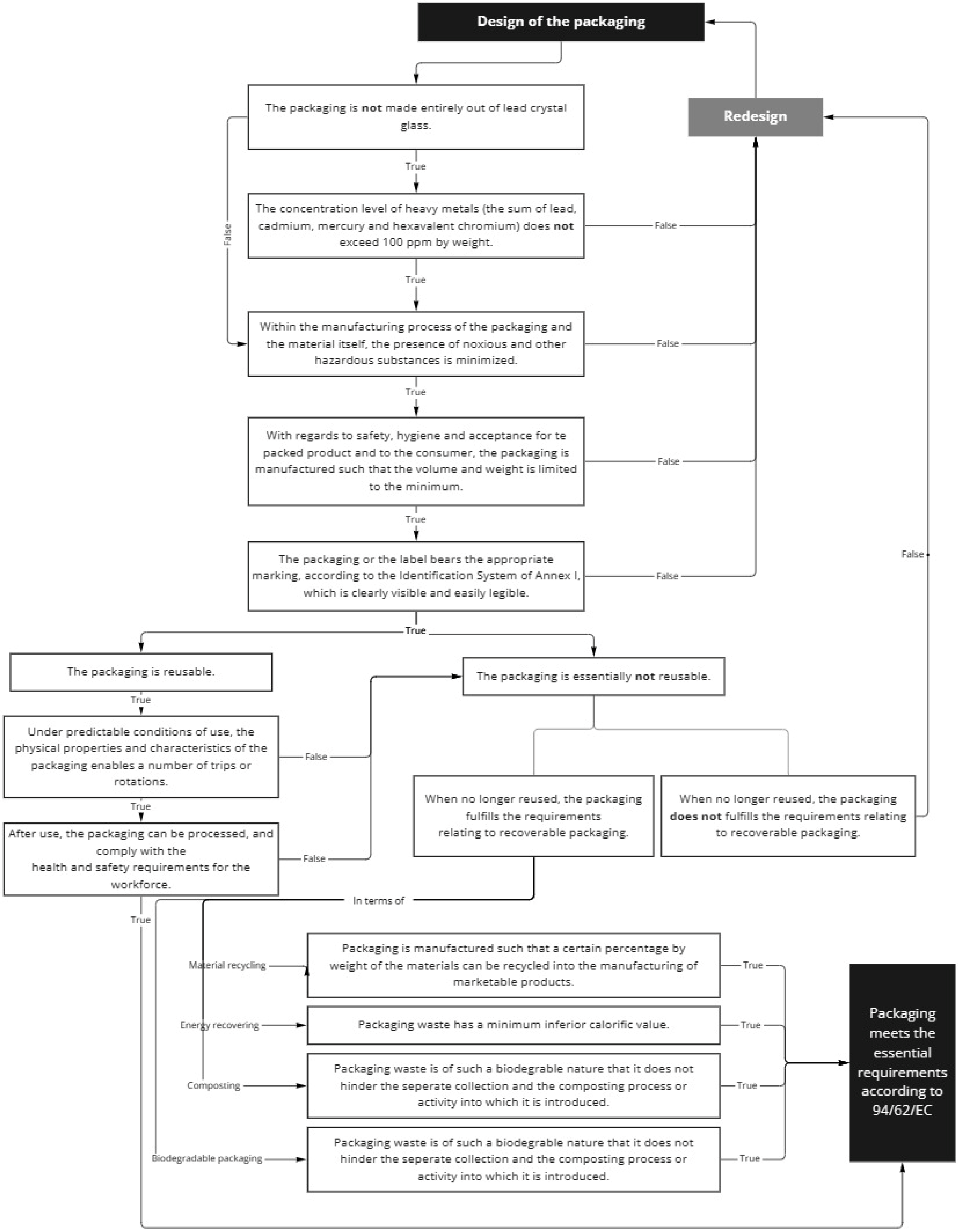

Figure 9: Requirements to comply with according to Directive 94/62/EC

How may food safety packages be designed according to the rules and regulations that are currently present in the European Union?

When designing packages that are intended to come into contact with food, they should be designed according to the Regulations as illustrated in Figure 10. The European Law is accessible via the website of EUR-Lex [48] in which each Regulation and Directive can be found. All restrictions applicable to the scope of the assignment were presented within this chapter and should be complied to, when designing a packaging that comes into contact with food.

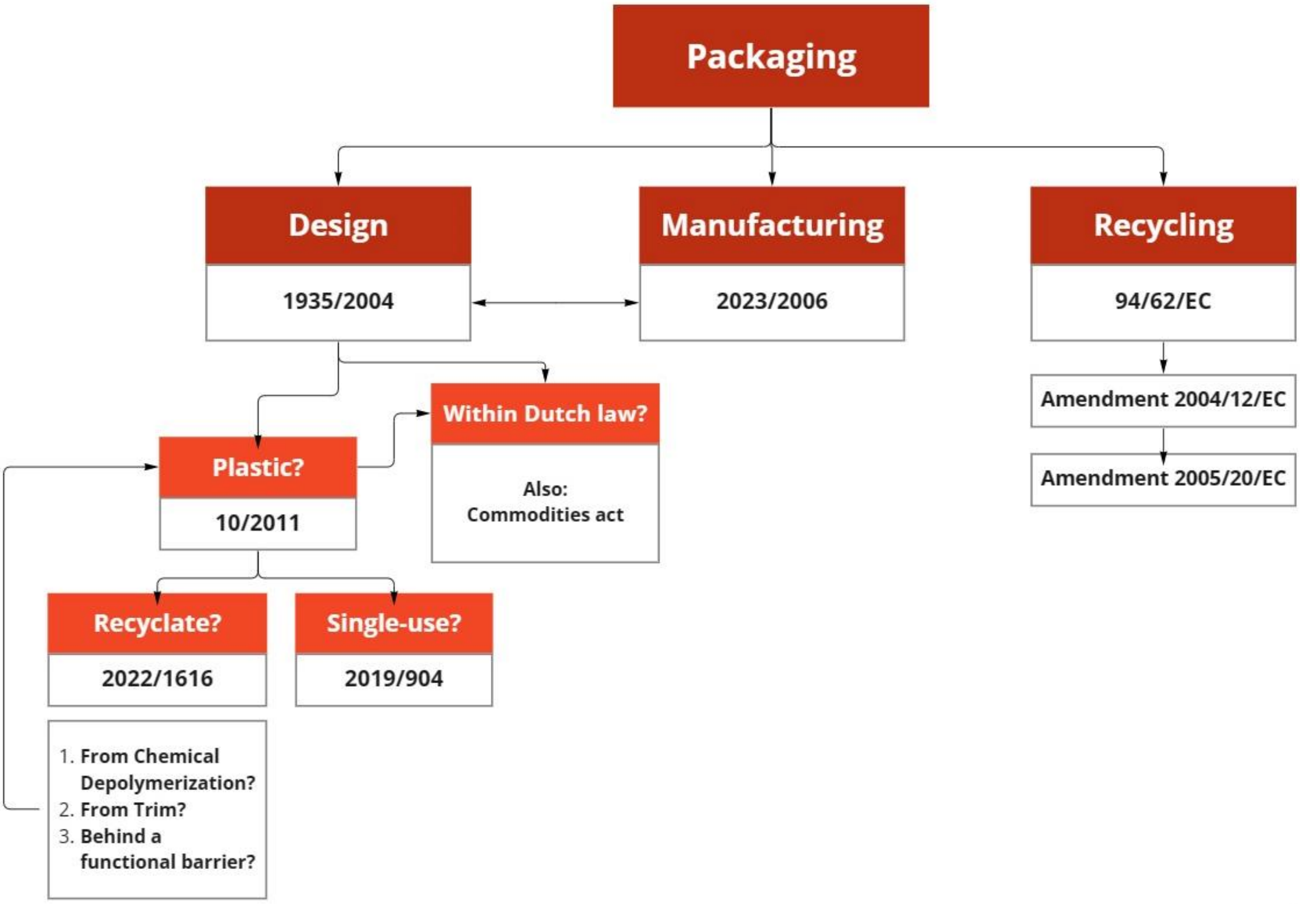

Figure 10: Regulations and Directives to comply with when designing food contact packaging

What should be taken into account when designing for food safety packages? Which design restrictions results from this?

When designing food contact packaging, the requirements resulting from the Regulations and Directives discussed in this chapter should be taken into account. These are summed per Regulation individually such that a (future) design can be checked following the schematic representations of the requirements presented in Figure 3-9. Please note that only the restrictions, in consideration of the Scope and those that apply to the design or manufacturing stage have been accounted for.

2.3. PRODUCTION PROCESSES

The production, use and disposal phase cover the life cycle of any arbitrary product, as simplified in Figure 11. Recovery solutions such as recycling can be added to the life cycle in order to benefit the environmental impact. Within this section the production process of the packaging solutions made from PB, glass and plastics will be discussed, aiming to answer the second sub research question:

How are food containers currently being produced?
Which insights does this give in terms of possibilities and constraints?

Figure 11: Roadmap of steps illustrating the production, use and disposal phase of a product-packaging combination

2.3.1. Paper & Board food containers

Before discussing the production process of PB food containers, it is important to be familiar with the consistency of the material. The recycling of PB is embedded in the Dutch system and this reflect in the amount of recycled content used in the creation of new product. Sources present that an average of 82 to 86 percent of the created paper and board in the Netherlands consists of recycled PB materials [33], [34], [49]. PB materials can be recycled around 7 cycles, before the fibers become too short [34]. However, within the production of PB food containers this percentage is expected to be lower, due to the desired material properties and rules and regulations to comply with. Together with the 'virgin' pulp, consisting of wood fibers and water, the pulp creates the base for new PB products. The pulp has a share of around 99% water, towards 1% wood fibers [49]. In the end, the material consists of an average of 15.2% non-fibrous material additives [33]. Though, as can be imagined, this amount variates much over specific product categories.

Within the production of PB food containers additives are most commonly necessary to create, amongst others, a strong moisture barrier. This results in a higher percentage of non-fibrous material additives of which examples can be found in clay and calcium carbonate as filling or coating, or starch to strengthen the paper [33]. It is also possible to add other materials, such as plastics or aluminum, to strengthen the moisture barrier or add barriers against gasses, fats or aroma's [33].

The paper cycle in the Netherlands can roughly be described among five consecutive processes: the PB production, PB processing, B2B use, consumer use and collection of old paper. A representation of these steps is presented in Figure 12.

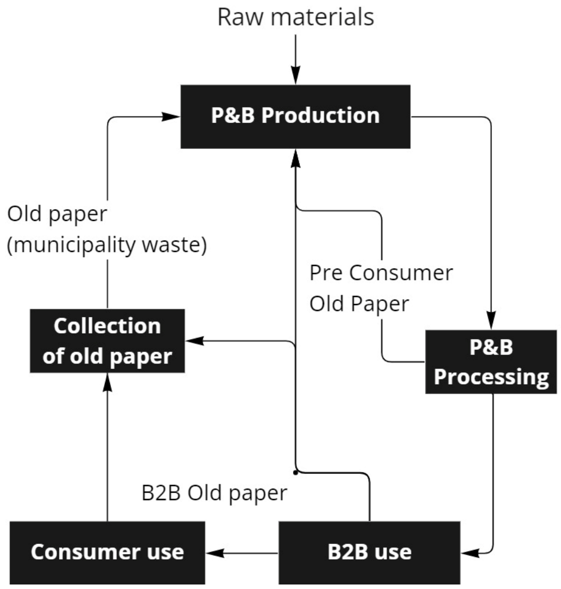

Figure 12: The PB cycle in the Netherlands, described among five consecutive processes

Before the material is converted into a food container, the material itself needs to be created, which is done in respectively the PB production and processing phase. A more in-depth version of these phases is presented in Figure 13. As illustrated in Figure 13, a set of consecutive steps needs to be performed in order to produce PB materials that are ready to be used as food-contact materials. It should be taken into account that on top of the conventional steps, presented in Figure 13, additions will be made to create a material that is resistant to, amongst others, the moisture of fresh food. Depending on the type of barrier that is added, the shelf life of the food can be prolonged.

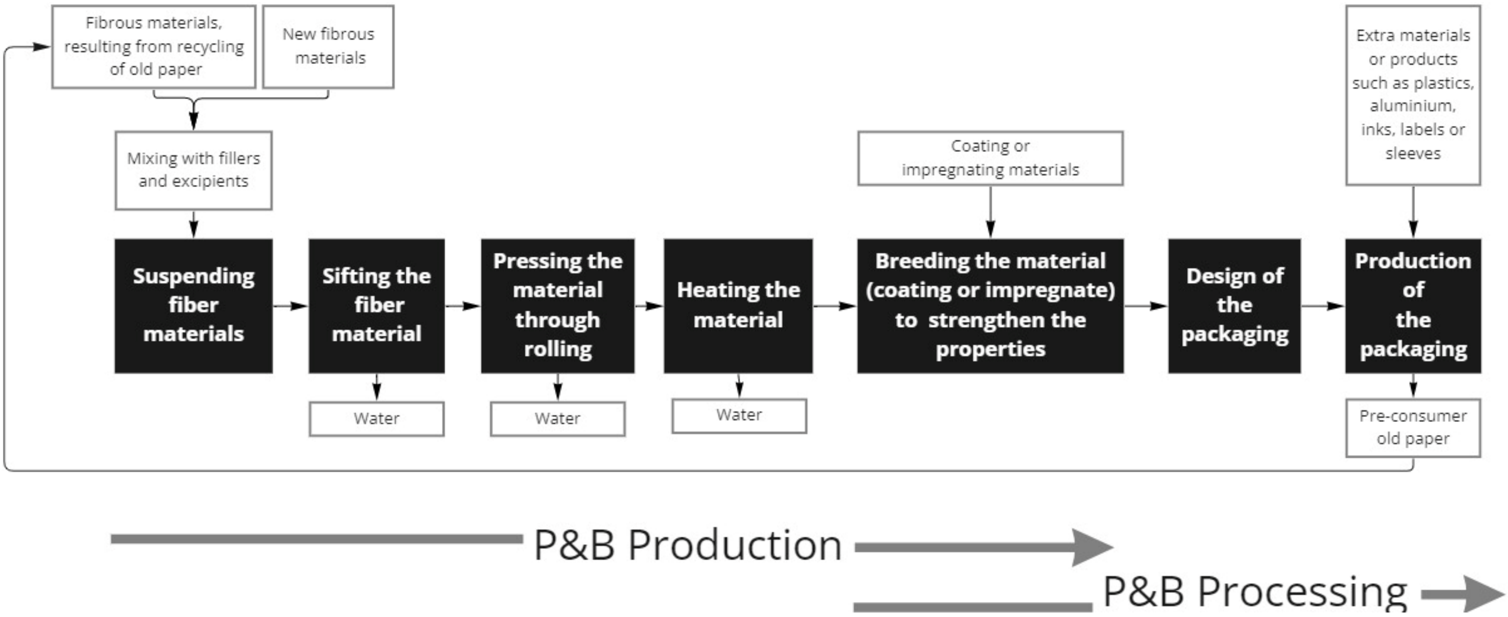

Figure 13: An in-depth view of the PB production and processing phase of the PB cycle in the Netherlands

2.3.2. Glass food containers

As discussed, within the glass industry high recycling rates (up to 90% [38]). Specifically for glass, the use of so-called 'shards' offers many benefits in the manufacturing of new packaging solutions and is embedded in the system. Within chapter 2.4.6, more information will be presented about the effects of using shards, while discussing the numbers and facts for the Dutch glass industry.

Within the production of glass packaging solutions, three common production methods can be described: either based on 'blowing', "extrusion" of tubes or "pressing" the heated glass [35].

Most common is the process of blowing, in which two production processes can be distinguished: blow-blow molding or press-blow molding. In both cases, the packaging is molded by blowing the heated glass, shaping and cooling it. Within the shaping process a preform will be made, followed by a form in which the definite model is created. Figure 14, presents an illustrative figure of the consecutive steps of both processes, retrieved from 'Zakboek Verpakkingen' [35]

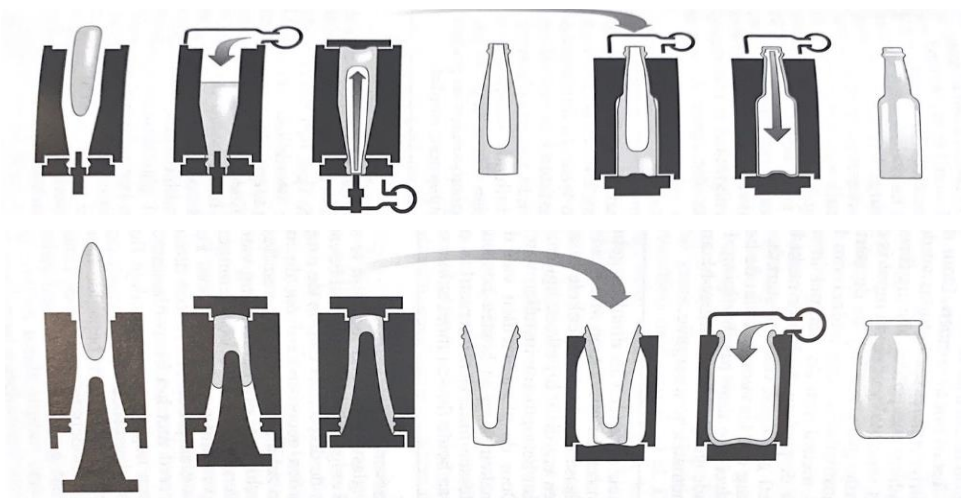

Figure 14: Consecutive steps of blow-blow molding process and press-blow molding process, retrieved from [35]

The second method of tube extrusion is known for the application of thin and respectively long packaging solutions as, for example, ampoules [35] that does not match with the scope of the assignment. Lastly and less common is the process of pressing heated glass. However, applications can be found in small bowls and containers used for the packaging of, amongst others, sauces and desserts [35] fitting the scope of the assignment. It is described as a method in which heated glass is dropped in a specific shape, resulting in the bottom part and side walls of the packaging [35]. Subsequently, a mold will press the viscous mass into the definite packaging shape. The packaging will be cooled and released from the mold. As with any method, the glass will be heated and cooled controllably in order to reduce tension.

To maintain, and perhaps enhance the mechanical properties and the processability of glass, a coating can be added: either hot-end or cold-end coating [35]. Hot-end coating is used to reduce the loss of strength through the addition of tin- or titanium oxide. Cold-end coating is used to make the material more smooth, resulting in a lower chance of damages in the following steps [35].

Glass should have a minimum wall thickness of two millimeters, but depending on the production process, application and design this thickness variates. Although, the weight of glass has been reduced by an average of 30% in the last 25 years [37] it is still a heavy material compared to others, resulting in environmental effects.

Although the packaging and material themselve offer great opportunities in terms of sustainability, in the creation of glass packages high shares of fossil fuels are needed. In the current glass industry no renewable fuels and an estimate of only 10% renewable energy is used, as alternatives in fuels and applicable machinery are not available in these shares [37].

2.3.3. Plastic food containers

Within the industry of plastic food containers, a lot of differentiations can be found: either in materials, shape and corresponding production processes. As formerly declared, within plastics in this assignment the focus will be on PET. Using this polymer type in the creation of food packages, multiple production processes can take place, of which 'thermoforming' is only one. Within the production plant of Hordijk, this process is commonly used in the creation of PET containers and will therefore be discussed.

As illustrated in Figure 15, the process starts with the extrusion of (a combination of) materials. As declared in Section 2.2, the (recycled) materials have to comply with a set of rules and regulations.

Depending on the specific recipe, the foil is created by an extrusion process. Within this process the material is heated and pressed through a rolling surface, in order to create a thin foil. Interesting in this extrusion process is the addition of anti-block materials, in order to reduce the static properties and help separating the plastic products from each other. Moreover, a so-called A-B-A layer can be created, in which the outer A-layers represent the functional barrier of virgin material enclosing the B-layer representing the recyclate.

Although it is common for Hordijk to store the foil, in theory the foils can immediately be brought to the thermoforming machines in which the shape of the eventual packaging solution is created.

Within the thermoforming process, heat, vacuum and pressure are used to translate the foils into three-dimensional shapes, depending on the mold. Initially, the foil is heated again, resulting in a elastic material that can be stretched over/in a mold. The material is pressed and cooled into the mold, after it is trimmed, so that the product takes it final forms. The trim is shredded again and brought back to the extrusion process for new input material. Depending on the size of the mold and shape of the final product, an average of 45% excess material is present in the manufacturing plant of Hordijk. The packages roll down the conveyor belt and are checked, stacked, color-coded in bags and stored in baskets ready to be delivered to the customer.

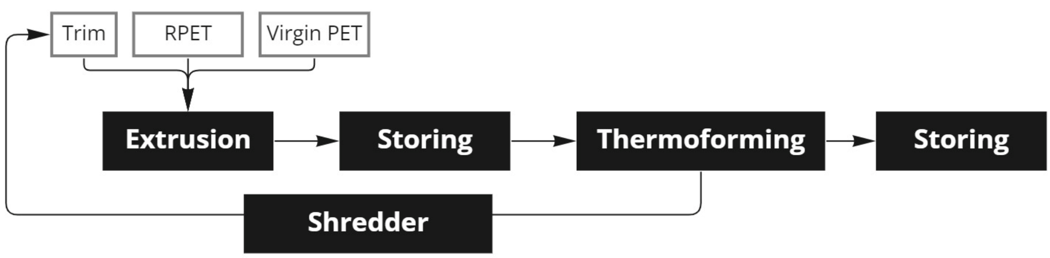

Figure 15: Simplified version of the production process of PET food containers at Hordijk

How are food containers currently being produced?
Which insights does this give in terms of possibilities and constraints?

Logically, differences exists in the common production processes for PB, glass and plastic food containers. As could be seen in all production processes, the possibility to use recycled content is quite embedded in each system. Hence, this section cannot stand on its own and more research should be done regarding the recycling of each material and respectively the use of recycled content. Especially, since the implementation of recycled content is an important aspect of all production processes. It is important that the effects and drawbacks of using recyclate are researched, amongst the recycling system and application of recyclate. Only this way, necessary numbers and facts regarding the use of recycled content and the implications in each system will become clear. These are necessary to conclude true insights for the LCA, answering the second part of the research question. An answer to this research question will therefore be discussed at the end of this chapter.

Still, the production of food containers in the Netherlands can be subdivided among the various materials and applications and knows different methods within each material type as well. However, a set of consecutive steps covering all methods can roughly be illustrated, as presented in Figure 16.

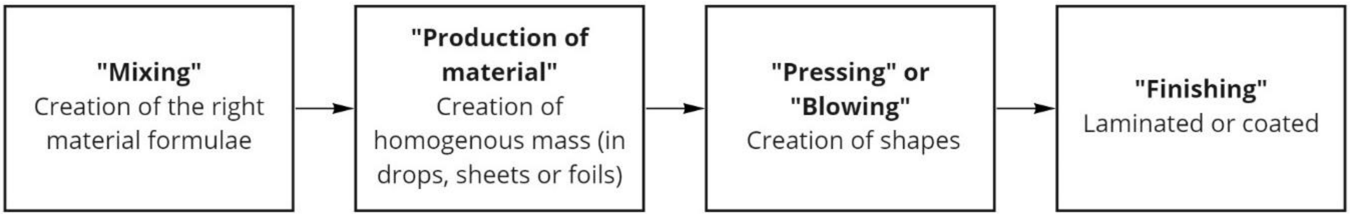

Figure 16: *Illustrative presentation of the consecutive steps describing the production process of food containers*

It should be taken into account, that within the production of each material solution specific characteristics cause important effects. To illustrate, in the production of PB no extensive heat is used, which can result in a lower energy consumption, compared to the production of plastics and glass. On the other hand, plastic is a very light material and very little amounts are necessary in order to create similar results, compared to PB alternatives. Moreover, with plastics and glass mono-materials can be used for the application of fresh food, which is not possible for PB solutions resulting in an extension of the process. How these differences reflect in specific numbers, will be discussed in the LCA (Chapter 4).

2.4. WASTE MANAGEMENT AND RECYCLING SYSTEMS

Besides the production process, the end-of-life scenario should also be taken into account, when designing a sustainable packaging solution. It is desired to become familiar with the waste management and recycling systems of packaging solutions, that comply with the scope. Moreover, it should become clear how recyclate can be used in new packaging solutions in order to create circular systems. All in order to answer the research question:

How are food containers currently being recycled?
Which insights does this give in terms of possibilities and constraints?

2.4.1. Collection and recycling management

Subject to the European Packaging Waste Directive 94/62/EC, recycling schemes for (plastic) household waste have been created within Europe. A common system is one that makes companies (that put packaging waste on the market) financially responsible for the recycling. The Green Dot system, which is active in the Netherlands as well, is a widespread system helping companies executing their responsibilities. Simply said, the companies pay a fee to the Green Dot organization for which they are released to their individual recycling obligation in return. This way, money is available to organize a collection and recycling system in the participating country. Companies paying the fee can put the symbol, presented in Figure 17, on their packaging. The symbol illustrates that that the company has fulfilled the financial obligations.

Figure 17:
The Green Dot Symbol

Within the Netherlands, the Nedvang foundation is the central player between waste funds, municipalities, authorities and businesses (i.e. producers and importers) that are held responsible for collection and recycling of packaging waste. How the Nedvang foundation operates between these players is illustrated in Figure 18. As presented, Nedvang supports municipalities, waste sorters and recyclers, due to the money paid by the packaging companies. The cooperation between KIDV, NederlandSchoon, VP|KT and Nedvang takes care of the complete collection, recycling and sustainability of packages in the Netherlands. One of the supporting attributes is the WasteTool. In this tool, municipalities and over two hundred authorized waste sorters and recyclers register their data with regards to collection and recycling each month (i.e. the amounts and material types). This way, it can be made sure that the municipalities, waste sorters and recyclers get their compensation and true collection and recycling data is available. This data, for each specific material type, can also be found in other literature and sometimes variates depending on different factors. The most relevant sources are presented in Table 1. For each source, per material type, the recycling percentage with specific remarks is mentioned. Within section 2.4.3, 2.4.4. and 2.4.6 more information regarding the number and facts of waste collection and recycling in the Netherlands will be discussed.

Percentage	*Date*	*Source*
Plastic packages		
50	*2017*	[50]
56	*2017*	[51]
50	*2019*	[31]
54	*2019*	[52]
66	*2020*	[52]
PB packages		
87	*2017*	[50]
87	*2019*	[33]
90	*2019*	[52]
90	*2020*	[52]
Glass packages		
86	*2017*	[50]
88	*2019*	[52]
90	*2020*	[52]
On average – packages		
78	*2017*	[50]
80	*2019*	[52]
82	*2020*	[52]

Table 1: Overview of different recycling percentages

Waste hierarchies

There are various ways to recover packaging waste for the fresh food industry. Logically, each method has its pros and cons when it comes to sustainability and different applications. Within the following sections two common principles will be discussed. First of all, a ladder regarding the prevention of food waste and secondly, methods about dealing with waste.

Ladder of Moerman

Within Section 2.1. packaging functions were described. In the case of food packaging, protection of that food plays an important role. In essence, packaging needs to contain the food (function one, as described in Section 2.1 [25]). However, packaging can also prevents food waste. One way to describe methods in dealing with food waste, is the Ladder of Moerman (Figure 19): a Dutch concept that ranks specific methods in order of preference.

The Drawdown project [53] seeks to help the world reaching the point in time where amounts of greenhouses gasses in the atmosphere are not increasing, but start decreasing. This moment of decrease is referred to as "the Drawdown". An interesting solution in the report can be found in the reduction of food waste as it immediately takes care of 85% indirect (i.e. less deforestation and more biodiversity) and 15% direct (i.e. production-distribution-consumption) pollution. Looking more thoroughly into food waste, in the Netherlands an average of two billion kilograms (1.5 to 2.4 kiloton) of food is wasted annually [54]. It is explained that this number comes down to (an estimate of) 34.4 kilograms per person per year.

Meaning that consumers contribute to the pollution along the entire chain by 23 to 32 percent [29]. That having said, the consumer has the highest share in this pollution. Keeping into account that food containers offering convenience to that same consumer, it has yet become more important to find a true answer in what is actually the most sustainable packaging solution.

Though, on the bright side, only 1.6% of the food (in kilograms) offered by the Dutch supermarkets did not end up in consumers households, in 2020 [55]. Within the research only the last three phases of the ladder of Moerman comply to the stated 1.6%, since re-using or converting the food has been left beyond the calculation. Still, this is a reduction of 3.6% compared to numbers of 2018, presenting a positive flow in the prevention of food waste. Although food is still bought and

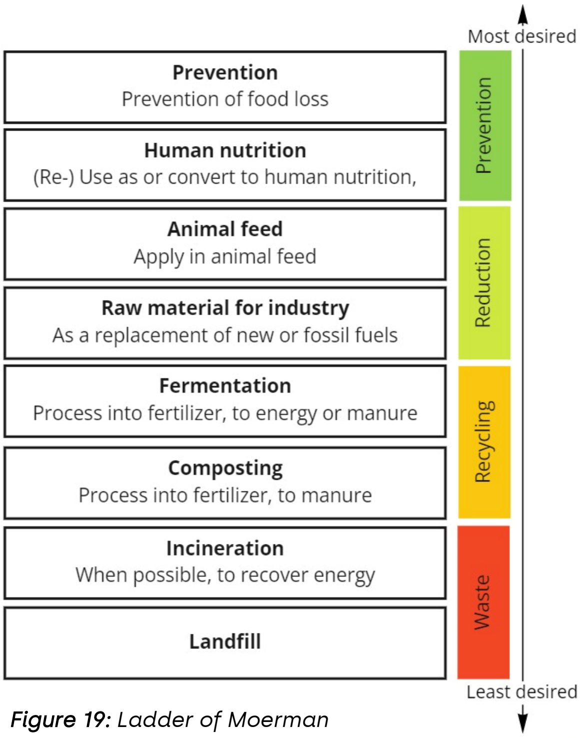

Figure 19: Ladder of Moerman

wasted or spilled within households, high numbers of waste can also be found in the hospitality industry, care institutions and businesses.

Despite the bad reputation of plastics ([7], [31]), plastic packaging offers promising results in extending the shelf life of food [2], [31], [56]. From this perspective packaging can prevent food waste and be seen as more sustainable, compared to alternatives where no or other packaging materials are used. Of course, the packaging itself creates waste as well, which should be weighted against the environmental effects of food waste. This is done in multiple Life Cycle Assessments [57], [58], from which it can be concluded that the effects of packaging waste are significantly less than those of food waste.

The numbers presented by the Dutch source "Samen tegen voedselverspilling" and the Drawdown project, together with the ability of (plastic) packaging to prevent food waste, presents a conclusion that packaging should not be seen as a cause environmental impact. Rather, it is a helpful tool in order to reduce food waste and hence climb up the Ladder of Moerman.

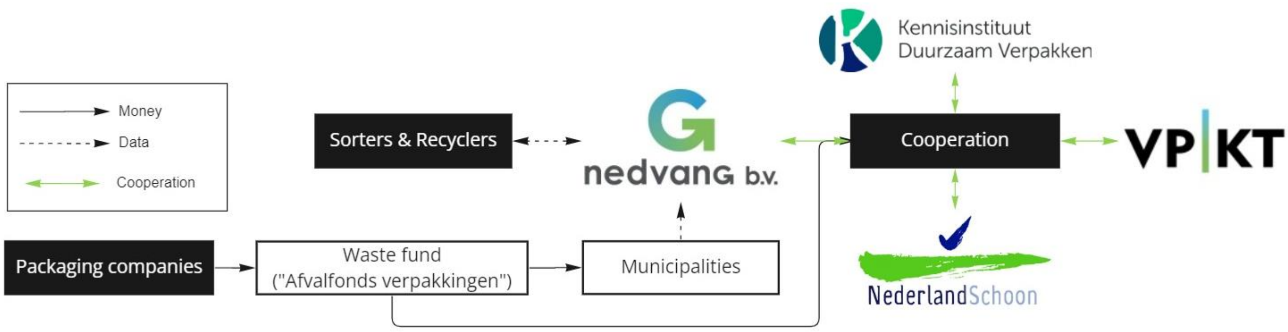

Figure 18: Schematic overview of Nedvang operation

Ladder of Lansink

One way to describe preferred methods in dealing with waste, is by using the Ladder of Lansink. The Dutch politician A.G.W.J. Lansink introduced this order of recovery and waste solutions in 1979. Later, it is adopted within the European Union and altered several times to the current Ladder presented in Figure 20.

The highest priority should be given to the prevention phase 'reduce', followed by (the highest quality in) 're-use' and 'recycling'. When these options are not possible, energy recovery in the incineration process should be aimed for. Otherwise it is only possible to deposit the waste as 'landfill', which should definitely be the least desired solution.

With reduce, qualitative as well as quantitative prevention is meant. Here, the creation of waste is avoided or extremely limited as (raw) materials are used in the production or preparation. Or, other products are used, that limit or do not cause adverse effects for the environment. With re-use, the materials, preparations or other products are used again, after the initial handling. In recycling the same held for the (raw) materials of which a product is composed of. When the 'green' (according to the ladder, Figure 20) solutions are not possible, the product should be incinerated. Incineration is a method of burning waste materials. In some cases it is possible to generate energy (i.e. heat or electricity) from the (mixed) waste materials. Composting organic waste or biomass waste to generated power also applies to the 'energy' step. Lastly, there is a possibility for landfill, in which the waste will buried in the ground. It is the least favored option due to the heavy polluting consequences and should be prevented in any case.

Figure 20: *Ladder of Lansink*

2.4.2. Recovery of packaging waste

Figure 21 presents common options to recover packaging waste in the Netherlands. Within the remainder of this section each recovery solution will individually be discussed.

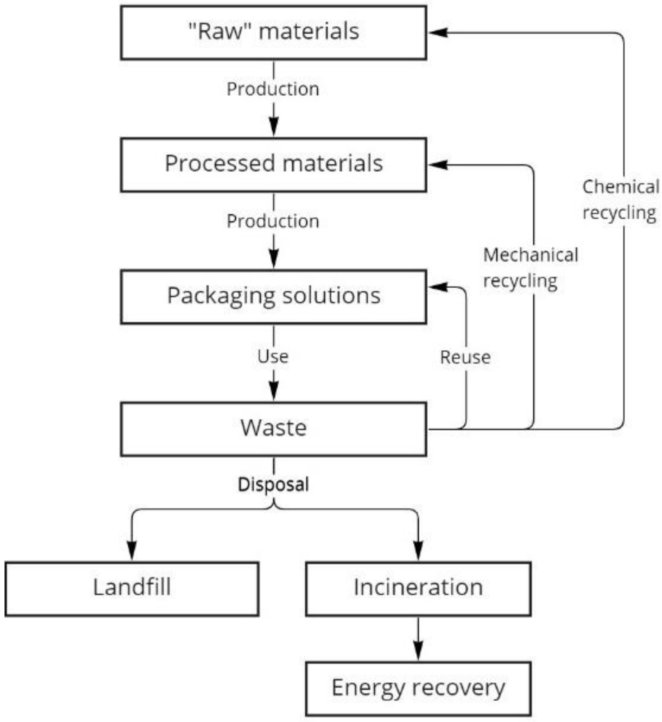

Figure 21: *Recovery options of packaging waste*

Reuse

As described by the Ladder of Lansink as well, reusing packaging materials has one of the highest priorities in recovering packaging waste. Regarding the scope, the process of reusing commonly takes place within the household. Also in the case of packages that are designed for a single-time use, reuse can take place. As it is ranked high upon the Ladder of Lansink, the process of reusing should not be forgotten when comparing materials. Especially, in the case where products are designed for a single use, but are commonly reused before thrown away. Since, in these cases the environmental effects can significantly be different in practice than theory as other assumptions are made. To illustrate, glass packaging used for desserts, illustrated in Figure 22, can be seen as a single use product. However, after cleaning the material the container can, and probably will, be reused multiple times within the household.

Figure 22: *Glass packaging for desserts*

Mechanical Recycling

Officially, the term mechanical recycling is used for the process of plastic waste recovery into secondary raw materials or products, where chemical compounds are not broken down [59]. However, in general it can also be stated that the presented recycling system of PB and glass are mechanical recycling system as they comply with the same terminology.

Around 79% of all packages in the Netherlands are being recycled [60], which is mainly due to the high collecting and sorting rates, increasing yields and embedded mechanical recycling systems. Although mechanical recycling is embedded in the Dutch system, it has the drawback that it cannot assure that plastics can be recycled infinitely and simultaneously, toxic additives can be filtered [1]. Mechanical recycling requires a respectively high quality sorted, reliable and quite consistent input [61]. However, pollution, especially in the industry of recycling food packages, can disrupt this input resulting in lower yields or quality loss [61].

Each (mechanical0 recycling system will be thoroughly discussed in Section 2.4.4. However, it is important to be aware of the advantages of mechanical recycling in general. Decades ago, a major share of the waste in the Netherlands was being incinerated or ended in landfills [59]. As can be derived from the current and increased recycling rates, the industry of sorting waste and translating it to secondary raw materials – either for higher or lower quality applications – offers potential. It is therefore important that industries keep motivated in innovating their business to create higher yields and qualities.

Chemical Recycling

In addition to the more common mechanical recycling processes, there is potential for chemical recycling technologies, e.g. chemical depolymerization, to contribute to PET circularity [62]. Chemical recycling techniques are only common in the plastic recycling industry and are currently being implemented in the Netherlands [61]. Moreover, major advantages can be found in the ability to recover more mixed and polluted waste streams. Compared to mechanical recycling processes, chemical recycling has the ability to recycle polluted waste streams into high quality recyclate [61].

Chemical recycling is also referred to as "feedstock recycling" as it has the purpose to translate the waste into raw materials that are chemically identical to virgin materials [63]. Within the process, the chemical structure of the polymer is interchanged and converted to chemical building blocks [63]. From these building blocks, such as renewed monomers, polymers can be created once again. In order to reach the chemical structure of the material, multiple processes that "break" the material should be performed, such as pyrolyze, solvolyze and depolymerization [63], as illustrated in Figure 23.

In order to accomplish the desired recycling rates of the Plastic pact [10] new technologies and innovations should accompany mechanical recycling systems in the Netherlands. One promising way is the implementation of chemical recycling. Not only because extra recycling sites enlarge the scale, the quality of the recyclate can be guaranteed and less impurities are expected. Moreover, it offers the ability to recover the packaging waste that is currently not mechanically being recycled and hence incinerated, creating profound environmental benefits.

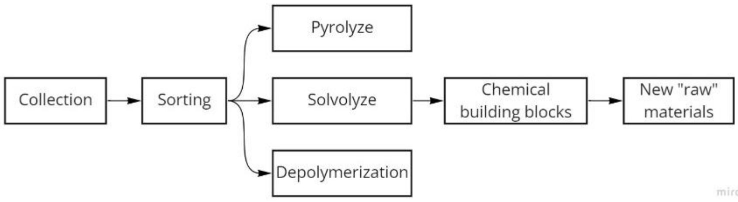

Figure 23: Consecutive steps of chemical recycling

Landfill

Although landfill is displayed as a recovery method, it is actually a method of 'disposal'. Since, a packaging can be disposed off either via incineration, landfill or recycling. To be able to stimulate sustainability goals, only processes within the recycling chain can be accepted. Moreover, landfill is prohibited within the Netherland, resulting in energy recovery via incineration when waste cannot be recycled [50].

Incineration and energy recovery

Of course, it should always be the intention to truly recover packaging waste and preferably, translate into materials that can be used in the creation of new applications. Even when the quality is reduced and downscaling is necessary. Only this way a circular economy can be achieved. However, in some cases waste cannot be sorted properly or the stream is polluted in such a manner that incineration is the only recovery option possible.

The yield of energy recovery variates per material type, affecting the environmental impact of the incineration per material type [64]. Within incineration plants, it is estimated that averages of 15% electric yield and 28% thermal yield are recovered [64]. Depending on the material type, Table 2 presents the net climate impact (the sum of the (avoided) emissions) in the first column. The second column illustrates the difference of recycling the material, compared to incineration of the material with municipality waste. Negative values present a net climate gain as the avoided emissions are higher than the emissions themselve.

Material	System	Net climate impact (kg CO2-eq)	Difference
PB	Energy recovery Recycling	-400 -400	- 0
Plastics	Energy recovery Recycling	1730 -780	- -2510
Glass	Energy recovery Recycling	40 -130	- -170

Table 2: Overview of net results and the difference to incineration of the material in an incineration plant [64]

It can be concluded from Table 2, that especially in the case of plastics, recycling is desired over incineration with energy recovery, as there is a significant difference in net climate impact. A difference is also present at the recycling of glass, but the impact is, compared to plastic, significantly small.

2.4.3. Waste streams

Within the Netherlands, separate waste streams can be found for, amongst others, PB, plastics and glass. Moreover, each household can dispose mixed waste within a separate steam, that can be sorted mechanically in recycling system as well. Information about the recycling of these separate streams is desired to become familiar with the waste management of each material type.

Recycling and waste stream of Paper and Board

There are different routes that lead to the recycling of PB. First of all, a distinction can be made between pre-consumer (66% [33]) and postconsumer old paper. In controverse to the commonly known origin of pre-consumer old paper, the 34% postconsumer PB materials [33] have an unknown origin, variating composition and pollution. This results in many difficulties for the recycling system.

The recycling of PB waste basically comes down to recovering wood fibers that can be used in the production of new paper products again. The ability to actually use this recyclate (i.e. recovered fibers) in new packaging solutions, is depended on the preceding life cycle of the (packaging) material. One of the importance's is the recyclability of the disposed packaging, that can be influenced by maintaining the 'design for recyclability' rules, to be discussed in Chapter 2.4.5. Still, there is a limit in using PB recyclate in new packaging solutions. Since, fibers cannot be recycled endlessly and every cycle has impact to the mechanical and chemical properties of the fiber. Hence, a certain downcycling of individual fibers is present and new fibers needs to be added in the production when a proper quality PB is desired [33].

The recycling of paper basically comes down to pulping (i.e. fiberizing) and cleaning the sorted old paper. In the pulping process a bale of old paper is rotated and grinded in the surrounding of warm (in between 15-65 degrees Celsius) water and optionally, chemicals [33]. Depending on the pollution of the old paper, the fiber mush contains all sorts of contaminants, such as laminates and food waste. Hence, other sorting steps follow in which contaminants are sieved from the fiber mush. When a recyclate of homogeneous color is desired, inks needs to be removed in the recycling process as well. This can be done by a process called floatation. With the use of chemicals, air bubbles can be created in the suspension that stick to ink particles and together come to surface [33]. From this position the inks can be separated from the mush and processes of bleaching, with for example hydrogen peroxide, ozone or other chemicals, can take place [33]. Within figure 24 a illustrative explanation of a PB recycling process is presented.

Recycling and waste stream of glass

Within the Netherlands high recycling rates are present for the glass industry. The separate recycling system for glass, via shared collection bins in municipalities, exists over forty years in the Netherland and is hence embedded in the system of consumers [37]. This reflect in the high recycling rates of around 86-90% [38], [65]. Next to the separate waste stream, a small amount of glass is also sorted from the mixed municipality waste stream. Although this amount will not be used as shards in the production of new packaging glass, it can be repurposed [37].

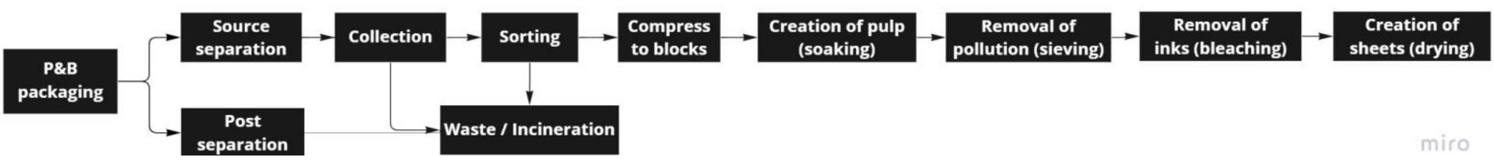

Figure 24: Representative figure of PB recycling process

In controverse to PB packages, glass can be thrown in the separate waste stream while not being "clean and dry" and thus, containing some food waste. Most commonly, recycling system have an installation in which organic material will be burned, resulting in a relatively clean stream of shards [66]. The ease of disposing glass with some food waste, results in a convenient return system for the end consumer, in which high recycling rates can be maintained.

Of the high recycling rates, discussed above, also a high number of recyclate can be used in the production of new glass. However, some interesting effects should be taken into account, such as the discoloration and possibilities to interchange the color. The application of recyclate in new glass packaging solution will more thoroughly be discussed in Chapter 2.4.6.

Recycling and waste stream of plastic

Within the Netherlands, plastics can be disposed of in the "PMD" waste stream. Freely translated, this abbreviation refers to 'Plastic bottles and containers', 'Metal packaging' and '(Drink) beverage cartons'. Plastic has the highest share of about 83.3% in this waste stream, followed by 5.6% metal and 11.1% beverage cartons [67]. More specifically, 61% can ben devoted to plastic packaging of which the other share is covered by, amongst others, the collecting bags that are also made from plastics (3%), non-packaging plastics (9%) and plastic contaminants (2%).

However, in specific municipalities in the Netherlands, no separate PMD waste stream is available in households. These municipalities are covered by a system in which the PMD fraction is mechanically sorted from the mixed waste stream, after collection [68]. In these post separation systems, the different polymers can for example be separated by the use of infrared [68]. Anyhow, in both pre- as well as post separation systems, the recycler will recover the waste in recyclate. With the use of new techniques, an increasing amount of recyclate is generated over the past years, which will be discussed in Chapter 2.4.6. A generalized view of one of the recycling techniques in the plastic industry is presented in Figure 25.

Different numbers about the recycling of plastics exist. Around 250-300 kiloton plastics per year are being recycled in the Netherlands [1], while producers of plastics bring circa 2000 kiloton to the market (2018). However, it is also demonstrated that only 56% of the plastic packages in the Dutch households can be recycled 'good' and respectively 6 and 10 percent are 'not ideal' or 'only recyclable in the near future' of five years [51]. Other sources presents that the amount of plastic packages that are recycled equals 50% [50].

Anyhow, more than a quarter of the packages brought to the Dutch market are not, or can not properly be recycled and often disrupt the process [51]. Although this number is, especially when compared to the recycling rates of PB and glass, quite high, it can be declared by some unique properties of the recycling system. First of all, plastic is a collective for different types of polymers, resulting in a complex recycling system. A wide range of shapes, colors and labelling techniques exists in the plastic packaging industry, resulting in sorting dilemmas. Especially, when multiple layers or combinations of different polymers are in use within one single packaging. Also, a lot of pollution can be expected within the system due to the high application of plastic in food packaging. In controverse to the separate waste stream for PB, plastics may be thrown away with food waste [18]. In controverse to glass recycling, sorting steps are necessary to decrease the influence of pollution on the quality of the recyclate. This also declares the respectively high (13%) share of good recyclable products that is found in the Mix sorting product [51].

Important aspects that needs to be taken into account when discussing the recycling of plastic, are pollution and disruption of the process. Although the sorting yield has increased in the last couple of years, the purity of the sorted waste has decreased [69] which should be taken into account for the creation of useable recyclate.

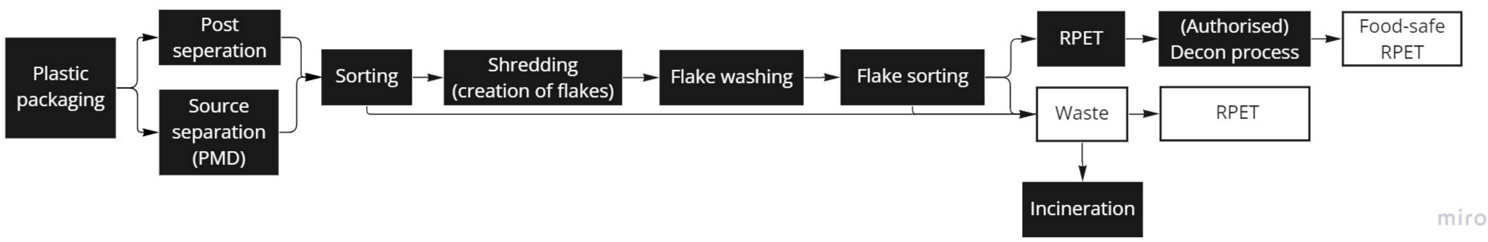

Figure 25: A generalized view of the recycling system of plastic within the Netherlands

2.4.4. Design for Recycling

To improve recycling rates, as discussed within Chapter 2.4.3 and 2.4.4, three possible solutions can be implemented [51]:

1. Better sorting
   to produce les Mix sorting product
2. Design for recycling
   to create packages that can be recycled
3. Design from recycling
   Redesigning the recycling technologies

For the *Design for recycling* improvement, the Netherlands Institute for Sustainable Packaging (KIDV) provides a 'recycle check' that supports companies in determining if the (to be) designed package is properly recyclable in the Dutch system. The recycle checks are annually updated and available for packages made from rigid plastics, flexible plastics, paper and board and glass. Designing according these checks supports packages to be recycled in the Dutch recycling system.

In all recycle checks, four conditions are discussed that define a recyclable packaging. First of all, the package should be composed in such a way that it can be collected by authorized waste collectors. The package should be sorted and/or bundled in predefined streams or recycling processes. The material should be able to process and reclaim to a raw material in a recycling process on industrial scale. Lastly, the reclaimed raw material should have an unambiguous composition and can be used in the production of new packages or products.

The recycle checks are intended for the material of each individual 'disposal unit'. In the case where a package has multiple components two options are possible; either the user disposes the packages in one go or separates the parts and disposes them individually. Depending on the situation, the recycle check should be followed for the entire package or an individual component. Of each disposal unit the main component should be determined. The material of the main component determines which recycle check should be followed. When the components are 'easy' (without any tools, such as a scissor, necessary) to separate, each individual component should follow the recycle check individually.

Within the following subsections the Recycle Checks, complying with the scope of the assignment, will briefly be discussed.

Paper and Board

Within the recycle check of paper and board [36] three important restrictions to recycle packages made from paper and/or board are presented. In short, the packaging cannot be a beverage carton, should be disposed within households and is allowed to be collected within the separate stream of paper waste. Moreover, it should be made clear the packaging can be disposed of, dry and clean. The use of laminates, coatings, fillings, additives, inks and obstructing glue should be reduced as much as possible. This also held for the use of other material types. On the other hand the use of cellulose fibers should be benefited. If a packaging complies with all improvements, it is likely that the packaging can be recycled properly.

Glass

Also within the recycle check of glass [70] a list of restrictions is given to recycle glass packages. The packaging cannot be meant for medical products or is in need to be disposed with chemical waste. Moreover the packaging cannot contain clinging ceramics, porcelain, stone, crystal glass, heat-resistant glass, metal brackets, coatings, a full body sleeve (unless it can be easily separated when breaking the glass) or non-glass substances (with the extinction of paper labels). Also, the packaging should be able to transmit light and be made from transparent, green or brown glass in order to be recognized by the system and have no negative influence on the quality of the recycled glass. When complying to all, the packaging can be easily collected and sorted and does not contain any interfering substances. This results in a recyclate of acceptable quality.

Plastic

Lastly, the recycle check of (shape retaining) plastics [18] provides three lists with restrictions. In January 2023 these lists have been updated, which is taken into account for this section. In order to complete the recycling process fully, a shape retaining plastic packaging cannot contain oxo-degradable materials, PVC, PVdC or PETG, elastomers or silicones. Moreover, for the sorting process it is important that the packaging has any other color than black and is has a minimum size of 3 centimeters, with a maximum volume of 5 liters. Cylindrical or conical packages with a volume below 200 milliliters should be compressible. Lastly it is important to mention that the main component is made from PE, PP or PET as other polymers are being collected in the Mix stream.

Labels and sleeves

In the case of packages made from PET, the size and material of the label is the first obstacle to overcome in the sorting process. Since, a label can prevent the main component from being detected, by the Near Infra Red (NIR) Camera. When made from the same material (PET), it can be recycled quite properly. However when made from PE, PP or another polymer, the volume of the packaging and the size of the label is important. When the volume is smaller than 500 milliliters and the label covers more than 50% of the main component, recycling possibilities are limited. The same held for a packaging larger than 500 milliliter, with a label that covers more than 70% of the main component. This also held for metalized labels or labels made from paper. For the size of the packaging it is also import that at least 70% of the total weight is created by the main component.

Interestingly, labels from PE and PP are easier and more accurate to separate from the PET packaging than a label made from PET. This can be done by soaking the label loose from the packaging and separating it from the PET with a float-sink technique in a water bath. Separating a PET label from a PET packaging is done by a wind shifter and other float-sink techniques but has a risk of involving inks in the process. These inks can cause discolorations in the recyclate. Paper labels can also cause pollution or black spots in the RPET when fibers come loose in the washing process and are burned in the extrusion. Double perforation in full-body sleeves is advised to support the customer in removing the sleeve.

Sub-components
Within the recycling process, steps are included to separate the different components from each other. Snap caps made from unprinted PET can be recycled properly, since they most logically will come loose and act as individual components. This also held for printed snap caps. However, they can cause discoloration in the recyclate. When snap caps or lids, pumps or foils are made from PE or PP with a density smaller than 1 g/cm^3, the recycling process is also not hindered. However, when the density is higher or the material is not PE, PP or PET the designer should be aware of some restrictions again. Especially when the materials are not magnetic, very little, included or strongly attached to the packaging it is hard to separate it from the PET and the chance exists that it ends up in the mono stream. This should be prevented.

Adhesives
When using adhesives, it should be ensured that the adhesive does not disrupt the recycling process. In other words, they should come loose from the main component in the recycling process. This is the case when it resolves with hot water (between 60-80 degrees Celsius) or alkali. This also held for hotmelts, at a maximum of 80 degrees Celsius.

Color
Although almost any color PET packaging can be recycled, transparent packages are preferred in the recycling process. If colored PET is mixed with the transparent stream (uncontrolled) discoloration occurs which cannot be undone. The creation of black colored packaging should be limited, as it is hard to detect by the NIR in the current recycling techniques.

Layers
For the recycling process mono-materials, without any coatings or fillings are preferred. A multi-layer packaging is often difficult to separate from mono-materials and hence, end up in the wrong recycling stream. This results in a pollution or discoloration of the recyclate. Depending on the construction of the layers the recycling process is influenced variating from 'not' to 'extremely'.

2.4.5. Using recyclate in packaging

It can be imagined that with the use of recyclate in new packaging solutions a lot of environmental gain can be achieved as, amongst others, less new fossil fuels are needed. Hence, there are many parties [10], [71] that have the ambition to use more recyclate in the products. At first, there is the goal of the European Union to only place packages on the market that are either reusable or can be recycled in a cost-effective manner [71] by 2030. Also, in Article 24 of Regulation (EC) No 1935/2004 it is mentioned that "the use of recycled materials and articles should be favored in the Community for environmental reasons". Moreover, according to the ambition of 75 Dutch companies that signed the Plastic Pact (2019) there is a shared ambition to have an average percentage recycled plastic in products of at least 35% per company. Though, when using plastic recyclate in packaging, the design should comply with the rules provided by the European Regulations, presented in Chapter 2.2. As discussed, tough rules are in force for the implementation of recycled content and the, perhaps, conservative approach results in a difficult challenge for the packaging industry to actually use the amount that is desired.

Paper and board

Despite the high recycling rates of PB discussed in Chapter 2.4.1, PB may only be collected in the separate waste stream if marked as 'clean and dry'. In the case of packaging for fresh food, this is often a difficult measure and most commonly not the case. These packaging solutions will hence end up in the mixed waste stream and eventually be incinerated. Moreover, even when collected in the separate 'old paper' waste stream, packaging solutions for fresh food made from PB most commonly are supported by additives, for example to become moisture and grease resistant. When the amount of additives is too high, or at two sides of the material, the material will have insufficient time to fiberize in regular paper processing systems [33]. As a result, the material will also be separated from this waste stream. From these perspectives it can be concluded that a closed loop recycling system for paper and board packaging solutions for fresh food in the current situation is not possible.

However, interesting insights can be found in the recycling of beverage cartons, as a Tetrapak (Figure 26) that mainly consists of paperboard (around 75% [72]) which is layered with plastic (polyethylene) and most commonly also, aluminum [73]. This consistency is supported by the material composition of fourteen types of beverage cartons that are researched by Wageningen Food and Biobased Research, commissioned by the Dutch government [74]. All beverage cartons in the report mainly consist of wood fibers (67-79%) and PE foil (12-23%). In some packages. A share of aluminum (4-6%) was found and variating in composition also an extra layer of PP foil (if present, 1%). Moreover, shape retaining PE (2-14%) and PP (1-4%) was found in the analysis, which can be declared by the presence of a small cap. In general, the beverage cartons can be described by an average consistency of 74.6% wood fibers, 2.1% aluminum and 23.3% plastics.

Within the Netherlands these beverage cartons and similar applications may be collected within the separate waste stream for plastics as they theoretically, will be sorted out. This selection will be recycled in a separate logistic system where for example an extra rinsing step is taken into account [33]. From the beverage cartons, only the component of wood-fibers is being recycled in the Netherlands. In practice, the true recycling rate of beverage cartons is quite low and for example in the case of Tetra Paks globally estimated around 26% [72]. Within the Netherlands, research [74] presents that already 29.1% of the mass of a bale sorted beverage cartons from the separate plastic waste stream, is adhering moisture and dirt. The recycling rate for Dutch beverage carton is calculated to be around 31%, in 2020 [74]. When calculating the recycling rate for the entire packaging solution, taking into account that the share of plastic and aluminum will not be recycled (conclusively), the actual recycling rate will be lower. Though, when recycling beverage cartons in this system, undesirable hygienic situations can be prohibited compared to the usual PB recycling system, resulting in a promising (recycling) opportunity using PB for fresh food packaging.

Figure 26: Tetrapak, packaging consisting of multiple layers in order to contain and preserve (fresh) food and liquids [73]

Glass

As discussed in Chapter 2.1. and 2.3.2, the use of recyclate – shards – in the production of new glass packaging solutions is highly embedded in the Dutch system. However, there are also some interesting properties that should be taken into account. For example the discoloration and possibilities to interchange the color, when recycling glass. If transparent (white) glass is desired, the recycling system should aim for the collection of high quality sorted white glass without the addition of colored shards as these will cause discoloration. Using highly sorted white shards in the production of new transparent glass, a max of 60% recyclate can be used [35]. Around 40% virgin materials should accompany the recyclate in order to create the desired result without significant discoloration. Since, the addition of metal oxides, can decolorize the material as they add a complementary color. In contradiction to white glass, brown and green glass can be made from up to 80% recycled content [35].

The use of shards in the production of new glass is desired as it reduces the need of virgin materials, but also accelerates the melting process [35]. In case of reducing the amount of virgin material, it is calculated that one ton of shards saves 1.2 tons of virgin materials [37]. Moreover, the use of shards also saves in energy consumption. Compared to the use of purely virgin materials, around 2.5% per 10% shards can be saved, when using recycled shards [35], [37]. It is estimated that this saves 25% energy [65]. Depending on the color of the newly produced glass the following amount of shards can be used [35]:

- White glass: 25-60%
- Green glass: 85-92%
- Brown glass: 70-85%

The spread of using shards, within each category varies due to the design possibilities and also within these percentage, some nuances have to be made. As declared, within the creation of white glass, only sorted white shards can be used in order to create recyclate that is applicable to the production of new white glass. In contradiction, mixed colored shards can be used for the production of green and brown glass of which the amount is depended on the desired end color. Though, high amounts can be reached when the right purpose is found for the use of colored shards in the recycling. For example in the production of beer bottles, the use of 85% shards [37] is not rare, illustrating the circularity of the material.

Lastly, the use of shards reduce the CO2 consumption: when changing a ton virgin materials in shards, 0.6 tons CO2 can be saved within the entire chain [37].

Plastic

As declared before, PET is a thermoplastic resulting in the unique material property of being able to remelt and recycle into new applications [40]. Similarly to glass, PET is fully recyclable and can mechanically be recycled as often as required [14]. However, it is often the case that only a specific amount of recyclate is added into the new application, as it subjected by European Regulations when the origin of the recyclate cannot be guaranteed.

For high quality appliances such as food packaging, a few important impurities of the recyclate should be advanced in order to comply with the demand. This can only be achieved when investments are made in innovation and quality [50]. One of the innovations that is recently implemented is the recycling of PET trays. Namely, diverse sorting installations are currently offering sorted PET trays that are actually selected from pre- or post separated waste streams [50]. This results in a new stream of promising materials that can be recycled into granulate that is applicable to high quality applications such as new food containers.

Also, the European Regulation regarding the use of recycled plastics in food containers should be taken into account, as declared in Chapter 2.2.1. However, with an EFSA approved process, the application of the recyclate in food containers, can be maintained and perhaps, increased. Keeping into account that more PET recyclate becomes available the upcoming years, due to the new innovations of recycling PET trays, it offers potential in creating circularity.

Depending on the share and quality of the recyclate, discoloration of the PET packaging occurs. The waste stream differs anytime, resulting in a granulate that has a grew to brown discoloration. When higher sorting yields are presented, especially when color sorting is extensively applied, the discoloration can be decreased. However, this is a time consuming manner and hence, cost excessive.

2.4.6. Labels and marketing

When walking into a supermarket an entire portfolio of food packages can be found. As the demand of consumers towards sustainability and subsequently recyclability is growing, more and more packages can be found using different labels. This seems logical, as it is demonstrated that the visual appearance of packaging design can influence consumer behavior [75]. More specifically, when two products are being equally identified, sustainability characteristics can determine which product will be chosen [76]. Consumers are even found to be willing to trade product features for environmentally friendly packaging, with the exception for taste and price [76]. This consumer behavior does not only cover the purchasing process, regarding conscious sustainable decisions, it can also influence the sorting waste process after use [75]. It is demonstrated that the decisions of the consumer regarding the packaging are most commonly based on graphics rather than information and form [75]. Moreover, it is demonstrated that packaging should first be perceived as sustainable before the consumer is willing to recycle it.

Although consumers are able to comprehend ways to achieve greater sustainability in packaging design, intuitions of consumers are found very inaccurate and sometimes even the opposite of life-cycle assessments [24]. Consumers are for example able to distinguish recyclable, reusable or the use of renewable material sources [77]. On the other hand, consumers rank a bioplastic pot first regarding sustainability, while it causes a comparatively large environmental burden in the LCA [24]. Despite the limited knowledge of consumers, they are not withhold from forming opinions and consequently, mislead sustainable purchasing motivations [24]. As declared above, the visual appearance of packaging, for example graphical packaging cues, can influence the consumer perception. First of all, the material is the main contributor of environmental impacts, followed by the graphics, colors and verbal features used on the packaging [24]. Moreover, it is demonstrated that the highest consumer response can be achieved with graphics on naturalness, followed by material choice [24]. The labels that can be added to packaging to perceive this response are added to Appendix B.

It is demonstrated that gender, age and environmental awareness can influence the purchase intention [76]. For example: females and older people are found to be more ecologically conscious, as they engage more in the purchase of environmentally friendly packaging solutions [76]. Besides specific product features, the overall design strategy of sustainable packages is of importance. Namely, (re)designs that follow a circular design strategy are preferred over (re)designs with a linear redesign, such as the reduction of material [77]. Additionally, it is demonstrated that combining multiple sustainable design strategies, is not adding relative effect. Lastly, it should be taken into account that the sustainability of packaging is only part of the design. In the end, the consumer always purchases – in conformity with the scope – a product-packaging combination to consume the product. Next to sustainability, also the quality, health, sensory appeal, naturalness, price and convenience should be taken into account while designing a product-packaging combination [24]. This entire package, together with the sustainability cues discussed, should be implemented to generate consumer impressions and influence the purchase behavior and respectively, recycling attitude. Since, the combination of cues may lead consumers interpret the packaging as sustainable, affecting the perceptions of the product contained within [24].

CONCLUSIONS

How are food containers currently being recycled?
Which insights does this give in terms of possibilities and constraints?

For each material type, the common situation of recycling has been discussed, answering the first research question. Though, it should be noted that recycling is not the only recovering solution and that other recovery options should also be taken into account. Within Chapter 2.4.2, waste hierarchies have been presented from which some important conclusions can be drawn:

- Food waste results in environmental effects that can be suppressed by the use of packaging.
- Recovery options that are in theory not included, due to the category of the application, can actually influence the environmental effects. For example single use packaging glass, is assumed to be recycled, although it can be reused resulting in different environmental impacts.

Moreover, the environmental impact has been presented for the incineration of various material types, compared to the recycling of those materials. Especially for plastics, high environmental gain could be achieved when recycling the material instead of incineration, with energy recovery. To a lesser extent, the same held for the recycling of glass. From these insights it can be concluded that the recycling of plastic and glass should be favored and higher recycling rates should be aimed for. This also reflect in the design possibilities and constraints of these materials. The package should be designed in such a way that it can actually be recycled. To do so, it is advised to use the recycle check as presented in the Section 2.4.5.

Similarly to the production process, the numbers and facts of the entire recycling system in the Netherlands, and differentiations that exists between the material types, will be presented in Chapter 4 (the LCA).

3.CONSUMER ANALYSIS

Within this chapter the consumer analysis will be discussed. This analysis is conducted in order to verify and expand the information resulting from the current state of affairs. The second part of the main research question specifies one focus direction of the assignment: the 'wishes of the customer'. This seem logical, because a true advise can only be given if it matches with the purchase intentions of the consumer. Hence, a survey about the preferences of packages for the fresh food industry is carried out among a sample of 211 respondents, representing the Dutch customer. The approach, aim and results will be discussed and evaluated within this section. All in order to answer the fourth sub research question: **What are the most beneficial and desired packages, or packaging attributes, according to the preferences of the customer.**

Please note that this section is constituent of the denoted scope and notes of Chapter 1.5. For the sake of clarity some shortenings are used in this section. When denoting 'consumers', the respondents that represent the Dutch consumer of fresh food packaging are meant. Similarly, with 'packages' or 'packaging', the packages for the fresh food industry that comply with the scope of this report, are meant. With 'product' the fresh food as declared in Chapter 1.5, will be referred to.

3. CONSUMER ANALYSIS

3.1. SURVEY

The consumer analysis is designed based on a generic design cycle. It is the goal of the consumer analysis to become familiar with the preferences of the consumer. Since, it would be interesting to use the results of the survey as (renewed) input data for the Life Cycles. By performing a survey, information from the current state of affairs can be verified and new data can also be retrieved. To guide this analysis, a list of requirements have been derived. Also, the design, implementation, simulation and evaluation of this survey will be discussed.

3.2. ANALYSIS

Within the analysis phase of a design, a selection of the information that should be incorporated in the design, needs to be derived. The current state of affairs already researched the important information that is available around the topic. Within this section a brief evaluation of the results, that are of influence to the survey, will be presented. All in order to present a structured overview of all information that should be verified or created by the survey. For clarity, each topic is translated into one or more questions in order to evaluate the results in an organized manner at the end. For the sake of clarity, a brief proposal of how to translate each question into the design of the survey, has also been presented after each question. Within the following Chapter 3.3, the further transition of this information into a working survey will be explained.

Product packaging combination

A packaging that complies with the scope of this assignment is always purchased by the consumer as a product-packaging combination. Despite the influence of the packaging (attributes), the purchase decision is initially based on the product that is packed. Hence, it should be checked if this product is indeed of influence and if this influence differs among various types of products. This results in the following questions:

→ Is the choice of a specific packaging (attribute), influenced by the product that is packed?

→ If so, what can be concluded from the product type in relation to the preference in packaging?

To check if the choice for a specific packaging (attribute) is indeed influenced by the type of food that is packed, different types of food can be displayed throughout the questions, in the same type of packaging. When one question covers only one type of food, but packed in different packages, the preference of one food type over another, can be excluded. When similar packaging solutions would be used in other questions, with other food, it can be checked if significant differences are present. If so, it can be demonstrated if the food is of influence and to what extent. Thus, one part of the survey should present questions with different types of containers, of the same food, in which the respondent chooses preference.

Visibility of the product

When purchasing fresh food, it can be imagined that there is a desire of the consumer to see the product. For example to check the quality, amount or freshness of the product. The 'transparency' of the material is one of the unique material properties glass and plastic have to offer, compared to PB. It is interesting to research this aspect, for the application of fresh food, as it can exclude the use of (purely) PB.
The (R)PET containers created at Hordijk are most commonly used for the fresh food industry, of which a high share finds an application in the 'luxury' or 'convenient' food as spreads, appetizers or ready-to-eat applications. If the visibility turns out to be of influence, it is interesting to check if this differs over various product categories.

Also, it should be taken into account that the visibility of the product is not only influenced, purely by the material. Since, plastic or glass packages could also have a limited visibility of the product, due to the addition of labels or sleeves. Therefore, the visibility of the product will be researched according to the following question:

→ Does the consumer want to see the product and if so, till what extent?

→ Is the visibility of the product more/less important over different product categories?

This question can be implemented in the design discussed in the topic 'product-packaging combination'. As discussed within that topic, it is desired to let the respondent choose between different product-packaging combinations in each question. To evaluate the visibility of the product, product packaging combinations can be displayed to the respondent that either do or do not show the product. This can be done for multiple product-packaging combination with different extents of visibility and containing different food types. Also, the opinion of the consumer, regarding the visibility, can directly be asked in an open question.

Visual appearance of packaging

As discussed in the current state of affairs (Chapter 2) , it is demonstrated that visual attributes can influence the purchase decision [75], [76]. Examples can be found in the shape, color and additional influences, such as labelling and (combination of) materials. For the consumer analysis it would be interesting to check if these preference are indeed present and to what extent:

- → Does the consumer has a preference for certain aesthetic characteristics of a packaging (i.e. shape, color, labelling or combination of materials)?
- → If so, what is preferred and till what extent?

Again, this topic can be covered by presenting different images in one question, in which the decision should be made between different attributes. When this is done repeatedly for multiple product types, the preference can be generalized and hence, demonstrated.

Use of recyclate (RPET) in packaging and the acceptance among consumers
Since RPET has proven its potential and Hordijk is experimenting with the addition of recyclate, substitutional questions about this specific 'attribute' should be asked as well:

- → What is the consumers opinion about the use of RPET in plastic packaging and the discoloration resulting from the addition of RPET?
- → If the addition of RPET is accepted, till what extent can RPET be added?

As this question stand alone, some individual questions should be devoted to the application of RPET in plastic packaging. It is wise to first ask the respondents opinion about the discoloration of plastic, without further knowledge about the origin of the discoloration. Since, this would be the case in real life situations as well. After, it is explained why the discoloration is present, the respondents opinion can be asked again. This time it can be asked while presenting multiple shares of RPET, resulting in higher levels of discoloration to check till what extent RPET is accepted.

Personal circumstances of influence
It is demonstrated that personal circumstances such as gender, age and environmental awareness are of influence to the purchase decision [76]. As the survey is likely to be filled in by a mixed group of respondents, it should be evaluated if these effects are indeed present in the data. If so, the data should be altered or notes should be presented.

3.3. DESIGN

Within the design phase, the goals, limitations and information resulting from the analysis phase are all translated into a functional design. As with any design, a list of requirement is derived on beforehand in order to state the boundaries. After, the information from the analysis phase is structured in four sections that represent the framework of the survey.

3.3.1. List of requirements

The requirements are covered by the following lists and subdivided into: requirements regarding the creation and implementation of the survey and the evaluation of the results.

Design of the survey
The survey should ...

1. Be a result of independent and scientific based research to the best of the knowledge of the author.
2. Comply with the scope of this assignment.
3. Verify and check the results of the current state of affairs.
4. Present questions to respondents that are imaginable and close to reality.

Implementation of the survey
The survey should...

1. Be filled in by sample that represents the 'consumer'
2. Be able to complete by a sample that represents the 'consumer'.
3. Be able to complete within a maximum time of fifteen minutes on a mobile or desktop device.

Evaluation of the results of the survey
The survey should...

1. Answer the questions presented in Chapter 3.2.
2. Present data that can be researched with quantitative methods, in programs such as SPSS or Excel.
3. Present data that can be used as an input for Life Cycle Assessment in Gabi.
4. Present data that supports in determining what packages or packaging attributes are (un)favored by the 'consumer'.

3.3.2. Framework of the survey

Within Chapter 3.2, the analysis phase, a couple of insights for the design of the survey were already presented. However, the requirements of Section 3.3.1. also lead to specific demands for the survey. Within this section a closer look will be taken into the structure of the survey, as a results of the earlier presented ideas and requirements.

First of all, it is desired to keep the questions as close to reality as possible. Therefore, it has been decided that all questions covering packaging solutions are accompanied by images.

Making consumer decisions usually involves trade-offs, meaning that the weakness of one attribute can be compensated by the strengths of another attribute [78]. The same held for picking a product-packaging combination in the supermarket. Namely, the customer does not specifically choose paper over plastic or purely base the purchase decision on the size of the product. Multiple attributes are of importance and the customer weighs preferences.

Within Chapter 3.2, the idea has been suggested to present the respondent a list of choices. Within each choice, different images could be shown to the respondent, from which the preferred solution should be selected. All topics of Chapter 3.2 could be covered via multiple questions, for multiple food types. For example; one question could display different packages, made from either plastic, glass or PB, containing olives (Figure 27a). Another question could present the same packaging solutions, now containing stuffed peppers for example (Figure 27b). Presenting the images like this, it can be checked if significant differences are present among food types. Multiple questions can cover different choices each time.

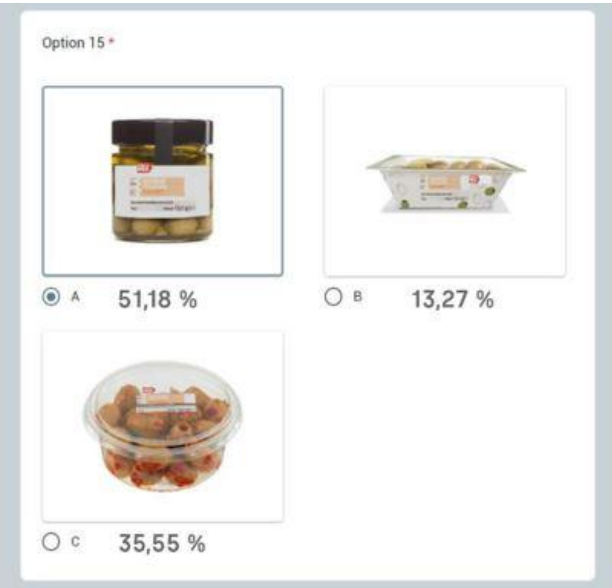

Figure 27a: Option 15 of the survey, presenting the choice between different material types.

Figure 27b: Option 16 of the survey, presenting the choice between different material types.

This way, preferences can be demonstrated among different topics. Such as visibility of the product (Figure 27c), material (Figure 27a-b), shape (Figure 27d) or color of the packaging (Figure 27e) as presented among various questions. Please note, in Figure 27a-e the results to each answer are already presented (the grey numbers below each answer). This way, these images do not need to be illustrated again in the evaluation of this chapter. Moreover, the chosen answer 'A' (denoted by the bullet and grey square) in all questions is purely illustrative.

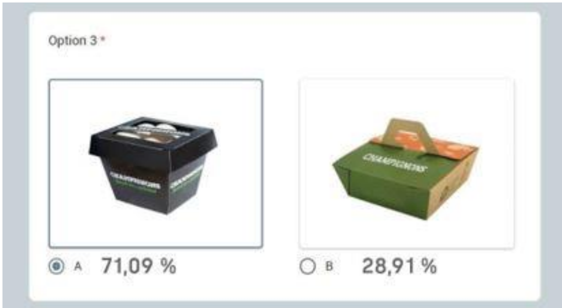

Figure 27c: Option 3 of the survey, presenting the choice between a (not) visible product.

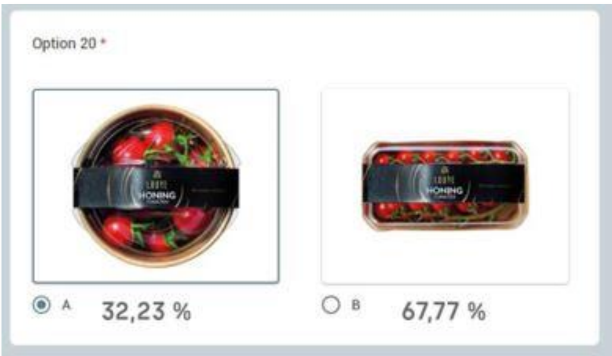

Figure 27d: Option 20 of the survey, presenting the choice between the shape of the packaging

***Figure 27e:** Option 34 of the survey, presenting the choice between different colors of the material*

As declared, choices are usually made, involving trade-offs. Hence, the preference of a consumer cannot purely be concluded by just analyzing the preference of one packaging over another. Especially, since it is desired to present real-life packaging solutions, that most commonly cover multiple topics at once. Another part of the survey should therefore be devoted to the different attributes of packaging and the specific preference of each. One way, to understand how people make these choices is by conducting a conjoint analysis [78]. By breaking the object into constituent parts (i.e. attributes and levels) and presenting a sample group different combinations of these, the preference of a consumer can be derived. In the end, a conjoint analysis can support in product development. Since, the consecutive utility of all attributes and levels of a product can be derived and the greatest can be used in designing a product. Hence, it has been decided that one section of the survey will be devoted to a conjoint analysis.

To summarize, it is desired to design the survey covering at least two directions. First of all, a conventional quantitative analysis based on consumer choices for different product-packaging combinations (based on images). Secondly, a conjoint analysis to research the utility of each packaging attribute. Looking at the analysis phase, a few questions should still be covered by other parts of the survey (i.e. personal circumstances). Moreover, it is useful to ask the respondents opinion (for example with regards to the use of RPET in plastic packaging) in a separate section. This results in the following four sections:

1. Personal information
2. Preference in product-packaging combinations
3. Conjoint analysis
4. Extra information

For the conjoint analysis it is important that the consumer bases the decision purely on the packaging solution. To assure that the type of food packed does not influence the decision, the packages should be presented empty. However, it can be imagined that the application as a packaging for the fresh food industry can be of influence to the decision. Thus, the respondent should be made aware of this application before conducting the conjoint analysis. Therefore, section two 'the preference in product-packaging combinations' will be conducted, before the conjoint analysis. This way, the respondent is familiar with the different applications.

Throughout the survey it is desired to exclude personal preference for a specific brand or flavor. Hence, all items displayed (either in the conjoint analysis or other parts of the survey) should be in presence of the same label and clearly containing the same product. Also, it should be made clear to the respondent textual, that the specifications of the product, is identical in all choices. This way, data is presented to the best of the knowledge and as close to reality as possible.

3.4. IMPLEMENTATION

Invitations to participate to the survey, were sent out via multiple sources, online as well as offline. Within each invitation two links were presented: either for the Dutch or English version of the survey. Online channels such as a personal Facebook and LinkedIn profile and Hordijks LinkedIn profile were used to spread the invitation. Moreover, the invitation was spread via e-mail and WhatsApp messages. Due to the different sources, a wide and diverse set of participants could be reached. To actually gain interest, a specific introduction text was created for every other source. This way, each source could be motivated to participate and some extra information could be enclosed, when necessary. In the case of the employees of Hordijk, it was for example asked to share the link with friends, rather then responding themselves. Since, this might lead to influenced responses. By requesting to forward the invitation, the method of 'snowball sampling' take form. This snowball sampling method is a non-probabilistic method, capable of recruiting participant at low costs and from a large geographic area [76]. To keep the participation anonyms, participants were only asked to denote a small amount of personal data, that does not indicate the identity of one. However, it was desired to validate the sample. In other words, to verify if the respondent is familiar with packages for the fresh food industry in the Dutch supermarket. Moreover, it should be clear what the average age and share of gender in the respondents is.

3.5. SIMULATION

The framework has been translated into two identical surveys – in Dutch and English, within the program 'Google Forms'. A few illustrations of how the survey was presented to the respondents, was already presented in Figure 27a-e. The entire survey can be found in Appendix B.

In order to simulate a valid conjoint analysis, a few steps should be conducted before the cards presented in section three of the survey, could be presented to respondents. First, attributes and their levels should be selected (1). Then, stimuli had to be created (2) to present the data to the respondents. All in order to eventually collect the data (3), estimate the utility function (4) and interpret (5) and validate (6) the results, which will be done in the conclusion of this Section, together with the other results. The first two steps will be discussed briefly in chronical order here.

1. Select attributes and their levels

With attributes, factors or variables that define the product are meant. For example, the 'ability to protect the product' is an attribute when comparing different packaging solutions. Each attribute itself consists of specific levels. For the 'ability to protect the product' one could for example use three levels: '1', '2' or '3' or 'low', 'medium' or 'high'. It is important to select attributes that are essential determinants of consumer choices. The important influences affecting the consumers choice could be derived from the analysis phase in Chapter 3.2. Moreover, the attributes and levels should apply to a few restrictions, in order to create a fair comparison. Namely:

Attributes should [S1]

- Be relevant: they should matter to consumers and be practicable and influenceable by the producer.
- Be independent: the level of an attribute should not affect the level of another attribute.
- Not contain exclusion restrictions: the level of an attribute cannot prohibit the occurrence of the level of another attribute.
- Be in a compensatory relationship
- Be limited in order to create a workable amount of products.

Together with the results from the analysis, the following attributes and corresponding levels could be derived:

ATTRIBUTES

	Material	Visibility of the product	Presented information about sustainability	Packaging color
LEVELS	1.PB 2.PET 3.RPET 4.Glass	1.Yes 2.No	1.None 2.Visible 3.Extremely Notable	1.Original 2.Altered

Table 3: *Attributes and corresponding levels used to create the conjoint analysis*

2. Create stimuli

For this conjoint analysis, a full profile method will be used, resulting in a stimulus (the choice presented to the respondent) that consist of all attributes. In order to consider all realistic possibilities, a fractional factorial design is performed. In other words, in SPSS each stimulus is transformed into a 'card', that is presented to the respondents. These respondents can choose, rank or rate the cards based on the application of the conjoint analysis. The research has the desire to comply with a realistic situation and hence, the decision has been made to apply a choice-based conjoint analysis. Also, because much variations exist and choice-based conjoint analysis saves time in responding. With the same reasoning, the cards are translated into images; in order to provide many options to the respondents without asking for too much effort in time.

In SPSS, an orthogonal design can be defined in order to understand how much value each attribute creates for consumers. Different factors (attributes) are added in SPSS, for which the values are represented by the levels of each attribute. The specifications of this orthogonal design in the programming system SPSS are added in Table 4.

Factor name	Factor label	Values	Labels
Material	Material	1,2,3,4	1 = PET 2 = RPET 3 = Paperboard 4 = Glass
Visibility	Visibility of the product	1,2	1 = yes 2 = no
Information	Presented sustainability information	1,2,3	1 = None 2 = Visible 3 = Extremely notable
Color	Packaging color	1,2	1 = Original 2 = Altered

Table 4: *The specifications of the orthogonal design, as modelled in the programming system SPSS*

Typically in an orthogonal design, are factor-level combinations – better known as holdout cases, which are rated by the respondents without using it for the preference model [79]. These holdout cases are used to check the validity of the model. Based on the amount of attributes and level, three holdout cases will be used to verify the model.

To perform a conjoint analysis, a dataset with all possible 'cards' is generated by performing an orthogonal design with the information of Table 4 and the addition of three holdout cases, in SPSS. This results in the cards as presented in Table 5.

	Card ID	*Material*	*Visibility of the product*	*Presented sustainability information*	*Packaging co*
1	*1*	*Glass*	*Yes*	*None*	*Altered*
2	*2*	*PET*	*Yes*	*Extremely notable*	*Altered*
3	*3*	*Paperboard*	*No*	*Visible*	*Altered*
4	*4*	*Glass*	*No*	*Extremely notable*	*Original*
5	*5*	*Paperboard*	*Yes*	*None*	*Original*
6	*6*	*PET*	*No*	*None*	*Original*
7	*7*	*RPET*	*Yes*	*Visible*	*Original*
8	*8*	*RPET*	*No*	*None*	*Altered*
9	*9*	*RPET*	*Yes*	*None*	*Altered*
10	*10*	*RPET*	*No*	*Extremely Notable*	*Original*
11	*11*	*Glass*	*No*	*None*	*Altered*
12	*12*	*Paperboard*	*Yes*	*Extremely notable*	*Altered*
13	*13*	*Paperboard*	*No*	*None*	*Original*
14	*14*	*PET*	*Yes*	*None*	*Original*
15	*15*	*Glass*	*Yes*	*Visible*	*Original*
16	*16*	*PET*	*No*	*Visible*	*Altered*
17[a]	*17*	*PET*	*Yes*	*Visible*	*Original*
18[a]	*18*	*Paperboard*	*No*	*Visible*	*Original*
19[a]	*19*	*Paperboard*	*Yes*	*None*	*Altered*

***Table 5**: Card list retrieved from SPSS software, based on input of Table 4*

As it difficult to rank this amount of cards, or choose between nineteen options the decision has been made to present all cards individually and ask for the respondents opinion via a Likert scale. This way it becomes relatively easy and time efficient to respond to all options. Moreover, as declared the cards are translated into pictures illustrating real packaging solutions. An example of this translation is presented in Table 6, with the corresponding question (as presented in the survey) next to it.

Profile Number 14

Card ID	Material	Visibility of the product	Presented sustainability information	Packaging color
14	PET	Yes	None	Original

***Table 6**: Plancard of SPSS translated into an image presenting all (levels of) attributes, as presented in the survey*

3.6. EVALUATION

Before the data of the survey can be evaluated, it should first be made clear how the data of the survey is collected and analyzed. After that, the conclusions will be discussed per questions (Section 3.6.3, 3.6.4 and 3.6.5). Then a final conclusion of this consumer analysis can be drawn and recommendations can be presented.

3.6.1. Data collection

The software of Google Forms presents a datasheet in which the answers are drawn per respondent. This entire sheet is downloaded and checked on inconsistencies or misleading information, in Excel at first. Of course, the data of Section 3 (the conjoint analysis) was in need for a specific analysis method, performed in the software of SPSS. As consecutive steps (declared in Chapter 3.5) are in place for a conjoint analysis, these steps will individually be discussed throughout the following sections. At first, the following steps have been taken to analyze the dataset:

- The responses of the Dutch as well as the English survey were downloaded and combined in one Excel file.
- The responses that were not filled in completely, or filled in with non-qualitative answers (i.e. similar responses to all questions) were subtracted from the dataset. This results in a dataset with **234** responses.
- The results of the important questions were collected in a separate Excel sheet, summarizing all interesting data in an organized manner, as will be discussed individually in the conclusions per topic (Section 3.7.1). To do so, the total scores to each individual question was first calculated:
  - → To make it easy to 'search' and collect data using the 'If' function in Excel, all English responses were translated to the Dutch version of the response.

*This dataset combining all 234 valid responses of both surveys was saved and is added to Appendix E. For the sake of clarity, this dataset will be referred to as **'total dataset'**.*

- The responses that were expected to have an influenced perception regarding the preference in packaging, were individually checked. When influenced results were found, the respondent was subtracted from the dataset.
- Within Appendix D, the validation of the results is more extensively discussed. In conclusion, 46 respondents were working in the field of packaging, of which 20 were excluded. Also, 3 respondents were excluded as they claimed to be "not" familiar with the Dutch supermarket.

*The final dataset, with **211 valid** responses was saved and is added to Appendix F. For the sake of clarity, this dataset will be referred to as **'subtracted dataset'** as data is 'subtracted' from this dataset.*

- By comparing the control questions, the survey was checked upon consistency. An average margin of inaccuracy of 2.10% was found.

To ensure that the used data is truly valid, different samples have been analyzed and are compared to each other. Also, various calculations have been done to check the consistency of the answers. The calculations and reasoning behind this validation, are also presented in Appendix D.

- The results of the survey were validated and conclusions could be drawn.

From the first section of the survey, some personal data could be evaluated. First of all, the survey is completed by 62% female and 38% male respondents, ranging between 19-75 years old. The age categories of 26-35, 36-45, 46-55 and 56-65 were all represented by a share of 12-20%. The age category of 66-75 was only covered by 2% of the respondents and a higher share (33%) had an age between 19-25. Although some differences are present, it is assumed not to be of signifcant influence. Espically, since women have a higher share in doing groceries, compared to the male customer in the Netherlands [80].

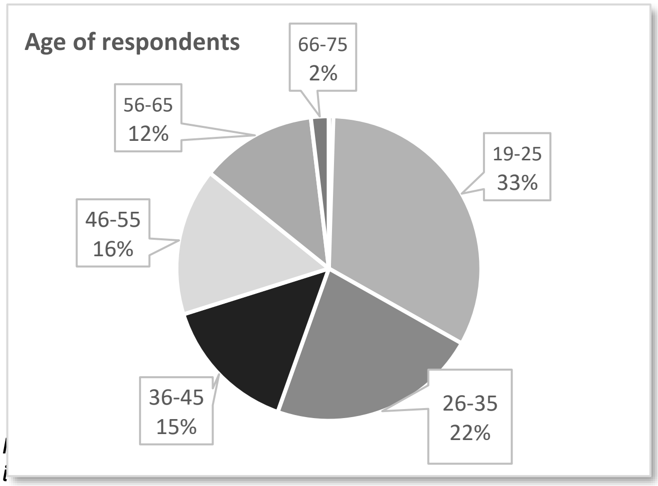

Figure 28: Pie chart illustrating the share of different age categories, responding to the survey

3.6.2. Data collection of the conjoint analysis

The results of the conjoint analysis were also verified according to the alterations of Chapter 3.6.1, resulting in a dataset that could be added to SPSS, as illustrated in Table 7. Please note that only twelve responses are represented, were (of course) 211 responses were added to this dataset.

	@1	@2	@3	@4	@5	@6	@7	@8	@9	@10	@11	@12	@13	@14	@15	@16	@17	@18	@19
1	3	3	1	3	1	3	3	3	3	3	3	1	1	4	3	1	3	1	1
2	4	2	1	4	3	4	4	4	4	4	4	4	2	4	4	3	4	2	3
3	3	2	2	3	2	4	2	2	3	2	3	3	2	3	3	2	3	2	3
4	3	4	2	4	3	3	3	2	3	2	4	4	2	4	3	3	3	2	4
5	3	4	1	3	2	4	4	4	4	4	3	2	2	4	3	4	3	2	2
6	4	4	1	4	4	3	3	1	1	1	4	1	1	2	5	4	1	1	4
7	4	4	3	4	4	4	2	3	2	1	4	3	3	2	4	4	2	2	3
8	4	4	3	4	3	4	4	4	4	5	4	3	3	4	4	4	4	3	3
9	5	3	3	5	5	5	5	5	5	5	5	3	3	5	5	3	5	3	4
10	3	4	5	3	4	4	4	4	4	4	3	4	5	4	3	4	4	5	5
11	5	4	4	5	5	3	3	3	3	4	5	2	2	3	5	3	3	2	2
12	2	3	2	3	4	2	2	4	3	4	2	3	4	3	4	3	3	4	5

***Table 7**: Responses of twelve (out of 211) responses in SPSS*

After the collection of data, the conjoint analysis could be conducted in SPSS. Within Table 8 and 9, respectively the Summary of the utilities and the Importance Values are shown. As can be seen in Table 9, the material has the highest influence, followed by the color of the material, presented information and visibility.

Utilities

		Utility Estimate	Std. Error
Material	PET	-,227	,041
	RPET	-,202	,041
	Paperboard	-,021	,041
	Glass	,450	,041
Visibility	Yes	,014	,024
	No	-,014	,024
Information	None	,010	,032
	Visible	-,049	,037
	Extremely notable	,039	,037
Color	Original	,048	,024
	Altered	-,048	,024
(Constant)		3,094	,025

***Table 8**: Utility scores in SPSS*

Importance Values

Material	76,126
Visibility	3,206
Information	9,823
Color	10,846

Averaged Importance Score

***Table 9**: Importance Values in SPSS*

From this information, the utility score of each product can be calculated. To illustrate, Table 10 declares how the utility score for Card fourteen (as presented in Table 6) would be calculated:

Card ID = 14		
Attribute	*Level*	*Utility Score*
Material	PET	-0.227
Visibility	Yes	0.014
Information	None	0.010
Color	Original	0.048 ______ +
Overall utility		*-0.155*

***Table 10**: Declaration of utility score for Card 14*

This overall utility score is calculated for all cards presented to the respondents and ranked upon preferences in Table 11. For the sake of clarity, the images representing the card numbers are added as well. To be clear; number 19 represents the least preferred solution and number 1 represents the most preferred solution.

Packaging	Ranking | Utility Score
	**19** | - 0.338
	**18** | - 0.254
	**17** | - 0.226
	**16** | - 0.222
	**15** | - 0.214
	**14** | - 0.189
	**13** | - 0.183
	**12** | - 0.155
	**11** | - 0.132
	**10** | - 0.129
	**9** | - 0.045
	**8** | - 0.036
	**7** | - 0.016
	**6** | 0.023
	**5** | 0.051
	**4** | .398
	**3** | 0.426
	**2** | 0.463
	**1** | 0.523

Table 11: Utility scores of all packaging solutions, from least to most preferred

3.7. CONCLUSION

What are the most beneficial and desired packages, or packaging attributes, according to the preferences of the consumer ?

To support the answering, topics from the current state of affairs were translated into questions. By answering these questions according to the results of Section 1,2 and 4 of the survey, a detailed illustration of the most beneficial and desired packages could be created. Within Section 3 of the survey, a conjoint analysis was created in order to quantify the importance of the attributes. With the results of this section, the information retrieved from Section 1, 2 and 4 of the survey could be verified or denied.

In order to present the conclusion in a structured manner, the questions created for analyzing Section 1,2 and 4 will be discussed first. Then, the information retrieved from the conjoint analysis will be concluded. Lastly, the final conclusion of the consumer analysis will be presented in Chapter 3.8.3.

3.7.1. Conclusions per topic

Product packaging combination

→ Is the choice of a specific packaging (attribute), influenced by the product that is packed?

→ If so, what can be concluded from the product type in relation to the preference in packaging?

First of all, the materials of the product-packaging combinations have been analyzed. When analyzing the preference between product-packaging combinations out of (mainly) PB versus (mainly) plastic, the PB as well as the plastic solution was preferred an equal amount of times. However, as can be seen in Table 12a, much higher preferences are found in preferring cardboard over the plastic, then the other way around.

Please note that Table 12a-f present a summarized overview of the results of the survey, per topic. Each left column presents the data of the total dataset, each right column the data of the 'subtracted' dataset.

The data of the 'subtracted' dataset is presented 'bold' and used for the conclusions.

As declared, choices are usually made, involving trade-offs. It is therefore difficult to actually say if cardboard is truly more preferred over plastic, purely based on the preferences illustrated in Table 12a. When other packaging attributes were clearly present, it has been denoted in the last column of the Table. For example, within option 15 and 16 of Section 2, a significant preference for plastic (and glass) over PB could be found. However, within these options a lid was clearly visible, illustrating a re-closable solution. Though, because of the significant higher preference for PB, it can be stated that PB is preferred over plastic in general. From Table 12a, it also becomes clear that glass is a wise material for the packaging of fresh food, as glass is in all cases preferred over the other types of materials presented.

	Plastic		PB		Glass		Coloured plastic				
Preference in material	All	Subtracted	All	Subtracted	All	Subtracted	All	Subtracted	PB vs Plastic	Glass vs Plastic	Remarks
Option 2: Mushrooms	*40,17*	**36,02**	*59,83*	**63,98**					27,96		
Option 6: Sushi	*26,07*	**20,85**	*47,01*	**51,18**			*26,92*	**27,96**	30,33		
Option 7: Meal salad	*41,88*	**36,02**	*58,12*	**63,98**					27,96		With the PB version the lid is clearly visible, which is not the case with the plastic packaging. This could be of influence.
Option 8: Salad mix	*58,53*	**54,5**	*41,45*	**45,5**					-9		
Option 9: Quinoa mix	*39,74*	**34,12**	*60,26*	**65,87**					31,75		Two PB options presented; visibility is important, expected to have more influence on the decision than the combination of materials.
Option 12: Cucumber salad	*63,25*	**59,72**	*36,75*	**40,28**					-19,44		
Option 13: Appetizer, chicken	*49,57*	**45,02**	*50,43*	**54,98**					9,96		
Option 15: Appetizer, olives	*39,32*	**35,55**	*11,97*	**13,27**	*48,72*	**51,18**			-22,28	**15,63**	With the plastic and glass option the lid is clearly visible (representing a reclosable solution), which is not the case with the PB option.
Option 16: Appetizer, stuffed peppers	*37,18*	**32,7**	*14,53*	**16,11**	*48,29*	**51,18**			-22,28	**18,48**	
Option 17: Appetizer, sundried tomatoes	*48,29*	**44,07**			*51,71*	**55,92**				**11,85**	
Option 18: Tomatoes	*56,41*	**55,45**	*43,59*	**44,55**					-10,9		
Option 21: Tomatoes			*88,89*	**89,57**			*11,11*	**10,43**			Two PB option presented; with and without (coloured) plastic. The solution with plastic has the preference.
Option 22: Lasagna	*47,86*	**43,13**	*52,14*	**56,87**					13,74		
Option 23: Aioli	*33,76*	**30,33**			*66,24*	**69,67**				**39,34**	
Option 24: Cilantro	*43,16*	**37,44**	*56,84*	**62,56**					25,12		
Option 25: Meal salad	*35,9*	**30,33**	*55,56*	**61,61**			*8,55*	**8,06**			
Option 28: Strawberries	*58,11*	**53,56**	*41,88*	**46,45**					-7,11		
Option 30: Berries	*49,15*	**44,55**	*50,85*	**55,45**					10,9		
Option 31: Hamburger	*55,56*	**50,71**	*44,44*	**49,29**					-1,42		
Option 32: Minced meat	*55,98*	**51,18**	*44,02*	**48,82**					-2,36		
Option 35: Meal salad	*53,85*	**51,18**	*46,15*	**48,82**					-2,36		
Option 36: Pasta Salad	*48,29*	**43,13**	*51,71*	**56,87**					13,74		

***Table 12a:** The results of section 1, summarized on 'preference in material' in a separate Excel sheet*

Still, it should also be noted that there are cases in which the plastic solution is preferred. Especially, within the application of moisture products as spreads, meat or more 'luxury' food products as appetizers. Although these preferences are only minor, it can be concluded that the plastic packaging container in the supermarket is not as disliked as concluded from the current state of affairs (Chapter 2). Especially as the plastic containers Hordijk creates, most commonly find their application within the above mentioned classifications. This gains opportunities in (keep) using plastic as a container for the fresh food industry.

To refer to the research question of this section, it can indeed be concluded that the preference for a specific product (attribute) is influenced by the product that is packed. Since, different numbers can be found throughout the preference for each type of material, as illustrated in Table 12a. It can be concluded that the packages made from (mainly) PB and glass are more preferred. However, for the application of 'moisture' products, meat or 'luxury' food types, plastic can provide opportunities as well.

Visibility of the product

- → Does the consumer want to see the product and if so, till what extent?
- → Is the visibility of the product more/less important over different product categories?

Within Table 12b, the options that were presented to respondents, illustrating the differences in transparency, are shown.
From this table it can be concluded that the consumer finds it indeed very import tot actually see the product. This can also be concluded from the question in which the consumer was asked about the desire to see the product through the packaging. 98.6% Of the respondents found it important to actually see the product, as declared in the dataset (Appendix C, E). Thus, it can be concluded that the consumer does want to see the product. Within the attached question, reasonings were most commonly given about 'checking the quality', 'freshness' or 'consistency' of the product.

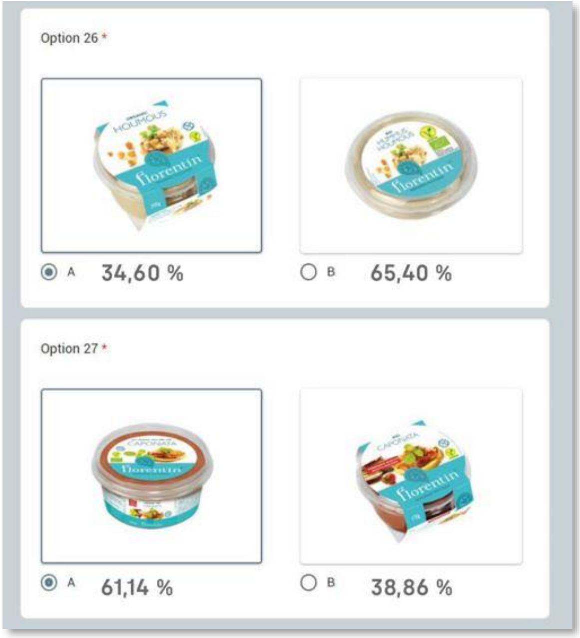

Table 12b: The results of section 1, summarized on 'transparency/visibility of the product' in a separate Excel sheet

Based on the results of option 26 and 27 (Figure 29) it can be concluded that a transparent top part is preferred over a transparent side view. Something that was noted in the remarks as well; 'only party transparent, would be sufficient', Again, different numbers were found over the product categories, so the preference does variate over the different product categories.

Visual appearance of packaging

- → Does the consumer has a preference for certain aesthetic characteristics of a packaging (i.e. shape, color, labelling or combination of materials)?
- → If so, what is preferred and till what extent?

Within Table 12c-f, different aesthetics of product-packaging solutions have been analyzed. The influence of the different materials have already been discussed, from which it is demonstrated that PB and glass packaging solutions are preferred over plastic food containers. This preference is still present when looking into the combination of packaging materials, as presented in Table 12c.

Transparancy/visibility of the product	Yes		No		Difference	Remarks
Option 3: Mushrooms	69,66	**71,09**	30,34	**28,91**	42,18	
Option 9: Quinoa mix	85,47	**83,88**	14,53	**16,11**	67,77	
Option 10: Empty containers	64,96	**62,09**	35,04	**37,92**	24,17	Within this question the colour of the material could be of influence as well.
Option 11: Empty containers	66,67	**64,45**	33,33	**35,54**	28,91	Within this question the colour of the material could be of influence as well.
Option 26: Salad spread (Sleeve)	67,52	**65,4**	32,48	**34,6**	30,8	Product is still visible, but reduced due to the sleeve.
Option 27: Salad spread (Sleeve)	62,82	**61,14**	37,18	**38,86**	22,28	Product is still visible, but reduced due to the sleeve.

***Figure 29:** Option 26-27 of the survey, presenting the choice of a label or sleeve (illustrating the visibility of the product)*

Combination of packaging materials	PB Only		PB + Plastic		Plastic only		Other		PB vs Plastic	Remarks
Option 4: Mushrooms			24,79	23,22			75,21	76,78		
Option 6: Sushi			47,01	51,18	52,99	48,81			2,37	Two options in plastic; black and transparant.
Option 7: Meal salad			58,12	63,98	41,88	36,02			27,96	
Option 8: Salad mix			41,45	45,5	58,53	54,5			-9	
Option 9: Quinoa mix	14,5	16,11	45,73	49,76	39,74	34,12			15,64	
Option 10: Empty containers	35	37,92	64,96	62,09						
Option 11: Empty containers	33,3	35,54	66,67	64,45						
Option 12: Cucumber salad			36,75	40,28	63,25	59,72			-19,44	Two options in plastic; round and oval shaped.
Option 13: Appetizer, chicken			50,43	54,98	49,57	45,02			9,96	
Option 15: Appetizer, olives			11,97	13,27	39,32	35,55	48,72	51,18		
Option 16: Appetizer, stuffed			14,53	16,11	37,18	32,7	48,29	51,18		
Option 18: Tomatoes	43,6	44,55	56,41	55,45						
Option 21: Tomatoes	31,2	32,7	57,69	56,87	11,11	10,43			46,44	
Option 22: Lasagna			52,14	56,87	47,86	43,13			13,74	
Option 24: Cilantro			56,84	56,84	43,16	43,16			13,68	
Option 28: Strawberries			41,88	46,45	58,11	53,56			-7,11	Twee opties in alleen plastic; met deksel of zonder deksel
Option 30: Berries			50,85	55,45	49,15	44,55			10,9	
Option 32: Minced meat			44,02	48,82	55,98	51,18			-2,36	
Option 35: Meal salad			46,15	48,82	53,85	51,18			-2,36	
Option 36: Pasta Salad			51,71	56,87	48,29	43,13			13,74	

Table 12c: *The results of section 1, summarized on 'combination of packaging materials' in a separate Excel sheet*

As can be seen, the preference of the respondent is not affected when the material is combined with another material. Conclusions can especially be drawn about the use of plastic in PB containers; in all cases the PB container in which a plastic lid, seal or liner was used was of preference. This is interesting as it could be concluded from Chapter 2.4 (Waste management and recycling systems) that using plastic in PB food containers, affects the recycling of the container in a negative sense. When comparing the plastic solutions to the PB solutions in which plastic was (more or less) used, a significant preference for the PB containers (with or without the use of plastic) could still be found. In terms of solutions regarding the closing system, Table 12d present some more information.

Preference in closing solution	Lid		Foil/seal		Other		Difference	Remarks
Option 4: Mushrooms			24,79	23,22	75,21	76,78		Other = Solution of closing via a 'net'
Option 5: Mushrooms	66,7	67,3	33,33	32,7			34,6	
Option 17: Appetizer, sundried tomatoes	33,8	29,38	14,53	14,69	51,71	55,92	14,69	Other = Glass solution with a metal lid.

Table 12d: *The results of section 1, summarized on 'preference in closing solution' in a separate Excel sheet*

Although the closing solution could only be analyzed from three questions, the option for a re-closable solution (i.e. the lid) was significantly preferred. This could be concluded throughout other questions, where other trade-offs were included, as well. In terms of the color of the material, significant preferences were found for the original color (i.e. transparent plastic, kraft PB) (Table 12e).

Colour of the material	Original		Other		Difference
Option 1: Mushrooms	47,01	44,08	52,99	55,92	-11,84
Option 10: Empty containers	93,59	92,9	6,41	7,11	85,79
Option 11: Empty containers	94,02	93,83	5,98	6,16	87,67
Option 21: Tomatoes	88,89	89,57	11,11	10,43	79,14
Option 29: Strawberries	70,09	67,3	29,91	32,7	34,6
Option 34: Minced meat	50,43	46,92	49,57	53,08	-6,16

Table 12e: *The results of section 1, summarized on 'color of the material' in a separate Excel sheet*

For the shape of the packaging, Table 12f present interesting results. Four scenarios illustrate that a round shape was disliked, compared to the oval or rectangular shape.

Shape of the packaging	Round		Oval		Squared		Rectangular	
Option 12: Cucumber salad	24,79	22,75	38,46	36,97				
Option 14: Appetizer, Prosciutto	38,03	36,49					61,97	63,57
Option 19: Tomatoes					64,53	64,93	35,47	35,67
Option 20: Tomatoes	32,91	32,23					67,09	67,71

Table 12f: *The results of section 1, summarized on 'shape of the packaging' in a separate Excel sheet*

For all data representing this topic, significant preferences could be found. However, it should be noted that this preference is only based on a small amount of questions. Though, it can be concluded that the consumer is open to other aesthetic characteristics, varying over different product categories. Hence, opportunities for designing can be found within this topic.

Use of recyclate (RPET) in packaging and the acceptance among consumers

- → What is the consumers opinion about the use of RPET in plastic packaging and the discoloration resulting from the addition of RPET?
- → If the addition of RPET is accepted, till what extent can RPET be added?

In Section 4 of the survey, the opinion of respondents regarding the use of RPET in plastic packaging containers was asked. The respondent was presented with the discolored RPET container versus the fully transparent PET container. Despite the discoloration, still 91.94% would accept the RPET container. From the follow-up question, even more interesting results could be derived. Namely, 58.76% would accept a discoloration resulting from a recycled share of more than 40%. From these results it can be concluded that the consumer has a positive opinion about the use of RPET in plastic packaging. Though, the discoloration of 40% RPET as illustrated within the question, would not be in line with the conclusions about the transparency of packaging. Thus, smaller shares of RPET should be added to comply with this topic or a transparent lid of virgin PET should provide the visibility of the product.

3.7.2. Conclusion conjoint analysis

Within the scope of the survey, the conclusions regarding the conjoint analysis were already presented in Table 8, 9 and 11. Within Table 11 the utility scores of all packaging solutions presented to the respondents, were summed. From this table it can be seen that glass jars were given the highest utility, followed by carboard packages and lastly, plastic solutions. Within the conclusions of Section 3.8.1, it was already stated that glass jars had high preference, followed by PB solutions. This can be verified with the results of the conjoint analysis. After the material, the color scores the highest utility, mainly reflecting in the negative results of Table 11. Since, the black colored plastic solutions were unfavored. The importance of the color is closely followed by the presented information regarding sustainability. Indeed, it can be seen that the packages in which the information regarding sustainability is presented 'extremely' are favored. Interestingly, because no differences are present between these packages and the packages were this information is not presented. Lastly, it is interesting to see that the respondents did not notice the difference between the PET and RPET packaging solutions, as these packages are not preferred consequently. This results in opportunities for designing with RPET as the discoloration does not affect the consumers perception significantly.

3.7.3. Conclusion consumer analysis

What are the most beneficial and desired packages, or packaging attributes, according to the preferences of the consumer ?

It can be concluded that it is challenging to actually name the most beneficial and desired packages or attributes, based on the preferences of the consumer. Since, the preference for one packaging over another usually consists of trade-offs. This has become visible in the results of the survey once again. Since, the preference shifted between the materials or shape over the different types of product-packaging combinations. This also held for packages where the product was more or less visible, or when different colors of packaging where displayed. However, in the end some interesting conclusions could still be found.

First of all, the consumer has a slight preference for glass and PB materials, over plastic. However, in the case of packaging for the fresh food industry, plastic does present some opportunities. Especially due to the transparency of the material. When using plastic, preferences could mainly be found when packaging 'moisture' food (i.e. spreads), meat or luxury products as appetizers. As the packages of Hordijk mostly covers these types of products, the use of plastic would not immediately be 'in danger' based on the consumers perception. When using plastic packaging, it would be advised to use a share of RPET. Since, it can be concluded that the consumer has a positive attitude against the use of RPET and would even accept a significant discoloration. Though, it should be mentioned that the concluded share of 40% RPET would not match the desire for transparency in the packaging. However, this can be solved by a share of RPET between 20-30%, or a higher share, in combination with a transparent (i.e. virgin) PET lid. Interestingly, cautious conclusions can be drawn about the addition of this lid, which is demonstrated to be preferred over the use of a seal. Moreover, it can be concluded that the consumer would accept another shape of the packaging, as cautious conclusions are also present about changing the shape from round to rectangular. Lastly, the conjoint analysis presents the utility of some of these topics. When the material has been chosen, one should assure that the color keeps as close to the original as possible and that sustainability characteristics are presented clearly.

4. LIFE CYCLE ASSESSMENT

This section will cover a Life Cycle Assessment in order to answer the sub research question: **"What is the most sustainable packaging solution, in terms of an LCA?"**

This will be done, by comparing the life cycles of four packaging solutions for the fresh food industry, variating in material, in terms of their environmental impact. This is done using the software Gabi Academic, with the EcoInvent 3.7 database. Within this chapter, information retrieved in the current state of affairs (Chapter 2) will be used to create life cycles of different packaging solutions. These life cycles are analyzed in order to calculate the actual impact.

4. LIFE CYCLE ASSESSMENT

According to ISO 14040 [81], there are four phases in a LCA study. Within this chapter, these phases will be performed in consecutive order. However, as this LCA is conducted as part of a master assignment, different sections are created in order to present all information logically. Within the declaration of each phase, it is presented how the information will be discussed within this chapter.

The goal and scope definition phase;
"The scope, including the system boundary and level of detail, of an LCA depends on the subject and the intended use of the study. The depth and the breadth of LCA can differ considerably depending on the goal of a particular LCA".

Within this phase it will be presented what is researched within this LCA. This will be done by discussing the subject of the study and the corresponding depth (i.e. scoping and limitations). Moreover, the functional unit will be presented and the specifications of each packaging solution.

The inventory analysis phase;
"The life cycle inventory analysis phase (LCI phase) is the second phase of LCA. It is an inventory of input/output data with regard to the system being studied. It involves collection of the data necessary to meet the goals of the defined study".

For this assignment the inventory analysis phase will be covered by the database development in which the processes of each life cycle are discussed. For clarity within the research, the specific data (characterization, normalization and weighing) necessary to actually put the databases into practice in a modelling software, will be presented in the following section. Since, discussions about the collection of this data was already thoroughly discussed in the current state of affairs. Though, the input and output flows (classification) will already be presented, by illustrating each process of each individual life cycle.

The impact assessment phase;
"The life cycle impact assessment phase (LCIA) is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance".

As stated above, this phase will be covered by presenting the actual data of each process' input and output. For the sake of clarity, this information is all collected in one table and presented in a consecutive order for each packaging solution (and corresponding life cycles).

The interpretation phase;
"Life cycle interpretation is the final phase of the LCA procedure, in which the results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition".

Lastly, the information of the first three phases is added to Gabi, from which evaluations are created and conclusions are drawn.

4.1. THE GOAL AND SCOPE DEFINITION PHASE

4.1.1. Subject of the study

As stated, this LCA is performed in order to analyze the environmental impact of packaging solutions for the fresh food industry. This will be done by elaborating on four different types of packages, made from different materials. To clarify, the assessment is focused on the environmental risks and the corresponding impacts to a single use of each packaging solution. This will be done from a cradle to grave principle, in which each stage of a product's life cycle (from the extraction of raw materials to the disposal process) are considered [81]. The ReCiPe method (version 2016 V1.1.) will be used to calculate the impact. The Normalized midpoints will be used, as calculated by Gabi, based on all 19 midpoints in the first place.

4.1.2. Scope definition

This Life Cycle Assessment (LCA) is conducted for 'Hordijk verpakkingsindustrie Zaandam B.V.' as part of the Master Thesis, being a graduation assignment for the Study Industrial Design Engineering at the University of Twente. This lead to the assumption that the target group of this LCA has some familiarity with the life cycles of packages for the fresh food industry. However, the discussion and conclusion of this LCA can be useful for the general public, those who are interested in this particular topic, as well. Since, this LCA aims to illustrate the differences in the bigger pictures by comparing different materials.

For geographical validity, this LCA focusses on the Dutch market. Using the most popular food packaging containers of Hordijk as a reference, the Functional Unit have been derived. Countries complying with similar techniques in manufacturing as well as disposal of these packaging solutions can use this report as a reference as well. However, it should be noted that countries beyond the European Union do not comply with the rules and regulation that created the boundaries of this assignment in the first place.

Concerning the temporal validity, the report is estimated to remain valid for about five years. This estimation is based on the current state of affairs. Here, it was already concluded that changes are to be foreseen in the rules and regulations and development of new technologies (i.e. recycling systems). This can lead to significant differences in the implementation of specific (raw) materials and recycling rates. As this could result in new or altered impacts, the validity of the report should be checked when used after this timeframe.

Scoping

Within a LCA, processes and emissions can be scaled in either the first, or second-order level of inventory. In any case, processes and emissions in the first order level should be included and examined in the LCA. For those in the second order level, the boundary of in-or exclusion is set to 10%. Meaning that, only emissions affecting the packaging solution for more than 10% will be included in the LCA. For clarity an example of this 'order level of inventory' will be given:

Of the environmental impacts of a packaging solution is created by the material. Assume the creation of a plastic container. Logically, (nearly) all input materials are used for the creation of the container. Thus the environmental impact can fully be determined to this packaging and is therefore referred to as: first-order intervention. However, for the secondary and tertiary packaging, it can be doubted if this is a first-order intervention as well. Since, multiple packages are packed in one secondary packaging. And multiple secondary packages are contained in one tertiary packaging. Depending on the functional unit, these parts can be classified as first or second-order intervention. The latter is the case when less than 10% of the impacts can be devoted to the total amount, as declared in the functional unit.

4.1.3. Functional unit

To compare the four packaging solutions, the following functional unit is defined:

> "TO PACKAGE 175 GRAMS OF FRESH VEGETABLE SPREADS PER UNIT, AT A TOTAL OF 10,000 PIECES"

The quantities denoted in the FU are based upon the specifications of (one of) the most popular packaging containers of Hordijk. Since, this assignment has the ultimate goal to advise Hordijk in, amongst others, selecting the right material for the next generation of food containers. The container that is used as a reference, represents a high share of Hordijks business. For this container, competitors with similar specifications can be found in other material types. Hence, by using this popular container of Hordijk as a reference, an advise can be given for this high share of packaging solutions for the fresh food industry.

The most popular PET container is model 147, with a height of 41 mm and consequently a (maximum) volume of 310 milliliters. This results in a Stock Keeping Unit (SKU) of 9120 pieces; representing one metal cage in which the containers are collected and transported, to the next industry. For the ease of calculating in the remainder of this LCA, the SKU has been rounded off to 10,000 pieces.

4.1.4. Specifications

Within the remainder of this section, the specifications of each packaging solution will be discussed. It is desired that this LCA presents an honest and transparent view of the market: the packaging solutions and their corresponding environmental impact. Therefore, packaging solutions (and their corresponding characteristics) have been chosen that actually apply to the FU as being used in real-life situations.

In each section a table will be presented, declaring the specifications of the container used as input for the life cycle as modelled in the software of Gabi. Within the table it is also declared which boxes are used as a secondary packaging. Within the classification (Chapter 5.2) and characterization (Chapter 5.3) phase it will be declared why this specific secondary packaging is used. The table also declares the recycling rate of the packaging. This percentage illustrates how much of the total input will be transformed into recyclate in the end.

PET Container

The 100% virgin PET container is made in Hordijks manufacturing plant. Model 147, with crease and a height of 41 and diameter of 115 millimeters is one of the most popular items of Hordijk and sold in high quantities. The model with crease is taking place of the similar model 147 without crease. This decision has been made as less material (the thickness could be decreased from 0.65 μ to 0.55 μ) is needed. After an extrusion process, the plastic containers are created in a thermoforming production process. Since the container has a round shape, around 45% of excess material (trim) is created. This trim will be used within the extrusion process as internal recycling. The container can package 175 grams of product (i.e. fresh vegetable spread) and can be described among the specifications of Table 13.

Multiple recycling rates for plastic were discussed in the current state of affairs (Chapter 2). For the LCA, it is concluded that 56% of the plastic packages from the Dutch household can be recycled 'good' [51] and 50% is actually recycled into recyclate [82]. Since the chosen PET containers fit the requirements of the KIDV to be recycled within the Dutch recycling system, the present recycling rate of 50% can in practice be higher.

SPECIFICATIONS PET CONTAINER

Figure 30: PET Container, used for the LCA

Capacity	175 grams vegetable spread
Materials	100% virgin PET (45% trim)
Dimensions	Diameter = 115 mm Height = 41 mm Volume = 310 Milliliters
Weight	7.97 Grams
Use Cycles	1
Recycling rate	50%
Secondary packaging, production phase	1 HDPE bag, per 250 pieces 1 LDPE bag, per SKU
Secondary packaging, use phase	Box 1
Closing system	Plastic top seal

Table 13: Specifications of the PET container, used for the LCA

RPET container

The to be discussed RPET container equals the specification of the PET container in terms of the dimensions, production-, use-, and recycling process. Only the input material varies. For this container 20% recycled polyethylene terephthalate is used, accompanied by 80% virgin PET. Similar to the PET container, 45% of the 'virgin' input, results from trim.

SPECIFICATIONS RPET CONTAINER

Figure 31: RPET Container, used for the LCA

Capacity	175 grams vegetable spread
Materials	80% virgin PET (45% trim) 20% recycled PET
Dimensions	Diameter = 115 mm Height = 41 mm Volume = 310 Milliliters
Weight	7.97 Grams
Use Cycles	1
Recycling rate	50%
Secondary packaging, production phase	1 HDPE bag, per 250 pieces 1 LDPE bag, per SKU
Secondary packaging, use phase	Box 1
Closing system	Plastic top seal

Table 14: Specifications of the RPET container, used for the LCA

PB Container

The PB container is represented by a cardboard container, of equal dimensions (compared to the PET container) and a thin polyethylene (PE) liner to preserve the moisture.

The weight of the PB container should be estimated, since this specific packaging (with identical dimensions) does not exist in practice. A random coffee cup, with PE coating, weighs 7.5 grams and is able to contain 240 milliliters [83]. Though, different sizes of coffee cups can be found in the Dutch market, resulting in weights of 5-10 grams, with an average of 7 grams[84]. The packaging to be discussed, should equal the volume of the PET container: 310 milliliters. This results in a weight of 9.69 grams (. Please note that the weight of the PE coating (assumed to be 5%) is already included in this weight. Though, some extra weight should still be added in the lamination/coating process of the paperboard, as the little barrier of a coffee cup would not comply with the barrier needed to preserve food for a longer period of time (days).

To calculate this extra weight, the beverage cartons discussed in the current state of affairs have been used as a reference. Since the container will preserve a fresh vegetable spread, with a limited shelf life, the aluminum layer is neglected. This results in a PB container made from a paperboard of 85% wood fibers (of which 60% results from recycled pulp), layered with 15% PE foil [33]. Similar to the creation of the PET container, trim will also result from the production process of the PB containers. It is assumed to be less, than trim resulting from a thermoform process: 25%

Since the PE liner is in contact with the food and hence, acts as a functional barrier as well, there is an ability to use a relative high share of recycled content. Therefore the amount of recycled input PB content is assumed to be 50%

It is assumed that all P&B packages will be disposed either with the mixed waste stream or the old paper waste stream. With the mixed waste stream, paper packages are most commonly not sorted out. For the old paper waste stream, the packages do not fit the requirement of 'dry and clean' and will hence also be excluded. Moreover, currently little technologies are in use to separate the foil from the paper. Therefore, it will be assumed for this LCA that all disposed P&B containers will be incinerated.

Figure 32: PB Container, used for the LCA

SPECIFICATIONS PB CONTAINER

Capacity	175 grams vegetable spread
Materials	50% new PB materials 50% recycled PB materials 10% extra coating
Dimensions	Diameter = 115 mm Height = 41 mm Volume = 310 Milliliters
Weight	9.69 Grams
Use Cycles	1
Recycling rate	0%
Secondary packaging, production phase	Box 2
Secondary packaging, use phase	Box 1
Closing system	Plastic top seal

Table 15: Specifications of the PB container, used for the LCA

Glass jar

The glass jar that will be evaluated in the LCA is based on a common clear (white) glass jar seen in the Dutch supermarket. The specifications are based upon averages and common facts of the glass industry in the Netherlands. Hence, a max of 60% recyclate is used, based upon data declared in the current state of affairs. The other 40% is covered by virgin raw materials. The glass jar is made by the press-blow molding process.

The weight of the glass jar should also be estimated. A common glass jar for the Dutch fresh food industry weighs 177 grams and is able to contain 370 milliliters [85]. When the glass jar would scale down to a Volume of 310 milliliters (similar to the (R)PET and PB container), it results in a weight of **around 148.30 grams.**

The dimensions of the glass jar should also be re-calculated. The common glass jar, with a theoretic volume of 370 milliliters, height of 99 mm and diameter of 80 millimeters should be scaled down for a proper estimation. To calculate the new dimensions, the jar is assumed to a perfect 'cylinder'. The capacity of a cylinder can be calculated with the formula:

$$Capacity\ of\ cyclinder = \left(\frac{1}{2} \cdot d\right)^2 \cdot \pi \cdot H$$

Within the formula the diameter is represented by 'd' and height by 'H'. With the dimensions of the common glass jar in centimeters this results in:

$$\left(\tfrac{1}{2} \cdot 8\right)^2 \cdot \pi \cdot 9.9 = 497.63\ cm^3 = 497.63\ mL$$

It seems logical that this capacity is higher than the denoted volume of 370 milliliters, as the jar has a smaller top part and rounded edges (illustrated in Figure 33).

Assuming that this difference is the same in the new glass jar with a volume of 310 milliliters (equal to the (R)PET and PB container), the theoretical capacity should equal 416.41 milliliters $\left(\frac{497 \cdot 310}{370}\right)$. Assuming that the diameter equals 70 millimeters, the new glass jar has a height of:

$$\left(\frac{1}{2} \cdot 7\right)^2 \cdot \pi \cdot H = 416.41\ mL$$

$$H = \frac{416.41}{(3.5)^2 \cdot \pi} = 10.82\ cm \approx 100\ mm$$

For the sake of clarity in further calculations, the height will be rounded of to 100 mm. The glass recycling system is embedded in the Dutch culture and hence, a high recycling rate of glass packaging exists. Based upon the current state of analysis, the LCA will make use of a amount of 88% (as an average of the sources [38], [65]).

SPECIFICATIONS GLASS JAR

Figure 33: Glass jar, used for the LCA

Capacity	175 grams vegetable spread
Materials	60% recycled white glass shards, 40% raw materials (new white glass)
Dimensions	Diameter = 70 mm Height = 100 mm Volume = 310 Milliliters
Weight	148.30
Use Cycles	1
Recycling rate	88%
Secondary packaging, production phase	Box 3
Secondary packaging, use phase	Box 4
Closing system	Metal lid

Table 16: Specifications of the Glass jar, used for the LCA

Notes on the specifications

Referring to the scoping, there are also some extra parts, in the first- or second order level of inventory, that should be taken into account. As each packaging itself will be accompanied by a label, closing system (e.g. seal or lid) and the preserved food, more attributes are to be added. Moreover, as the FU covers one SKU, the secondary packaging can also be imagined to have a significant effect. These items will be discussed within this section.

Label

For simplification in the process, it is assumed that all packages are labelled equally. Meaning that the same size, material, glue and ink is used to label the packaging. In all cases, a paper label is chosen since this can be washed off using hot water, as desired by the recycle checks of the KIDV [18], [36], [70]. As the highest impact is assumed to be a result of the printed paper, the other parts of the label are neglected.

Closing system

For the PET, RPET and PB packaging the same closing system will be used. In current practice of Hordijk, the lid is more and more replaced by a plastic top seal. As the PB already consists of a plastic liner it is assumed that the closing system is also created from plastic. This results in a similar top seal for all three packages, made from 100% virgin PET (created by an extrusion process). In nearly all cases glass jars are closed by a metal lid, which will be the case for this LCA as well.

Food

The FU already declares that the packaging solution should be able to contain 175 grams of fresh vegetable spread. For simplification in the process, a standard process of the Eco Invent 3.7 is used that represent the fresh vegetable spread at best.

Distribution distances

It is assumed that the different materials have equal distribution distances, for example from the manufacturing plant to the producer of the product (food).

Secondary packaging

Within each life cycle, the packaging is in need for a secondary packaging twice; within the production phase (for transportation to the producer) and the use phase (for transportation to supermarket). It is assumed that the filled packages are always transported in a cardboard box to the supermarket. As the dimensions of the PET, RPET and PB containers are identical, the same box can be used in those use phases. For the glass jar, a different box could be necessary due to the other dimensions of the packaging. Within the production phases, the packages are empty. This creates the ability to stack the PET, RPET and PB packages. The glass jars however, cannot be stacked and are therefore in need for a different box in the production phase. The PET and RPET containers are packed in HDPE and LDPE bags in the production phase, complying with Hordijks production process. It can be imagined that these different types of secondary packaging, results in a different transport capacity. An extensive declaration of these calculations is presented in Appendix G, from which the end results are used for the IAM.

4.2. THE INVENTORY ANALYSIS PHASE

4.2.1. DATABASE DEVELOPMENT

Within this section, a set of figures illustrate the complete life cycle of each packaging solution. The life cycle of any arbitrary product can be declared among three major phases, when discussing it from a cradle to grave perspective. Namely, the *production, use and disposal* phase. Consequently, each of these phases consists of different steps (processes) as well. By decomposing all processes of the entire life cycle into single steps, the elementary flows (input/output) of each process become clear. This way the overall environmental impact of each packaging individually can in the end be calculated and also, compared to each other. After classification and characterization has been done, the figures throughout this section – representing the entire life cycle – could be used to model the life cycles in Gabi and evaluate the functional unit.

For each packaging solution, as discussed in Chapter 4.1.4, figures will represent the production, use and disposal phase in consecutive order. It should be kept in mind that these figures only illustrate a representation of the life cycle and that the specified (raw) materials and in- and output flows of each process will be discussed in Chapter 5.2.1. How the figures discussed were translated as an input for the modelling software of Gabi, is presented in Appendix I. For clarity of the reader, the presentation of the processes and flows within Figure 34-37 is consistent:

- **Black squares:** indicating the main process
- **Black (stand-alone) text**: Input- or output flow, in between processes
- **Yellow squares**: indicating input or output flows, necessary for the accompanied process
- **Green squares**: indicating outflows that represent an 'avoided product'

PET

Production

Within Figure 34a the production process of a PET container is presented. The process starts with extrusion of PET film. In order to create a roll of PET film, (raw) materials, electricity and heat (i.e. steam) should be added to the extruder. Moreover, the roll should be supported, which is done by a cardboard roll. From current practice of Hordijk it is known that this roll is used twice. Hence, 50% of the product acts as an avoided product in the system, when modelling the life cycle. The other half should be modelled as waste. To create a virgin PET container, virgin PET flakes or granulate should be added to the extruder. Moreover, an anti-block coating is added in order to prevent the material from its static material properties. Though, the amount necessary for one SKU is too little to take into account according to the scoping of this LCA.

The actual containers are created within the second process: the thermoforming machine. Here, the extruded roll is conveyed within a machine in which the containers are created by heating, die-cutting and cooling the material. As the FU only covers one SKU, the machine and dies are not applicable to the scope. The water for the cooling system and the energy necessary to create the containers, should be taken into account. Next to the cardboard roll and containers, the process leaves the manufacturer with trim. Since this trim is a pre-consumer material, it can directly be used within the extrusion process again. Hence, it should be modelled as an avoided product.

Within the last step, the packaging is prepared for the next plan: the use phase. For a proper distinction between these plans, it has been assumed that the use phase starts at the moment a complete SKU arrives at the 'client' (i.e. the producer of the product or packing company). For the production phase this means that the last process should be covered by the addition of the secondary packaging and transport of entire SKU to the 'client'. A SKU unit of PET containers consists of the 10 000 packages as declared in the FU and secondary and tertiary packaging. The secondary packaging is illustrated in Figure 34a as the HDPE and LDPE bags, in which the HDPE bas unify one batch of containers and the LDPE bags unify all batches to create one SKU. This LDPE bag is usually transported in a metal cage (tertiary packaging), working with a deposit system. Meaning that the filled metal cages are transported to the client and are brought back empty, to be used again. As this can be done many times, accompanying many SKU of packages, the effect to one SKU would be less than the discussed 10% of Chapter 4.1.2. Hence, the tertiary packaging (the metal cages) is left beyond the scope of the assignment.

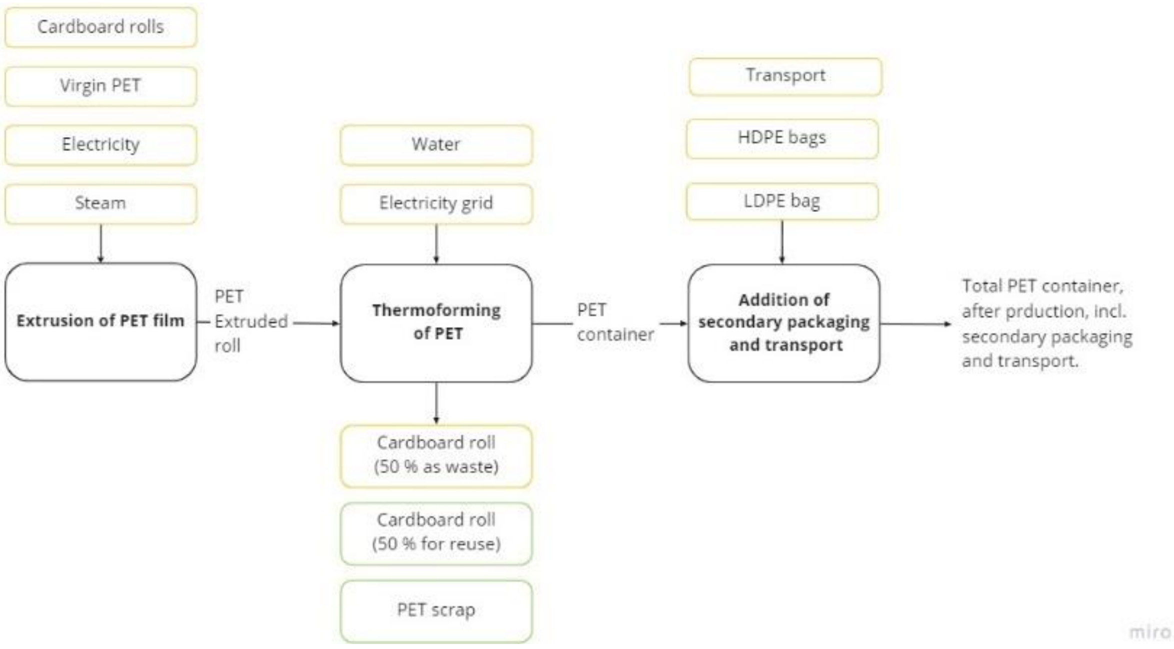

***Figure 34a:** Creation of life cycle plan; PET: Production*

Use

The use phase of PET is illustrated in Figure 34b. Please note that the plan is illustrated in two parts to assist the readability, but should be modelled as one line of consecutive steps. As declared in the production phase of PET, the use phase starts at the moment the SKU arrives at the client. Here the totality of the PET containers and secondary packaging will first be unpacked. As a result, there is an output of LDPE and HDPE bags which are assumed to be incinerated. The packages can now be conveyed, such that it will be filled with the product (food), enclosed and labelled. For each of these three processes, energy is needed: to convey the packaging from one process to they other and to keep the machines of filling, sealing and labelling running. Within the filling process a machine will drop the product into the packaging, resulting in a container filled with the food. Then the product will be enclosed by adding a seal (or lid), from which the packaging will be transferred to a machine that adds a label. At this point the product-packaging combination has been created and is ready to be transported to the next destination: the supermarket. It can be imagined that within these three processes more interventions can be created; for example the glue that is used to add the label. However, according to the scoping of this LCA, only the most important influences to one SKU are implemented in the plan. Thus, the inputs of energy, the food, seal and label. To keep the modelling of the life cycle uncomplicated, a food product that is available in the database, representing the 'vegetable spread' at best, has been chosen. Similar for the seal, which can sufficiently be replaced by an extruded plastic foil and printed paper, representing the label.

Similar to the production phase, the following processes encompasses the addition of secondary packaging and transport. As the product-packaging combination will be transported to the supermarket, in small batches, it is assumed to have a secondary packaging in the shape of a cardboard box. Since the FU declares a (fresh food) vegetable spread as the product to be preserved, refrigerated transport will be necessary and is added as an input to the plan. When entering the supermarket, the cardboard box can be disposed of and the product-packaging combination can be stored in a refrigeration system, for which cooling is needed as illustrated in the yellow square above the process. Although it is common for Dutch supermarket to reuse some of the secondary cardboard boxes one cycle (e.g. providing the boxes for free to customers), it has not been considered in the plan. Since, modelling the cardboard boxes as an avoided product would not be fair compared to other waste streams. Especially, as only part of the boxes would be used one extra cycle. Referring to the scoping of Chapter 4.1.2 and keeping the desire for an uncomplicated life cycle into account, the decision has been made to model the cardboard box as waste. However, for consistency throughout the life cycles, this effect has been added to all life cycles. Since, all packaging containers cycle through their use phase with a similar cardboard box.

When the product-packaging combination is purchased in the supermarket, it is assumed that a share of containers is transported to households by car, adding an effect that applies within the scope. Within the IAM, the characterization of this process should accurately be calculated, as this only applies to a specific share of the containers. Lastly, it is imagined that nearly all product (food) is consumed within the household and the packaging is disposed off with the label, seal and some residue.

For consistency and according to the FU, it will be assumed that all packaging solutions to be discussed are 'used' within the same circumstances. In other words; the same food product and label is added to the packaging containers. Moreover, all containers are transported to the supermarket within the same type of refrigerated truck and are stored among the same cooling specifications. It will also be assumed that, despite the material and corresponding dimensions, all packages are transported in equal quantities (pieces) to the supermarket, within the same secondary packaging. The latter is more extensively demonstrated within Appendix G. Furthermore, transport from supermarket to household and the transport from the household to the disposal system are assumed to be equal for all packaging solutions. Logically, a few distinctions can be found within the use phase of PB and glass, compared to the (R)PET packaging. When discussing the use phases of PB and glass, the focus will be on these distinctions.

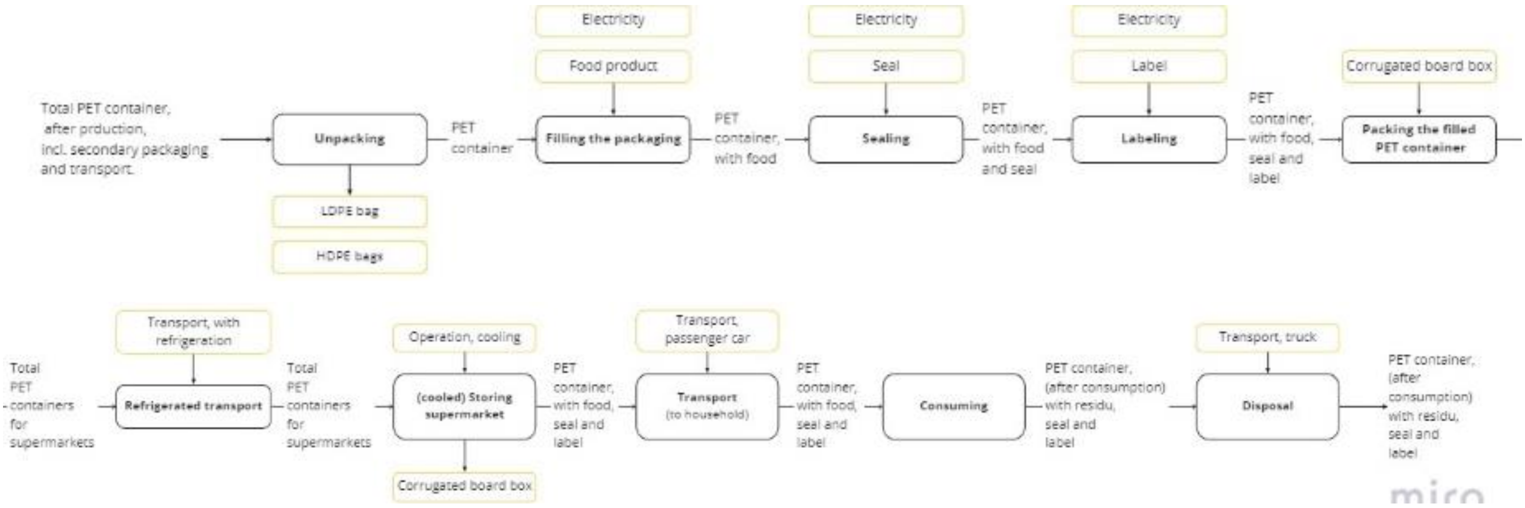

Figure 34b: *Creation of life cycle plan; PET: Use*

Disposal

After the production and use phase, the disposal phase of the PET container should be modelled, as illustrated by the plan in Figure 34c. It is imagined that the disposal phase starts at the moment the container enters the waste collector. As discussed within Chapter 2.4.4, it is common in the Netherlands to either make use of a post- or pre separation system. Therefore, within the second process of the disposal plan, some extra transport is added to the process of sorting the waste. Within this process it is also assumed that a share of containers are, although they can in theory be recycled, missorted. Since, the containers are collected with other types of waste that should be sorted from the share of plastic. Logically, due to pollution of the waste stream, a share of the input containers will be missorted and treated as waste. Again, due to the pollution and high share of other wastes or materials, this selection is assumed to be incinerated with the municipality waste stream. When the stream has been cleared from major pollutions, it is time to wash the input. Hence, water, electricity and gas is used as an input to clear out the residue, wash off the label and filter the seal. It is demonstrated that foils are difficult to recycle, especially with a polluted waste stream [S2, S3, S4]. Hence, it has been assumed that the yellow square illustrating the 'Waste PET film' in Figure 34c, should be modelled as an incineration process of plastic. The same held for the residue and label, which are incinerated with municipality waste due to the high level of pollution. A share of this residue and label will leave the process with the wastewater output. After the washing process, the PET is shredded into little pieces for which electricity is needed. Then a sorting procedure is necessary again, in which a selection of missorted PET flakes cannot be avoided. This can be due to the discoloration of the waste, the quality of the product or the presence of other materials, as seen in practice [S2, S3]. Lastly, the PET flakes are classified into either a mixed plastic waste stream or a higher quality of RPET flakes. Both flows should be seen as an avoided product, as it adds positive influence to the environmental impact.

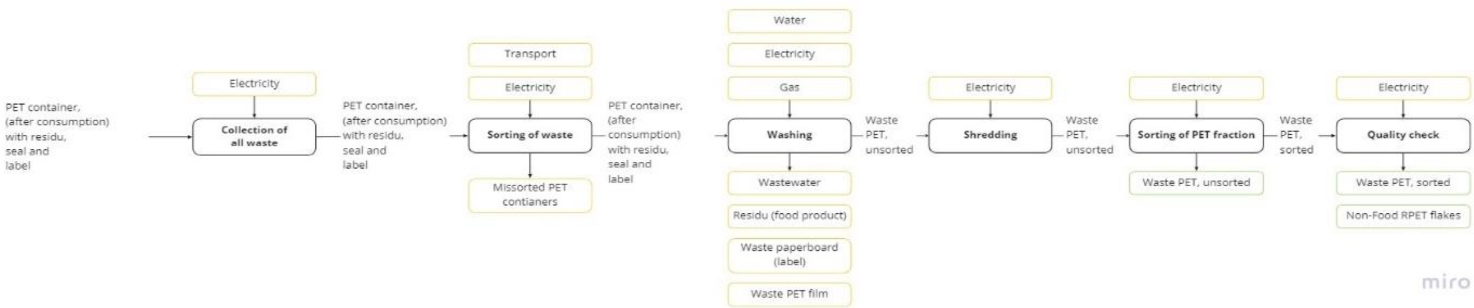

Figure 34c: *Creation of life cycle plan; PET: Disposal*

RPET

Production

The production of RPET food containers equals the production of PET containers in nearly all processes. Only the input flow of the extrusion process is significantly different. Here, not only virgin PET flakes or granulate are added to the extruder. Also, recycled PET flakes or granulate is added, as can be seen in Figure 35. Depending on the input, the trim that is created in the thermoforming process differs and instead of PET containers, RPET containers are the output of the process. This difference in terminology continues throughout the production, use and disposal phase of RPET. In theory, the processes themselve are equal when comparing the RPET life cycle to the PET life cycle. Hence, no further explanation will be given about the use and disposal plan of RPET. For the sake of clarity, the plans will illustratively be presented in appendix I, before displaying the actual plans as modelled in Gabi.

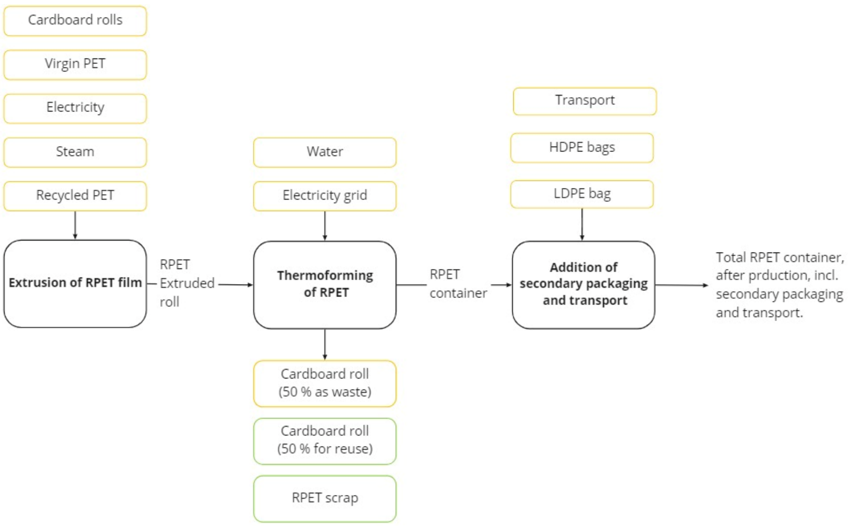

Figure 35: *Creation of life cycle plan; RPET: Production*

PB

Production

In order to produce the PB container (as illustrated in Figure 36a), it has been assumed that a sheet of PB material should be created before the packaging is shaped. To do so, pulp should be created of new and recycled wood fibers. With the addition of water, the pulp is created among specific circumstances, that are neglectable for this LC. By pressing and heating the pulp, a sheet can be created. Within this process a large amount of water is subtracted from the material, of which a share can be used for the creation of new pulp. The green line in Figure 36a, illustrates that a share of the wastewater will used as input again. Some water will always be remained within the resulting sheet, of which the amount depends on the product specifications. Since the PB material should preserve moisture products, the material needs to be prepared as illustrated by the next process. Within this process a plastic film (coating) is added to the PB surface. Therefore, the input of a plastic film and energy is needed. As a result a slightly heavier PB sheet continues to the next process. Similar to the extrusion process of (R)PET, the material will be stored on a cardboard roll which can be used twice for the entire production process. The shaping of the material can be done in multiple ways, of which in all cases energy is the only effect within the denoted scoping system. When the PB container is created, it is packed in a corrugated board box and transported to the 'client'.

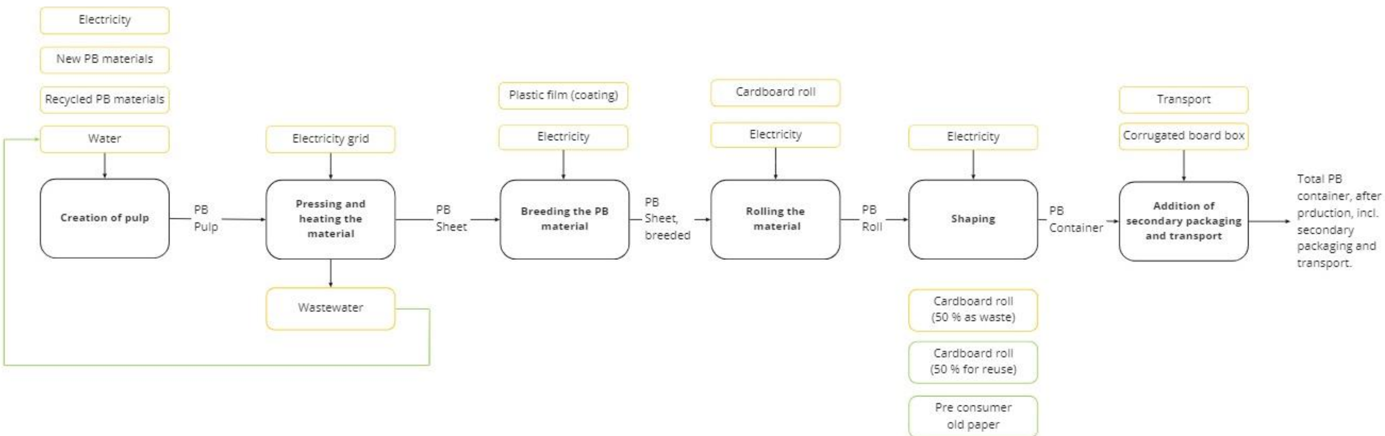

Figure 36a: *Creation of life cycle plan; PB: Production*

Use

As stated before, the use phase of the PB container is nearly equal to the use phase of the (R)PET container. However, within the first process no HDPE and LDPE bags are disposed of, but a corrugated board box as being the secondary packaging in the production phase. Similar to the use phase of the (R)PET container, these corrugated board boxes should be modelled as waste streams. The same held for the corrugated board box that is disposed in the process of '(cooled) storing at the supermarket'. This should be simulated in the modelling software with the same disposal system, throughout all use-phases of the packaging solutions. Other differences that should be taken into account for the use phase of the PB container lay within the characterization. Of course different input weights and energy usages are needed. Moreover, it should be checked how much more capacity of the truck is needed to transport the corrugated board box when filled, compared to transporting the containers empty.

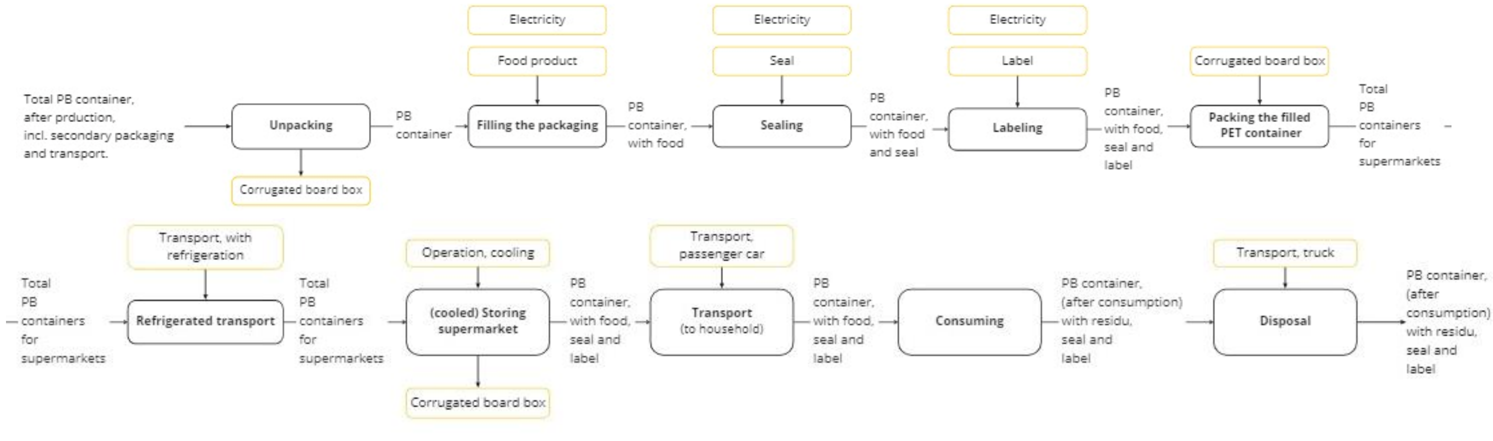

Figure 36b: Creation of life cycle plan; PB: Use

Disposal

Lastly, the disposal phase of the PB container is illustrated (Figure 36c). The disposal phase of the PB container can be described among two processes, due to the impossibility of recycling. Similar to the disposal phase of (R)PET, the container can be sorted via two systems adding an extra transportation step. In the end two waste streams are incinerated, either a mixed waste stream of municipality waste or specific PB waste stream.

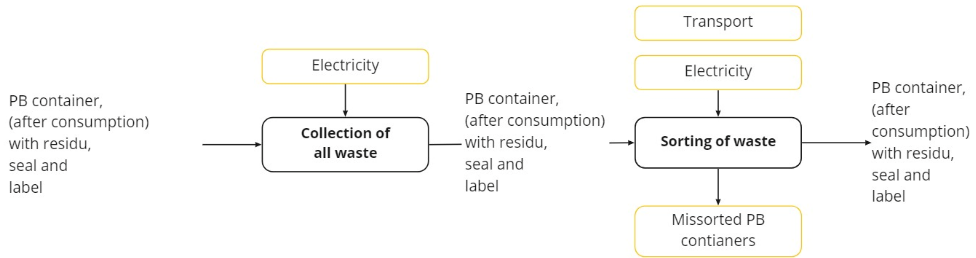

Figure 36c: Creation of life cycle plan; PB: Disposal

Glass

Production

The production process of glass jars is illustrated in Figure 37a. Due to the extreme heat that is necessary to create glass, it should be mentioned that the electricity presented in the production process should be characterized with a high voltage. The production process starts with the creation of a glass gob, made from an input of both new as well as recycled white shards. After the jar is shaped and annealed, the glass jar can be transported to the 'client' similarly as with the (R)PET and PB processes. Due to the respectively high weight of the glass jars, the secondary packaging is assumed to be covered by corrugated board boxes. Where the (R)PET and PB containers could be stacked in transport, glass jars cannot. Hence, smaller batches and more corrugated board boxes are necessary which should be taken into account.

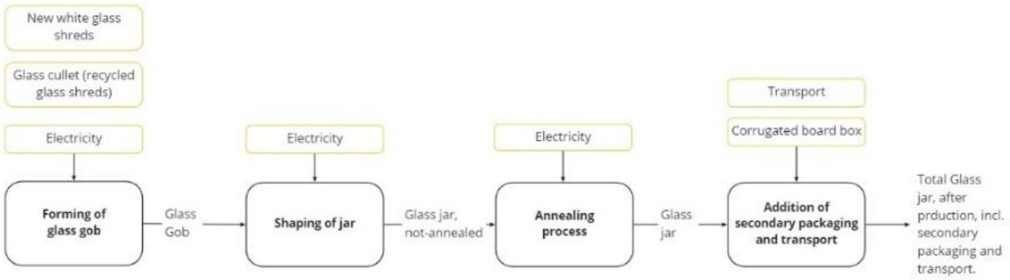

Figure 37a: Creation of life cycle plan; Glass: Production

Use

Again, the use phase of the Glass jar (illustrated in Figure 37b) is equivalent to the use phase of the (R)PET and PB container. One difference can be found in the third process; in which the packaging is not closed by a plastic seal, but by means of a metal lid.

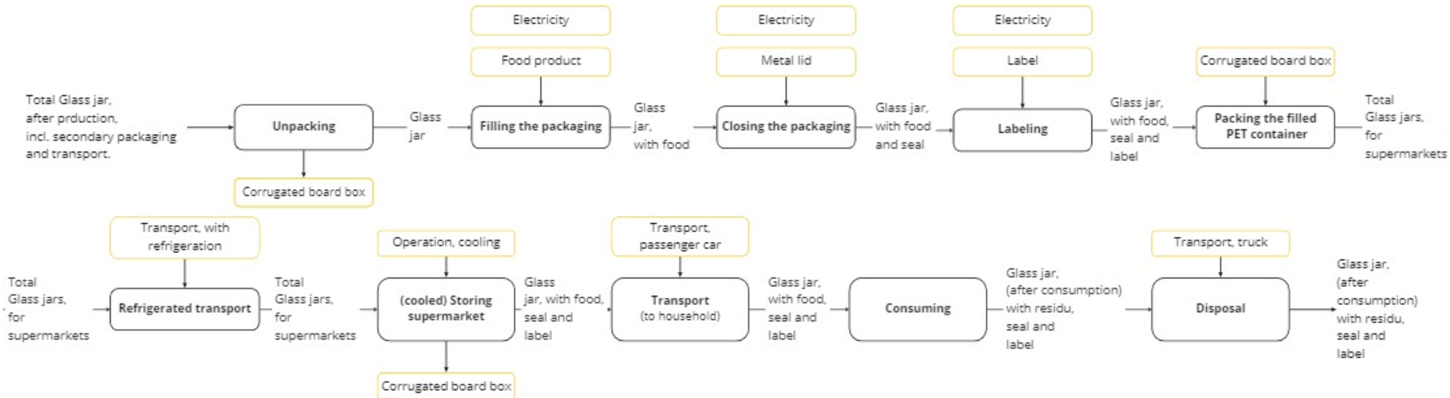

Figure 37b: Creation of life cycle plan; Glass: Use

Disposal

Within the disposal process of glass (Figure 37c), a high share of the jars will be recycled into new glass shards (also referred to as cullet). Equivalent to the disposal process of (R)PET and PB containers, some jars will be missorted due to the presence of multiple disposal systems. In real life situations, a share of glass jars is disposed with the municipality waste stream and as a result, does not end up in the recycling of glass. Therefore, a waste stream of missorted glass jars is illustrated in the second process of the plan, illustrated in Figure 37c. The high share of glass jars that do end up in the system, are already broken into pieces due to the effect of 'throwing' away the glass jar in the container. This should be taken into account in the transport of the waste. After the pieces are shredded further, the shards are sorted and sieved in order to, for example, get rid of the metal pieces (the lid). Some extra sorting will be done, in which – again – a small share of glass jars will be missorted, before recyclate is created. The latter is done by heating and cooling the shards again.

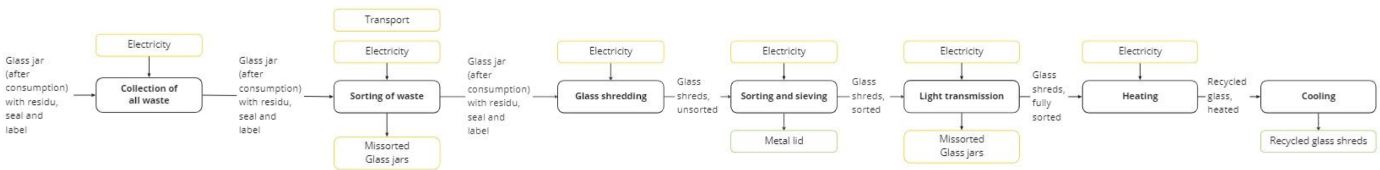

Figure 37c: Creation of life cycle plan; Glass: Use

4.3. THE IMPACT ASSESSMENT PHASE

The life cycle plans of each packaging solution were presented and discussed thoroughly in the previous section. Therefore, this IAM only covers the data behind the discussed life cycles.

From the plans, as declared in Figure 34-37, all input and output flows of each single process became clear. With the use of information found in the current state of affairs, EcoInvent 3.7 database or literature, each input and output flow could be paired with specific data (i.e. weight, energy use or distance).

SUBPLAN LC PET: PRODUCTION						Remarks		
Process	*Input / Output flow*		*Quantity*	*Unit*	*Amount*	*(Amounts are based on the FU)*	*Calculation*	*Source*
Extrusion of PET film	IN	Core board	Mass	kg	3	Assumed one roll necesseary for 1 SKU, weighs 3 kg		
	IN	Polyethyle terephthalate	Mass	kg	144,9	1 SKU = 7,97 grams x 10 000 products (79,7 kg), account for 55 % of the extruded plastic (since 45 % is trim)	79,7/55 = 1,449 kg per %. So 100 % = 144,9 kg	
	IN	Electricity	Energy	kWh	79,695	Extuder uses 0,55 kWh per purchased kg plastic	144,9*0,55	[S5]
				MJ	286,9			
	IN	Water	Mass	kg	13,75	For the creation of 1 kg plastic, 0,0949 kg water is used	0,0949*144,9	EcoIvent 3.7 database
	OUT	PET extruded roll	Mass	kg	147,9	Weigth of roll + weigth of the PET	3+144,9	
Thermoforming of PET	IN	PET extruded roll	Mass	kg	147,9			
	IN	Tap water	Mass	kg	0,004	For the creation of 1 kg plastic, 0,0000276 kg water is used as input	144,9*0,0000276	EcoIvent 3.7 database
	IN	Electricity	Energy	kWh	94,185	Thermoform machine uses 0,65 kWh per kg input plastic	0,65*144,9	[S5]
				MJ	339,07			
	OUT	Core board (Avoided product)	Mass	kg	1,5	A roll is used twice, so half of the input weight is an avoided product.	3/2	
	OUT	Core board (Incineration)	Mass	kg	1,5			
	OUT	PET trim	Mass	kg	65,205	45 % of the input plastic is trim		
	OUT	PET Container	Mass	kg	79,7	One product weighs 7,97 grams. FU = 10 000 products	(7,97/1000)*10 000	

Table 17: Illustration of table declaring the flows, quantities and amounts of creating a lifecycle in the modelling software

Table 17 declares the first two processes of the PET production plan, as illustrated in Figure 34a. Within each column, information is presented that supports in creating the actual LC in the modelling software. This has been done for all packaging containers, of which the entire table, per production, use and disposal can be found in the appendix H. For each Table the following structure of the columns applies:

1. Declaration of the process that should be modelled in the plan, as illustrated in Figure 34-37
2. Specification of the flow: input or output
3. Declaration of the flow
4. Quantity of the flow
5. Unit; for some quantities multiple units are presented, depending on the calculation and specifications desired in the modelling software
6. Amount; the specific amount needed for the corresponding flow
7. Remarks; declaring how the amount is calculated or assumed, for one FU.
8. Calculation: the actual calculation behind the amount
9. Sources; when applicable, sources (supporting the remarks or calculation) are presented

The actual life cycles were modelled within the software of Gabi, in which other terminology of the processes, flows and quantities exists. For these specific plans, please consult Appendix I.

4.4. THE INTERPRETATION PHASE

4.4.1. EVALUATION

To evaluate the life cycles, it has first been checked which processes had an extreme influence (positive or negative) to the outcome. These processes were changed by other processes of the EcoInvent Database, to check upon consistency. For example, initially an extreme impact was found in the production process of PB at the output process of 'pressing and heating the material'. Due to this extreme impact, other effects in the process became insignificant. It is logical that this process has a high effect, due to the large amount of wastewater that is created. However, not all water should be considered as waste and hence, a loop has been created, between the input and output of the (waste)water. This way, the lifecycle is consistent with reality.

Moreover, as declared, the processes with high assumptions (i.e. assuming that all cardboard boxes were disposed instead of reused) were kept equivalent for all materials. This way, differences can at least be balanced out when comparing all life cycles with each other, as was desired for this LCA. For the assessment of each life cycle individually it should be taken into account that these types of assumption were made.

Please note, all information is only used if verified with academic sources, opinions of experts or output of real-life machinery. Moreover, the used data is in all cases checked with standardized processes of the Eco Invent 3.7. database. However, simplifications are made throughout the entire LCA. This results in a margin of inaccuracy and uncertainty of the results, which should be taken into account.

For the final evaluation, the outcome of the assessment will be checked with existing life cycle assessments in the remainder of this section. Although a different Functional Unit is used in all life cycle assessments and each life cycle has its own scope, comparable conclusions can verify the final outcome.

After validation, the data can be used as an input for the modelling software. Within the modelling software the different plans, as illustrated in Figure 34-37, can be connected to create one overall life cycle for each packaging solution. These four plans can be compared to each other, from which the modelling software can calculate some valuable results. The overall environmental impact is based on the effects of the ReCiPe method (2016 v1.1) representing nineteen individual environmental impacts.

The ReCiPe (2016) method is a harmonized life cycle impact assessment method, at midpoint and endpoint level, that is often used in the Netherlands and Europe [86]. Within the precious sections, different life cycles were created that represent the packages. These life cycles were connected to a number of emissions as input and output data. This data can vary in the environmental relevance [86], but by proper characterization (as presented in Table 17), data could be indicated per FU. When calculating how this data results in an environmental impact, the ReCiPe method is used. This method provides harmonized characterization factors at nineteen midpoint and three endpoint levels. When using the processes from the Ecolvent 3.7 database, Gabi calculates the environmental impact for each process (and hence, flow) per midpoint and endpoint. This transition can be made visible in the program, of which the results will be discussed. What the midpoints of the ReCiPe methods are and how they affect the three endpoints, is illustrated in Figure 38.

The figures representing each effect of the ReCiPe method individually for each of the four life cycles, are added to Appendix J. From the figures it can be concluded that for 18 out of 19 effects, the life cycle of glass has the highest impact. For the effect of 'Marine Eutrophication' the highest impact can be devoted to the life cycle of PB. When looking more thoroughly into this effect, it can be seen that nearly the entire effect is created by the production phase of the PB life cycle. Even more specifically; by the sludge that is created from pressing and heating the pulp. When this process can be altered, the entire life cycle of the PB can benefit with regards to sustainability.

Within Figure 39, the normalized midpoint effects, as discussed above and presented in Appendix J, have been summed. By summing all normalized midpoint effects, the total score (in Person eq.) could be derived. For the calculations, please consult Appendix J.

- **PET:** 28.76 Person eq.
- **RPET:** 28.62 Person eq.
- **PB:** 37.01 Person eq.
- **GLASS:** 93,16 Person eq.

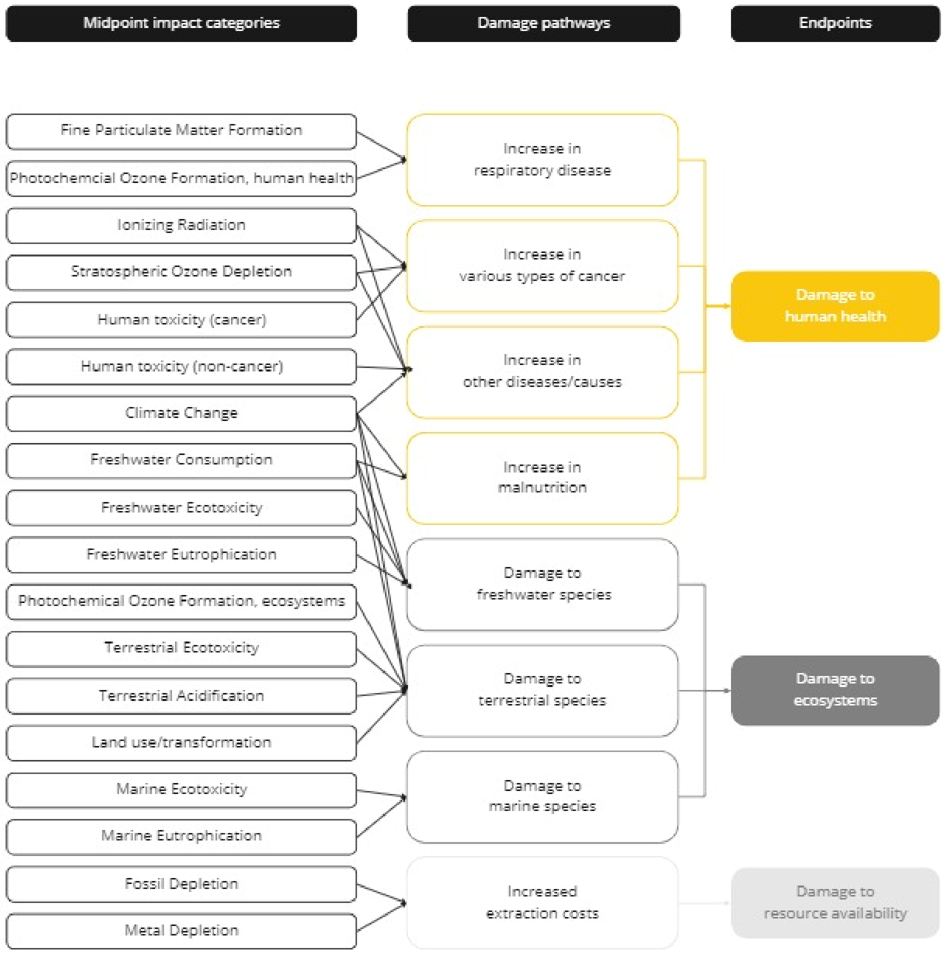

Figure 38: Declaration of ReCiPe midpoints and endpoints

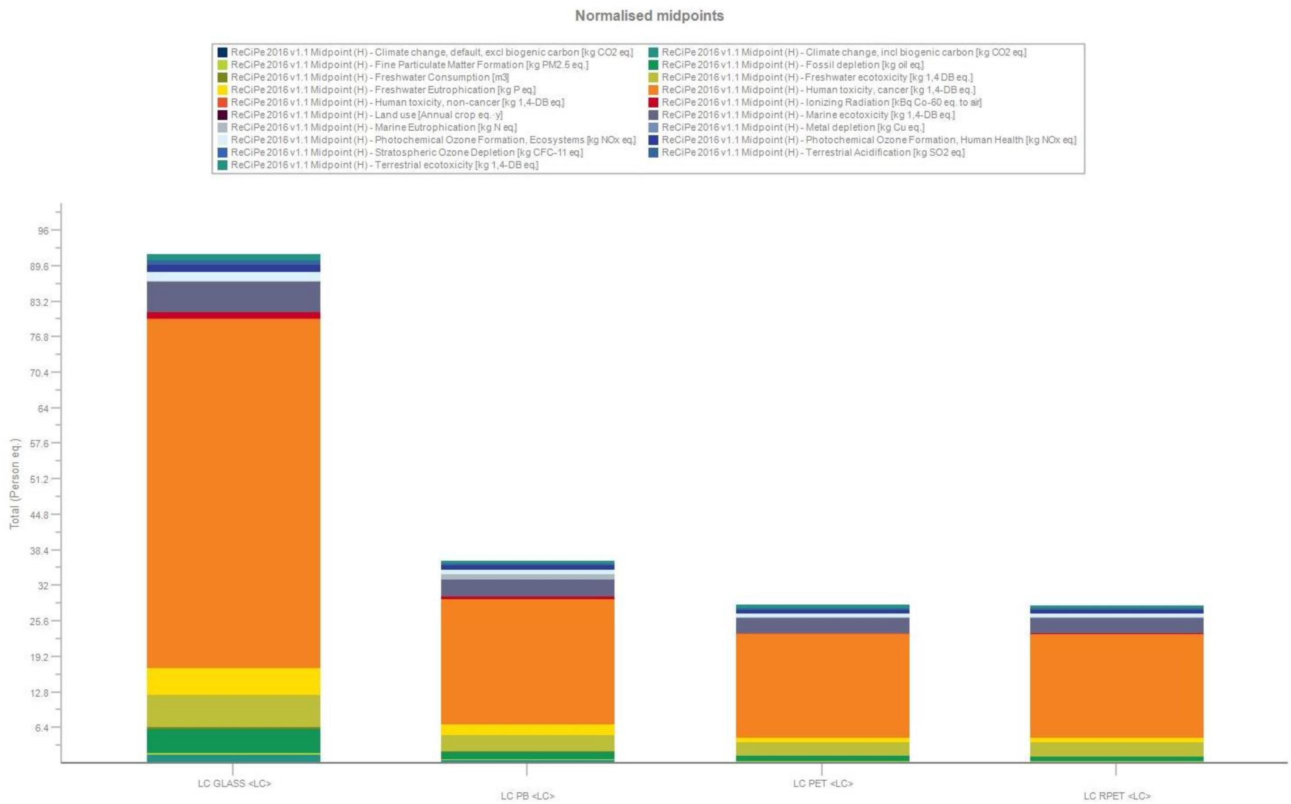

Figure 39: Total effect (based on the normalized midpoints) for the life cycles of each packaging solution, using the modelling software of Gabi

The unit of 'person eq.' stands for person equivalent and is a quantification of the environmental impact, caused by the activities of an average European annually. Using the calculated normalized midpoints of Gabi, the different containers can now be compared on fair ground. The normalization step expresses the given impact per functional unit. Since, the functional unit: "To package 175 grams of fresh vegetable spreads per unit, at a total of 10,000 pieces" was derived in order to compare products on fair ground. Knowing that each packaging has a life span of 1 cycle (in which 175 grams of fresh vegetable spread can be packed), the life cycle of all packaging solutions can fulfill 10 000 times the functional unit. *Thus, 1/10 000 of the life cycle is needed for one functional unit.* However, for a total of 1 SKU the normalized midpoints effect as declared above were derived. As this is normalized on the activities of an average European, it could be stated that the lower the number, the less environmental impact is caused. As illustrated, the RPET container has the smallest environmental impact, compared to the solutions made from PET, PB and glass. Although, there is only a minor difference with the environmental impact of PET, it should be taken into account that the results are based on 'only' one SKU.

For the validation of these numbers, life cycles with a respectively similar purpose, goal and subject have been researched. The conclusion can be drawn that for similar subjects such as coffee cups, reusable food containers and bags, plastic is the preferred solution, in terms of the environmental impact, as well [7], [87]–[91]. It should be kept in mind that the comparisons are always created for different Functional Units and calculated based on different material types (ceramics, PB that is not coated or other plastic types such as LDPE or HDPE). However, in all respectively similar cases the plastic solutions had the lowest environmental impact and thus, the outcome of this LCA is assumed to be valid.

More valuable data can be evaluated from the modelling software. First of all, a dive will be taken into the phases of each packaging solution (the production, use and disposal phase). Within Appendix J, figures illustrate the environmental impact based on the total input and output of each life cycle, per phase of the packaging.

It can be concluded that for the Glass jar, the highest impact can be devoted to the production phase, which seems logical due to the high energy uses and weight of the input materials. The use phase of the glass jars also add to the impact significantly. When looking further into the impacts per phase individually again, it can be seen that the 'food' has the highest impact within the use phase. This is no surprise, when compared to other researches that demonstrate the large effect of food on the sustainability of food packaging [7], [57], [58]. After the impact of food, high effects can be found for the secondary packaging (the cardboard box) which is needed for transportation to the supermarket and the metal lid. This also held for the life cycle of PB, in which the use phase also has the highest impact. Within the production phase, high impacts are shown for the input and output processes of (waste)water. As stated before, this is due to the extreme use of water to create and dry the pulp. For the PET and RPET container, respectively similar results can be found. Logically, as only the input material varies. The use phase has the highest impact, followed by respectively the production and disposal phase. This is interesting because this means that the disposal (i.e. recycling) process of PET has less effect than the production process. Hence, the input of recyclate (resulting from the disposal plan) can therefore add positive value. This can also be concluded, when comparing the total impacts of PET and RPET with each other.

From these figures it can be concluded for each packaging, which process in each phase has the highest environmental impact. As the RPET Container has been demonstrated to have the least environmental impact, this container will be thoroughly discussed. Since, it would be interesting to analyze the opportunities for this container, in order to answer the main research question.

As can be seen in Figure 40, the highest effects for the RPET container are found in the use phase.

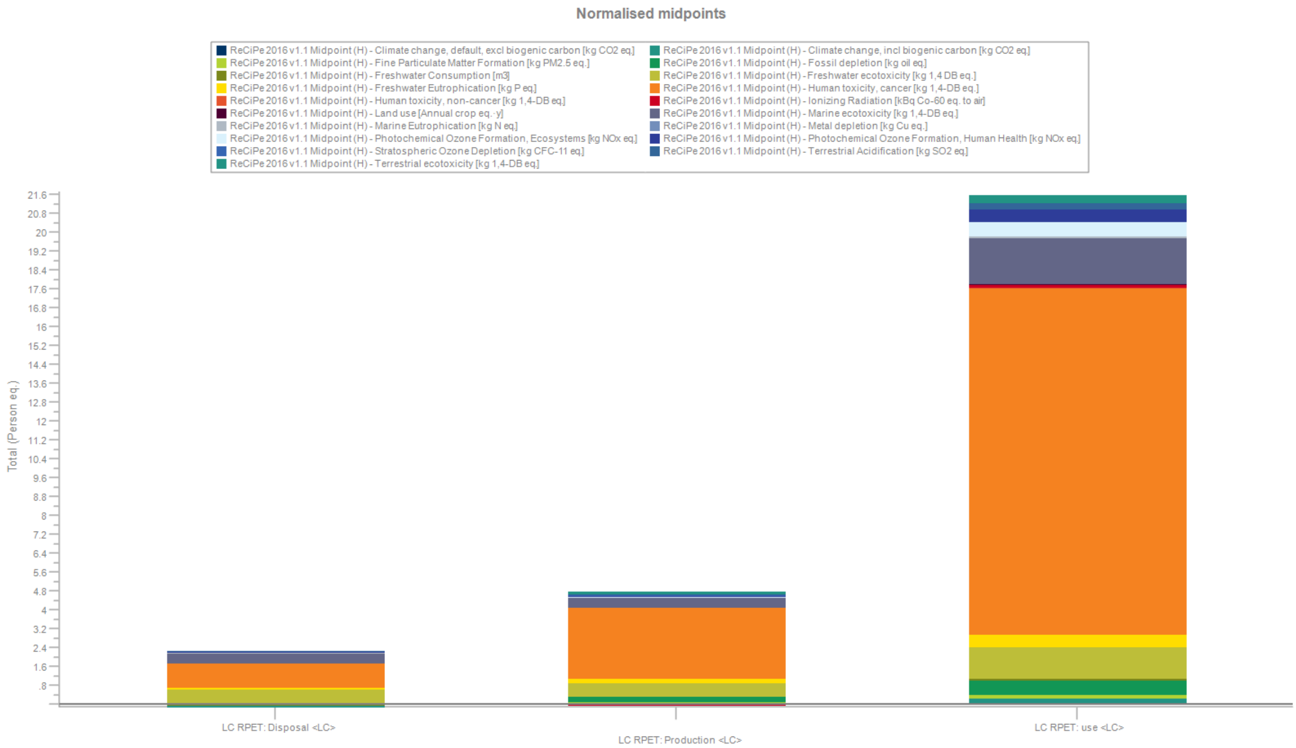

***Figure 40:** Overview of total normalized impact, based on the input/output of the entire life cycle of RPET, per phase*

Within Figure 41a-c, the impacts with the highest effects within each process are presented, consequently for the production, use and disposal plan of the RPET container. As can be seen in Figure 41a, the highest impact is created by the addition of respectively virgin and recycled PET, in the production process of the RPET container. It should be taken into account that the share of virgin PET is higher (80%) than the amount of recycled PET. However, to ratio the virgin PET still has a significant higher effect (80 % RPET would result in a total impact of (0.8*80)/20 =3.2 person eq.). Thus, from this figure it can be concluded that the addition of a higher share of RPET can result in a lower total impact. Another interesting effect is present at the creation of trim. As this is modelled as an 'avoided product' a negative impact is present; meaning that is positively adds (decreases) to the total impact. The amount of trim is significantly present in the calculations (45%) and reflects on the energy usages and input materials. Since all these processes are illustrated in Figure 41a as significant effects, it would be interesting to see if the amount of trim can be decreased in order to lower the total impact.

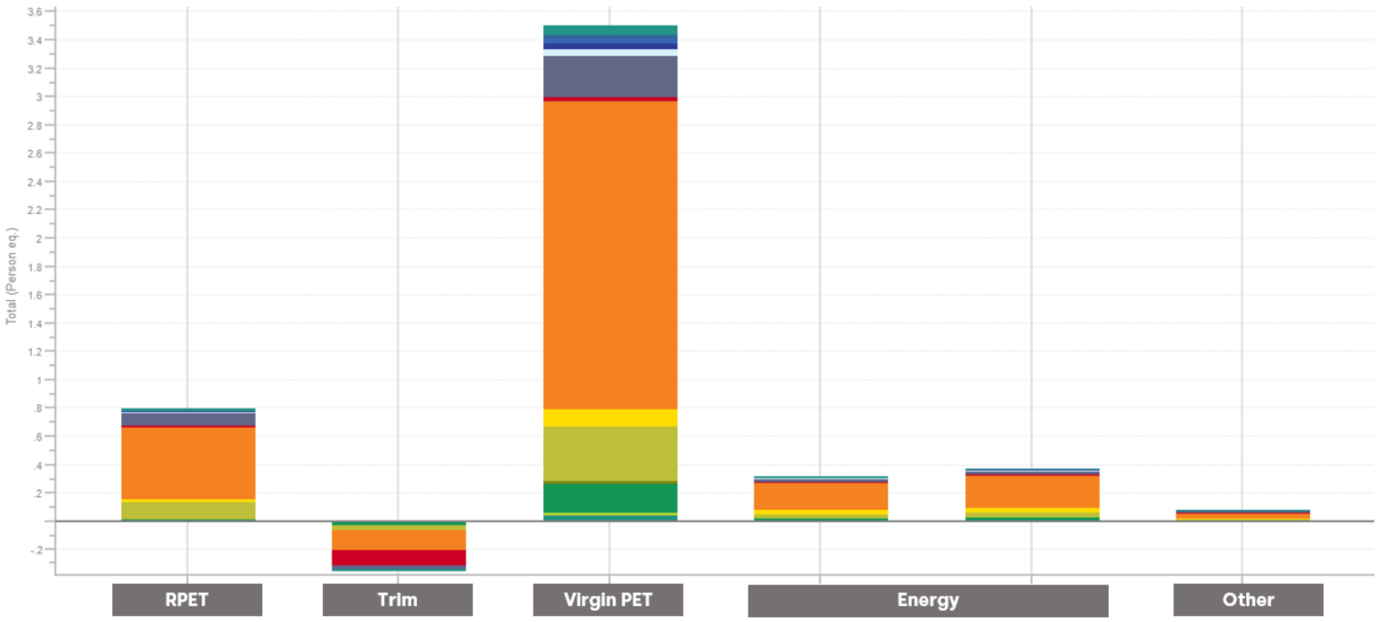

***Figure 41a:** Overview of the effects with the highest impact, within the production process of RPET*

Within the use phase (Figure 41b) the food product adds the highest effect to the impact. After the impact of the food, the different energies used to fill, label and seal (close) the packaging affect the total impact. Also the box, necessary to transport the boxes to the supermarket are found to be of influence. However, it should be taken into account that the box is modelled as 'waste', adding a significant effect that in practice can be lower, due to the possibility of re-using the box. Within the use-phases of the PET and PB container and the glass jars, an identical process is modelled for the box, resulting in a similar effect. Still, even when re-using a share of the boxes, significant effects can be found, especially when compared to other impacts of the use-phase. Lastly, the process of cooling the packages in the supermarkets adds to the total effect.

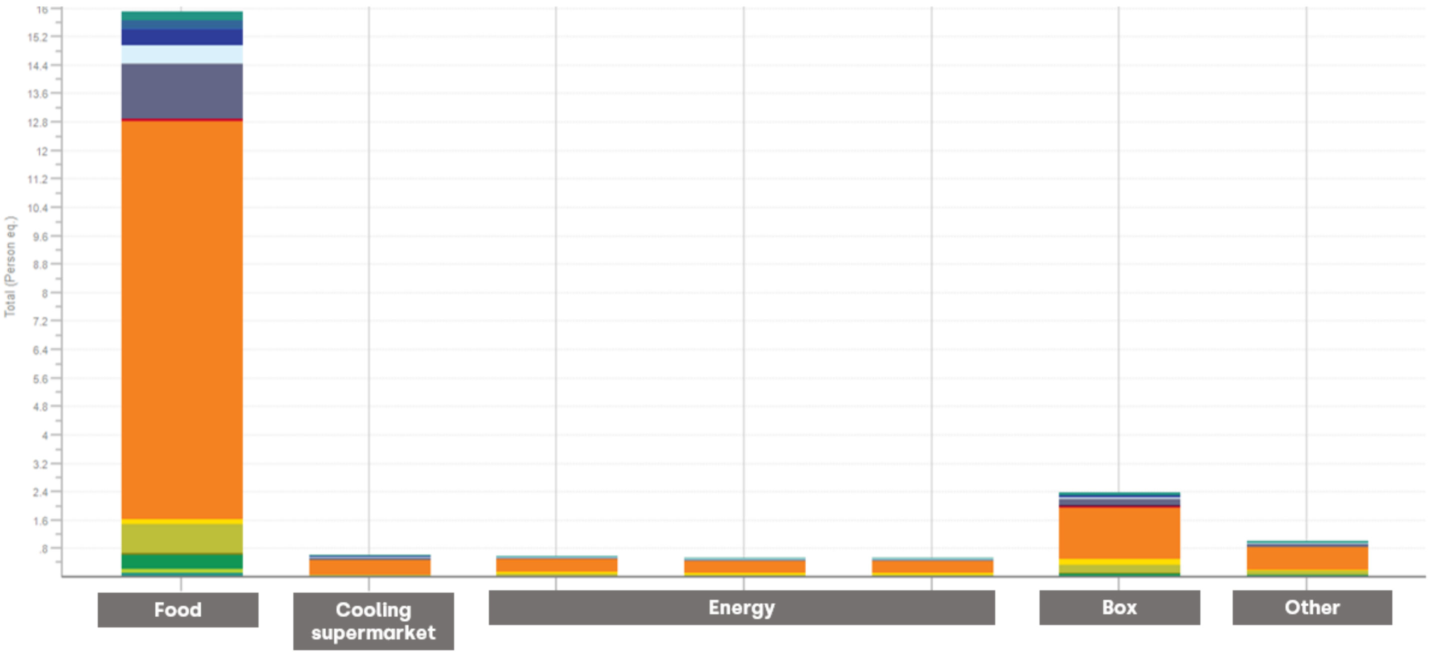

Figure 41b: Overview of the effects with the highest impact, within the use process of RPET

Lastly, impacts are calculated from the disposal process of RPET (Figure 41c). Here, the highest effects are created by the wastewater and incineration processes. Although the figure presents high 'bars' for these effects, it can be seen that the amount (y-axis) is respectively low, compared to impacts of the production and use phase. Moreover, a negative impact is presented in the last bar, representing the positive influence of creating RPET. When higher recycling rates can be achieved, not only the negative impacts can be increased, also the impacts of the incineration processes can be decreased, both adding a positive influence to the total impact. Keeping into account that the total impact created by the disposal phase is lower than the impacts created by the input materials in the production phase, possibilities for designing are present.

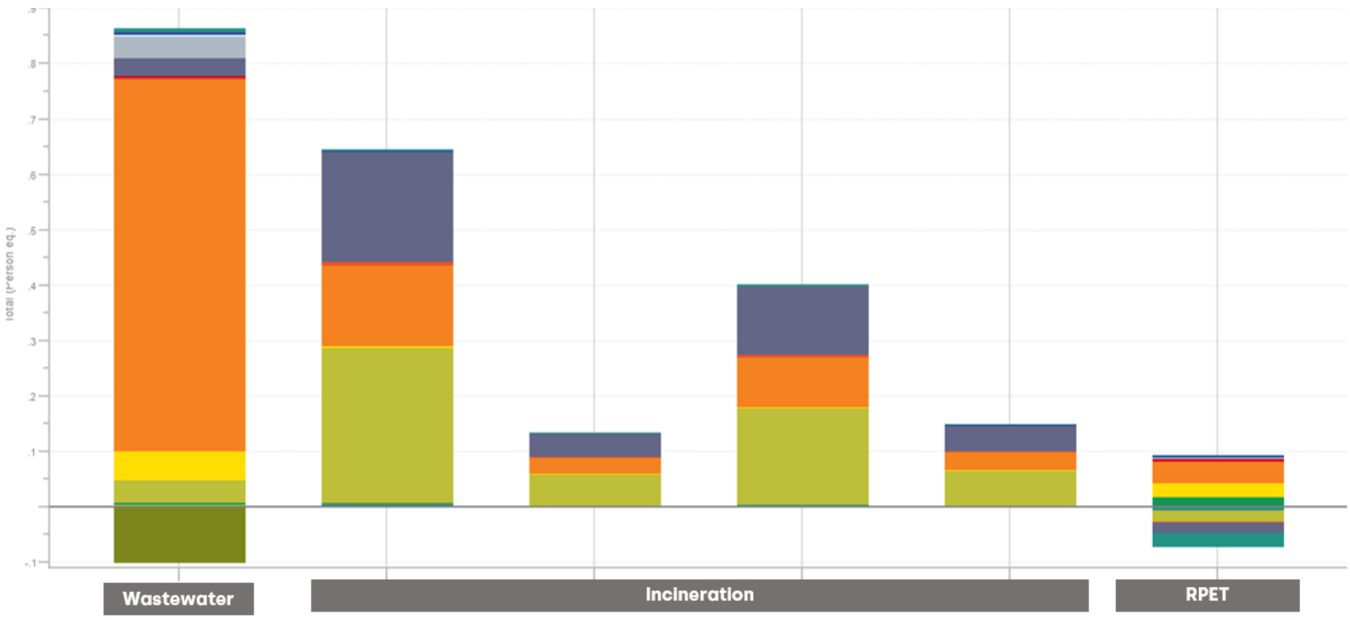

Figure 41c: Overview of the effects with the highest impact, within the disposal process of RPET

CONCLUSIONS

"How can packaging solutions for the fresh food industry be designed in the future, according to the product life cycles of different material types and the wishes of the customer and what is the place of PET as packaging material in this perspective?"

To answer the research question, it can in theory be demonstrated that the RPET packaging container is the most sustainable packaging solution, according to the scope of this Life Cycle Assessment. However, it should be noted that the total impact is calculated for one SKU and only minor difference were presents, when compared to the PET container for example. Keeping into account that the functional unit covers 10 000 packages, no significant differences will be found in the environmental impact of the four individual packaging containers, as discussed in this assignment. However, as millions (or even billions) of packaging containers are created, even the smallest difference can be of influence. Hence, significant impacts of the preferred RPET packaging of this assignment have been researched further.

Since the environmental effects can be calculated per phase (production, use and disposal) and (input and output) process individually, the opportunities for designing became visible. First of all it should be concluded (as done in multiple sources as well [7], [57], [58]) that a packaging solution for the fresh food industry only has minor impact, compared to the impact resulting from the food product. Within this LCA only a small residue has been modelled, creating little effects in the disposal phase of the packaging. However, when food waste would be taken into account more significantly, the share resulting from the packaging decreases. Keeping this reduction and the conclusions already presented in the current state of affairs into account, packaging provides an opportunity. Or in other words, within the fresh food industry packaging should not always be seen as an environmental burden, but as a solution to the environmental effects.

However, packaging still has a significant environmental impact which should be kept as low as possible. This can be done by using a share of recycled PET in the creation of plastic packages, as the RPET container has been demonstrated to be of smaller influence than the PET container. Moreover, the disposal phase of RPET results in significant low impacts, when compared to the production phase.

Another effect that significantly adds to the total impact, is created by the cardboard boxes needed to transport the RPET container to the supermarket. When less cardboard can be used within this process, less environmental effects are present and hence, less total impact is created.

Lastly, the input material had a significant share in the total environmental impact, which could be reduced by the amount of trim that is created. When less trim is created, less materials need to be supplied as input as well. Moreover, the energy of both the extrusion as well as the thermoform machine is depended on the input amount. When the input material can be decreased, less energy is needed. Thus, it can be concluded that new shapes can be researched in order to reduce the amount of trim and perhaps, reduce the total environmental impact.

5.PROPOSAL FOR DESIGNING

The conclusions of the consumer analysis together with the results of the LCA, create an opportunity for designing food packaging. By combining and validating these conclusions, the main research question can be answered: **"How can packaging solutions for the fresh food industry be designed in the future, according to the product life cycles of different material types and the wishes of the customer and what is the place of PET as packaging material in this perspective?"**

5. PROPOSAL FOR DESIGNING

Two similar conclusions were present in the both consumer analysis as well as the LCA. First of all, it is demonstrated in the consumer analysis that the consumer would accept a different shape of the packaging. Moreover, the LCA concluded that high impacts were found due to the amount of input material. One way to reduce the input material is by creating less trim. This also affects the needed energy throughout the production phase. When changing the shape from round to rectangular, not only these pillars can be affected, the efficiency of transport can also be increased. Since, rectangular shapes can be arranged with less 'loose' space in between. Thus, this design direction can gap the bridge between the consumers opinion and a calculated impact. The second design direction can be covered by the use of recycled material. Namely, the consumer analysis illustrate the high acceptance of using recycled (plastic) materials for food containers, among customers. On the other hand, the LCA presents the most positive results for the container in which a share of recycled PET is used. Hence, within this chapter it should be researched further if these two design directions actually bridge the gap and hence, answer the main research question.

5.1. CHANGING THE SHAPE OF THE (R)PET CONTAINER

The first design proposal can be covered by changing the shape of the container. As declared, this design proposal is assumed to bridge the gap between the desires of the consumer and the actual impact to the environment. Since, the outcome of the life cycle assessment demonstrated the effects created by the amount of input material. Amongst others, the high amount of trim that is created in thermoforming process adds to the initial input. Moreover, the energy usages of both the extrusion as well as the thermoforming machine are depended on the input material. When less trim is created, less material is needed as an input. Moreover, the consumer analysis demonstrated that the consumer has no specific preference in shape and is likely to accept a change of shape. Especially as the current state of affairs illustrate the effect of sustainability in the purchase decision, it would be an interesting perspective to research. If 'changing the shape' actually benefits the environmental impact for the positive, it can be used in marketing. However, this design proposal should be verified, which will be done in this chapter by analyzing the lifecycles of the round PET container versus a rectangular PET container.

Logically, the least amount of trim is created when thermoforming rectangular shaped packages. However, in practice, trim is always created as thermoformed packages needs to be cut and drafted in order to be released from the mold. Also, the extruded roll is always slightly bigger than in theory necessary, in order to maintain the process in high speed with some tolerances.

Within the portfolio of Hordijk a rectangular package with comparable dimensions (equal diameter and height) of the round package can be found. As can be imagined, the capacity of a rectangular shaped package is higher than the capacity of a round package, as illustrated in Figure 42.

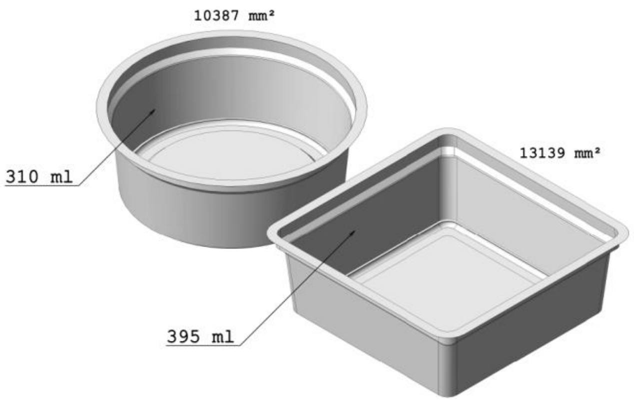

Figure 42: *Round PET container (used in the LCA) compared to a rectangular container with the same dimensions.*

However, within the portfolio of Hordijk also a rectangular container can be found that is comparable to the capacity of the round container. This rectangular container maintains the dimensions of 115x115 mm at the top surface, but is reduced in height: 32 mm. An illustration of these containers is presented in Figure 43. Still, the weight of a rectangular container is higher than the weight of a round container as more surface area is necessary to shape the container.

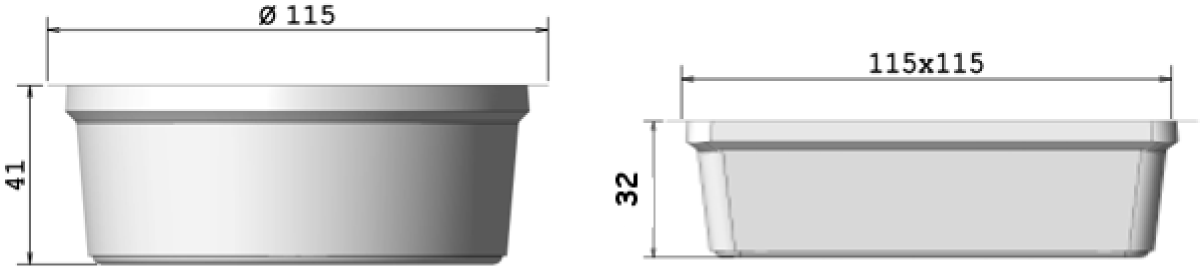

Figure 43: *Round PET container (used in the LCA) compared to a rectangular container with comparable specifications.*

From current practice of Hordijk, it is found that the rectangular container with a height of 32 mm can be made from foil with a thickness of 0,43 mm. This results in a rectangular container (Figure 43), with the following characteristics, compared to the round container:

- ✓ Less trim is created (more beneficial gross/net ratio)
- ✓ Reduce in transport (higher efficiencies in packing)
- ✗ An equal amount of material necessary to produce the containers

Changing the shape from round to rectangular would reduce the amount of trim by 20-25 percent. Moreover, the packages can be packed more conveniently in transport as less 'loose' space is needed. However, as the outer dimensions remain the same, little effect would be visible in the transport of empty containers. Since the packages are stacked in each other, only the height of one packaging container is of influence. For further calculations, this difference will be assumed to be neglectable. However, it does influence the box in which the containers are transported when full. Since, the packages cannot be stacked in high amounts anymore, reducing the total height significantly. For the sake of clarity, it will be assumed that this reduction is purely depended on the height, resulting in an amount that equals 85% of box 1. Moreover, it can be imagined that the packages can also be arranged with higher efficiencies in the cooling of the supermarket. As this effect cannot be validated at this moment, it would be assumed to relatively low; compared to the round PET container, it would be assumed that only 90% of the capacity is needed.

In the end, this results to the following specifications of the rectangular container:

SPECIFICATIONS RECTANGULAR CONTAINER

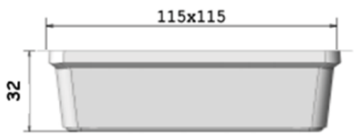

Figure 44: *Rectangular container*

Capacity	175 grams vegetable spread
Materials	100% virgin PET (25% trim)
Dimensions	Width: 115x115 mm Height = 32 mm Volume = 310 Milliliters
Weight	7.97 Grams
Use Cycles	1
Recycling rate	50%
Secondary packaging, production phase	1 HDPE bag, per 250 pieces 1 LDPE bag, per SKU
Secondary packaging, use phase	0,85 % Box 1
Closing system	Plastic top seal

Table 18: *Specifications of the rectangular container, used for the LCA*

From the specificantions above a new LC has been created. As can be imagined, only a few changes lead to a whole different set of in- and outputs and hence, effects. Since, most of the energy usages and transport in the system are based on the weight of the in- or output, nearly the entire system can be changed by altering the shape of the container. An overview of all effects is presented in Appendix K. Within Gabi, the 'common' PET container has been compared to the life cycle of the rectangular PET container with the specifications of Table 18. above. This comparison lead to the impacts presented in Figure 45.

As can be concluded from Figure 45, changing the shape of the container from round to rectangular leads to a decrease of the environmental impact. A difference of around 1.5 Person eq. could be concluded when looking at all normalized midpoints for the round PET container compared to its rectangular alternative. Compared to the earlier calculated normalized midpoint effect of al four packaging solutions of the LCA, this difference is higher than the difference between the PET and RPET container. Moreover, it should be taken into account that the functional unit used to create this impact only covers one SKU of packages. When creating millions or even billions of packaging containers, even the smallest impact should be decreased.

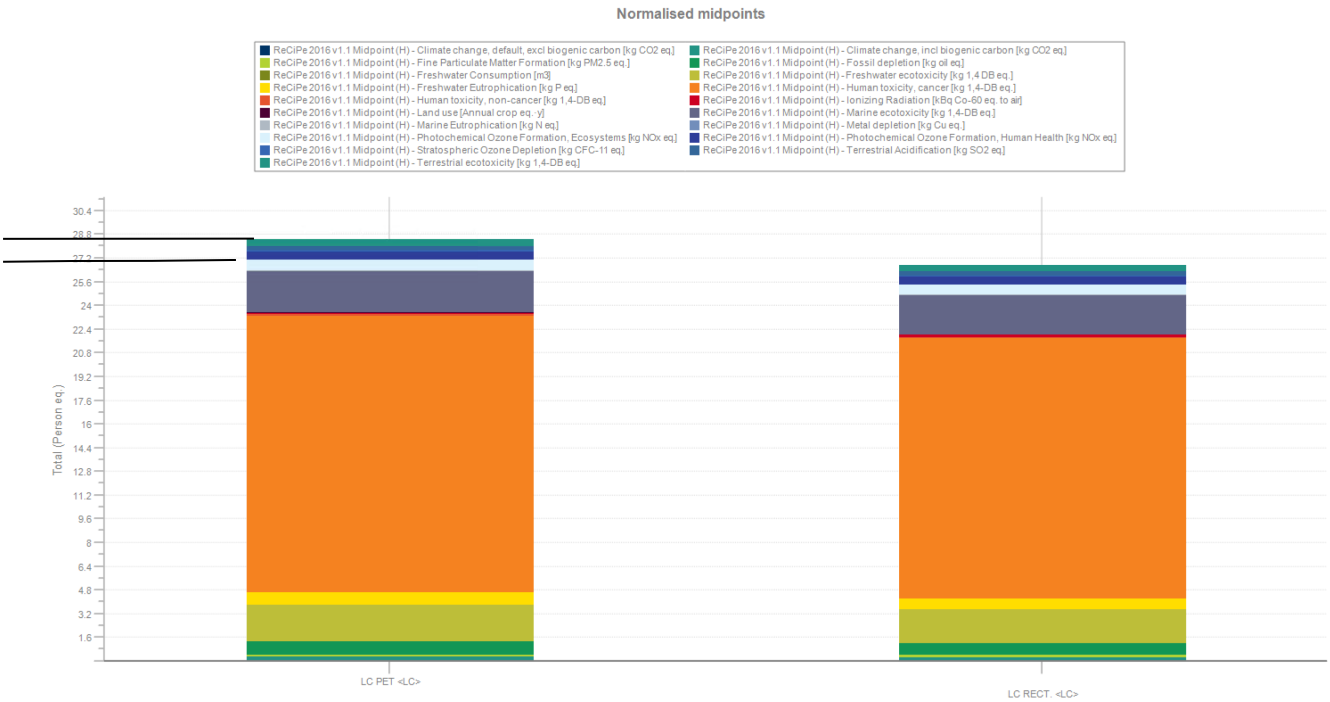

Figure 45: *Total impact of all normalized midpoint of the RPET containers versus a rectangular shaped container*

Thus, it can be concluded that changing the shape of the round container, of which Hordijk creates millions every year, to a rectangular one, results in a significant decrease of the total environmental impact. Therefore, it will be advised to dive deeper into this design solutions and consider the opportunities.

5.2. INCREASING THE SHARE OF RECYCLED PET IN THE RPET CONTAINER

Another interesting outcome of the consumer analysis, was the acceptance of a higher share of RPET. Hordijk already creates packaging solution with a share of 20% of recycled content when it adds a significant discoloration (and thus, results from household waste). This was represented by the RPET container, that was demonstrated to be the most beneficial in terms of the environmental impact. When higher shares of RPET could be reached, even better results are hypothesized.

Hence, within Gabi a new life cycle has been modelled that equals the life cycle of RPET, but now with an input of 30% RPET. This amount seems to be the right balance between the desire of having a high share of recyclate and the ability to see the product, in line with the conclusions of the consumer analysis. This life cycle has been compared to the original life cycles of PET and RPET. As can be seen in Figure 46, the total impact of the container with 30% RPET is indeed smaller. For clarification two lines in the y-axis represent the total normalized impact (in person eq.). Although no major difference in impact is found between the three types of input material, it is a proposed design solution.

Since, it should again be kept in mind that the calculated effect is only based on the input and output flows of one SKU. In practice, much higher amounts of packages are created and hence, bigger differences can be made. Moreover, it is discussed in the current state of affairs (Chapter 2) that changes are foreseen in the recycling of plastic containers. When mechanical or chemical recycling systems would present recyclate with a higher transparency in the future, a much higher share of recyclate can be added resulting in significant decreases of the total impact.

Moreover, within the current state of affairs different recovery solutions were presented. Also, the need for packaging solutions has been demonstrated. Moreover, it was declared that plastic packaging could even benefit the total environmental impact of food containers when food waste is taken into account. As there is currently no alternative for other materials, within the scope of the assignment, it is advised to use a higher share of recyclate to start with. When new regulations are in force and novel technologies

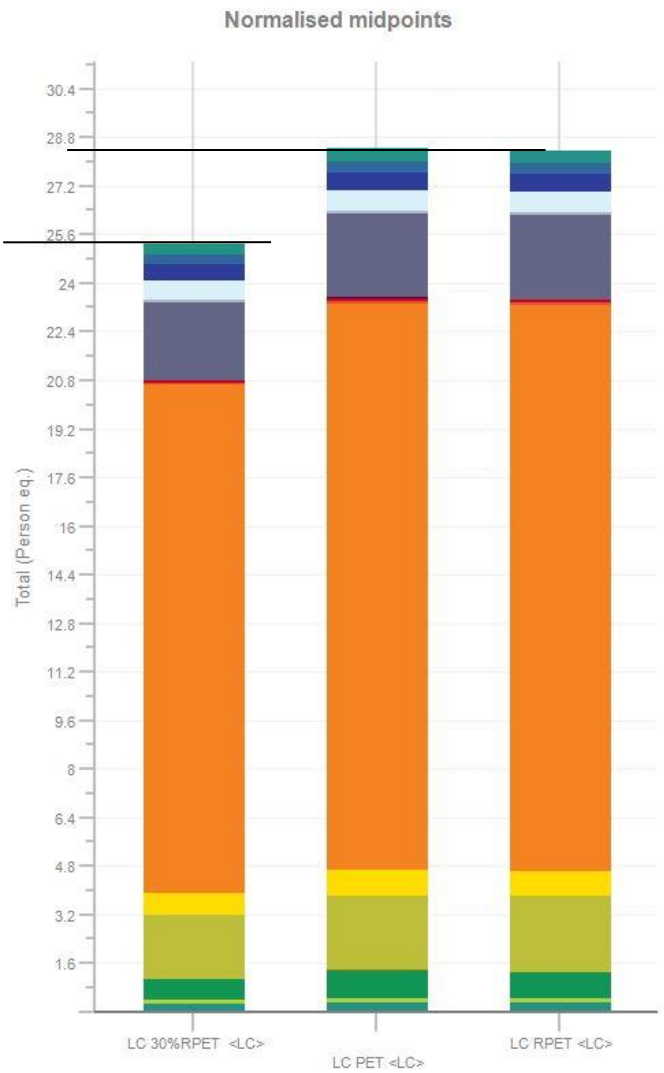

Figure 46: Comparing total impacts of the life cycles of PET and respectively 20 and 30 percent RPET

provide recyclate with high quality and less discoloration, higher shares of recyclate in new packaging solutions should be aimed for. Keeping in mind that packaging solutions are a necessity in the fresh food industry and billions of packages are produced, even the smallest reduction can influence the total impact. Thus, the entire industry should aim for a circular approach in which packages are not disposed, but recycled with high efficiencies.

6.EVALUATION

To structure the report one main research question was created for this assignment, which was supported by five sub research questions. All questions were discussed throughout the report and were individually evaluated and concluded after each chapter. Within these chapter not only these conclusions will briefly be discussed, the overall assignment will be discussed and evaluated and recommendations for further research will be presented.

6. EVALUATION

6.1. CONCLUSION

Within this last chapter the results of this master assignment will be discussed and evaluated. To state a final conclusion, the answers to the research questions will briefly be summed. For more in-depth conclusions to each question, the corresponding chapter will be referred to.

6.1.1. Answer to the research questions

1. **How may food safety packages be designed according to the rules and regulations that are currently present in the European Union?**

→ *What should be taken into account when designing for food safety packages / which design restrictions result from this?*

When designing packaging solutions that come into contact with food, specific rules and regulations created by the European Union should be taken into account. Within the conclusion of Chapter 2.2, Figure 5 illustrates all Regulations and Directives that should be complied with. Also, figures have been created that gain more insight in the understanding of each of the Regulations. As a conclusion it would be advised to consult the figure and access the European Law via the website of EUR-lex to verify the validity of the regulation. Moreover, the recycle checks of the KIDV as presented in Chapter 2.4.5 are advised to keep into account while designing. Only, when a packaging can be recycled the entire industry can aim for a circular economy.

2. **How are food containers currently being produced?**

→ *Which insights does this give in terms of possibilities and constraints?*

The creation of packaging solutions are most commonly depending on the material type. For the creation of plastic containers, PB containers and glass jars different production techniques have been discussed. A summary of all production processes have been presented within Chapter 2.3.1-2.3.4. From the illustrations and information presented in these sections, the production processes of the LCA could be concluded for each material as presented in Chapter 5.2.1.

3. **How are food containers currently being recycled?**

→ *Which insights does this give in terms of possibilities and constraints in the design of (new) packaging solutions?*

Similar to the second sub research question, the conclusion to this research question supported the LCA in creating a proper simulation model of the life cycles. To answer this research question, the common recovery solutions in the Netherlands were discussed. As recycling is realistic and preferred, the recycling process of each material type individually was discussed. Moreover, this section provided numbers and fats about the recycling rate and ability to use recyclate, which was used as input data for the LCA. For a more in-depth conclusion, Chapter 2.4 will be referred to.

4. **What are the most beneficial and desired packages, or packaging attributes, according to the preferences of the consumer?**

To answer this research question a survey was created in which the opinion of the consumer was researched. With other information of the current state of affairs, it could be concluded that sustainability is an important aspect for the purchase decision of the consumer. Though, there is a gap between what the consumer *thinks* to be sustainable and what actually *is* sustainable. Anyhow, with regards to the preferences of the consumer, it was demonstrated in the conjoint analysis that packages clearly illustrating (i.e. via a label) to be sustainable were of preference. Moreover, the material was of high influence to the preference; packages made from PB and glass were preferred over plastic solutions. However, for specific food types (moisture foods, luxury food as appetizers and meat) plastic was preferred over other materials. Hence, it could be concluded that the use of plastic would still suffice with the preferences of the consumer. However, if so, it would be advised according to the results of the survey, to use the original color of the material (transparent), perhaps with a lid instead of a seal and with a label clearly indicating that this solution is sustainable. An answer to this research question was thoroughly discussed in Chapter 3.6. From these conclusions, together with the conclusions of the LCA a design proposal could be derived.

5. **What are the most sustainable packages, or packaging attributes, according to a LCA?**

The results of the LCA presented a slightly lower total impact for the RPET container, compared to similar packages made from PET, PB or glass. It should be noted that a specific scope is used for the LCA and only minor differences were found in some processes. Looking more thoroughly in each process, it could be concluded that for all packaging solutions the use phase resulted in a significant high effect. This was mainly due to the application of food. This could also be verified with the outcomes of other life cycle assessments. From the perspective of food waste, it can be concluded from the LCA that packaging can actually benefit the total environmental impact. However, packaging still adds a positive effect, which should be kept as low as possible. By analyzing each life cycles input and output process on its individual impact, insights for the design proposal could be concluded. An in-depth conclusion to this research question was presented in Chapter 5.4.

"How can packaging solutions for the fresh food industry be designed in the future, according to the product life cycles of different material types and the wishes of the customer and what is the place of PET as packaging material in this perspective?"

As a final conclusion, the main research question can be answered. It can be stated that there is a future for PET as a packaging material for the fresh food industry. The consumer analysis demonstrated that the consumer does indeed prefer other materials over plastic, but also highlights the preference for the unique material properties plastic has to offer. Especially for specific types of fresh food, it could be concluded that plastic still has a high market potential. However, when using PET as a packaging material, it would be advised to use a share of RPET. More specifically, within the denoted scope and time frame of this assignment it would be advised to use a share of 30% recycled PET. When higher quality recyclate can be created by novel recycling systems that complies with the European regulations, the share of recycled PET should be re-evaluated and when possible, increased. Desirably, the recycled content originates from used packaging containers (i.e. household waste) to create a circular system for the future. Within the current state of affairs different recovery solutions have been demonstrated. Keeping into account that packaging is a necessity for the fresh food industry, the packaging with the lowest environmental impact should be used. Moreover, a circular approach should be aimed for, as waste cannot be avoided.

From the consumer analysis it could also be concluded that the packaging container with a share of RPET, should be designed without the addition of dyes and with a label clearly indicating the sustainability of the container. Moreover, to benefit the container in its recycling, the design should be accompanied with a washable label. By combining the results of the consumer analysis with the outcome of the life cycle assessment, the gap between the consumers opinion and the actual environmental impact could be bridged. Two interesting insights were translated into opportunities for designing food packaging for the future. First of all the amount of recyclate can be increased up to 30%. This amount will be accepted among consumers and the discoloration is likely to be accepted. Especially, when the top part (i.e. lid or seal) would remain virgin and hence, transparent. Especially when millions of packages are created, this increase of recyclate can decrease the total environmental impact. The discoloration resulting from the RPET share should be marketed as a label indicating true sustainability, to comply with the consumers preference. Moreover, another design opportunity is proposed by changing the shape of the round container into a rectangular shape. Although the weight of the rectangular packaging equals the weight of the round packaging, higher efficiencies are found in transport and less trim is created. The latter reflects is multiple processes of the entire life cycle, as less input material is needed which affects multiple energy usages throughout the production process.

6.2. DISCUSSION

Within this chapter the limitations of this research will be weighted and checked and remarks will be presented in order to state a validated result. Hence, a thorough discussion will be provided, after which the recommendations and evaluation of this project will be discussed.

The main research question could be answered within the assignment and the desire to expand the knowledge in the field of packaging for the fresh food industry is accomplished. Within the limited time frame a proper dept is created throughout the assignment. Though, further research is necessary to validate the results at high scale and check the outcomes with results in practice. To actually adopt the design proposal in industry, the design solution should be tested. First of all, among the acceptance of the consumer, but also in terms of convenience in production sights.

6.2.1. Recommendations

Due to the limited time frame and scope created for this assignment, some interesting insights have not been researched. Some recommendations are in place when continuing the work of this assignment.

Recycled PET

Within the life cycle assessment of RPET containers, a standard EcoInvent process has been used as an input of recycled polyethylene terephthalate granulate. The effects of this input have been checked with other types of RPET from the EcoInvent database, but also with data known from practice. However, it should be noted that many types of RPET exists, all resulting from a different type of input waste. Each process results in different impacts, depending on the technology used for the recycling as well as the input materials. As more recycling technologies are developing, higher efficiencies can be reached, resulting in an impact that might be lower than modelled in the current RPET life cycle.

However, the input of recycled PET also results in design limitations and demanding regulations to comply with. Especially if RPET results from household waste, or waste streams with high levels of pollutions, the recyclate has to meet many rules and regulations to guarantee human health. With the new Regulation 2022/1616 in force, no recycling technology that creates RPET from household waste is marked 'suitable'. 'Novel' technologies should be registered at the time of writing and are awaiting for their 'novel' approval. Hence, it is currently not possible to create this type of food safe recyclate and implement it in shares (up to 100%), like recyclate resulting from PET bottles. Moreover, recyclate that results from household or highly polluted waste is affected in color, resulting in a discoloration of the final container.

As the input of recyclate was found to be of influence in the research, it would be recommended to research the (technical) abilities of RPET further. Especially, since the research demonstrated the acceptance among consumers *and* a decrease of the environmental impact. More specifically, it would be advised to research the consistency of the recyclate and the effects on the extruded foil, the maximum recycled content that is allowed and the discoloration. Although it is a difficult task for manufactures to use the recyclate, as declared above, it can in the end be of significant influence and should be motivated.

Creation of new shapes

Within the research it has been demonstrated that the shape can be changed from round to rectangular, in order to reduce the environmental impact, while meeting the desires of consumers. However, some effects are not calculated in the lifecycle that should be taken into account when discussing the full picture. Within the modelling of the life cycle, the dies and machinery were left beyond the scope. When new dies should be made, billions of packaging solutions can be created and the affect to one SKU is assumed to be neglectable for this assignment. However, when entirely new molds should be made in order to create new shapes, it should be calculated if this effect is indeed neglectable.

Moreover, it is imagined that changing the shape from rectangular to round can result in some difficulties for accurate labelling and sealing. Since, round packages can be conveyed with lower tolerances, as the placing of the label and the seal is not depended on one specific location. Thus, if the design proposal would be implemented in industry, it is recommended to expand the life cycle assessment to verify all parts of the production process. Moreover, it would be advised to create a test batch and check upon difficulties.

Lastly, the decision for changing the shape from round to rectangular is found to be accepted among consumers. However, this conclusion was only based on a few preferences within a relatively small survey. To actually use this insight for practice, more research should be performed in order to verify if this change in shape would actually be accepted. Also, within the research the distinction between 'accepted' and 'preferred' is used. Due to the small amount of questions regarding the shape, it has been stated that a rectangular shape would be 'accepted'. However, high preferences were found for these types of shapes. Thus, more research should be performed in order to actually see if this shape would not only be accepted by consumers, but also preferred.

Lastly, the two design directions presented in this research both illustrated minor effects to the total environmental impact of 1 SKU of packaging containers. As millions or even billions of packages are made for the fresh food industry, even the smallest effect should be taken into account as each effect becomes significant. However, it would be advised to model a new life cycle with a higher amount of packages in the functional unit to validate this thought.

6.3. EVALUATION

Evaluating the overall assignment, it can be stated that the desired goal is achieved. Although some points of discussion and recommendations are present, the research question could be answered. Moreover, a realistic advice could be presented to Hordijk.

The results of the assignment present a practical solution to an existing packaging container. Two pillars were discussed in order to reduce the environmental impact, while maintaining the desires of consumers. Although these pillars (implementation of more recyclate and change of shape) are practical solutions that can, in theory, immediately be implemented, it should be taken into account that this assignment was primarily research based. In other words, the proposed results should be validated even further and the design proposal should be created and tested before the design should be altered. Though, when further research can validate the outcome of this report, interesting changes can be made to a large industry. Not only affecting the environmental impact, but hopefully also influencing the consumers perception.

The proposed solution offers potential for bridging the gap between the consumers opinion and the true environmental impact. In order to convey this message, it became clear in this assignment that circularity can only be achieved when working together. Not only marketing should push its limit to convey what is truly sustainable to consumers, business should work together to create high efficiencies in recycling and implement recyclate where possible. It should become clear that packaging is a necessity in the food industry and plastic can actually benefit the environmental impact (when compared to other materials). Of course, negative aspects as the discoloration of plastic are present, but it would be interesting to see this as a label instead of pollution.

BIBLIOGRAPHY

[1] Ministerie I&W & Ministerie van EZK, "Transitie-agenda Circulaire Economie Kunststoffen," 2018.
[2] C. Bruijnes, H. Diepenmaat, R. Ten Klooster, J. P. Van Soest, G. Langeveld, and V. Balk, *The State of Sustainable Packaging*, no. October. 2020.
[3] H. A. Leslie, M. J. M. van Velzen, S. H. Brandsma, D. Vethaak, J. J. Garcia-Vallejo, and M. H. Lamoree, "Discovery and quantification of plastic particle pollution in human blood," *Environ. Int.*, p. 107199, 2022, doi: 10.1016/j.envint.2022.107199.
[4] R. van Hooijdonk, "Mentos Gum Hero's hebben een nieuwe verpakking," 2022. https://www.levensmiddelenkrant.nl/levensmiddelenkrant/nieuws/mentos-gum-heros-hebben-een-nieuwe-verpakking (accessed Apr. 07, 2022).
[5] D. Worford, "Wendy's to Start Including Recycled Plastic in Cups," 2021. .
[6] Albert Heijn, "AH-gehakt van bakje naar zakje: jaarlijks 500.000 kilo minder plastic," 2021. https://nieuws.ah.nl/ah-gehakt-van-bakje-naar-zakje--jaarlijks-500000-kilo-minder-plastic/ (accessed Apr. 07, 2022).
[7] C. De Armitt, *The Plastics Paradox*, Phantom Pl. 2020.
[8] Friesland Campina, "Campina Biologisch verwijdert plastic dop van literverpakkingen," 2021. https://www.frieslandcampina.com/nl/news/campina-biologisch-verwijdert-plastic-dop-van-literverpakkingen/ (accessed Apr. 07, 2022).
[9] Hordijk, "Hordijk - About us," 2022. https://www.hordijk.nl/en/over-ons-en/ (accessed Mar. 07, 2022).
[10] Plastic Pact NL, "Plastic Pact NL." pp. 1–18, 2019.
[11] nu.nl, "Plastic bekers en bakjes buiten de deur vanaf 2024 in de ban," 2022. https://www.nu.nl/economie/6192028/plastic-bekers-en-bakjes-buiten-de-deur-vanaf-2024-in-de-ban.html (accessed Apr. 12, 2022).
[12] Voor de wereld van morgen, "Politieke standpunten over plastic," 2021. https://www.voordewereldvanmorgen.nl/duurzamekieswijzer-plastic (accessed Apr. 12, 2022).
[13] P.-P. Verbeek, "Mediation Theory," 2020. https://ppverbeek.org/mediation-theory/.
[14] F. Welle, "The facts about PET," 2016.
[15] U. Thoden van Velzen, M. Paillart, and I. Smeding, "Bestaat De Duurzame Verpakking?," 2022.
[16] R. Franz and F. Welle, "Recycling of Post-Consumer Packaging Materials into New Food Packaging Applications—Critical Review of the European Approach and Future Perspectives," *Sustain.*, vol. 14, no. 2, 2022, doi: 10.3390/su14020824.
[17] M. D. de Loû, "Packaging and Packaging Waste Directive," 2020.
[18] KIDV, "KIDV Recyclecheck Vormvaste Kunststof Verpakkingen," 2022.
[19] U. Nations, "Definition of Sustainability," 1987. https://www.un.org/en/academic-impact/sustainability#:~:text=In 1987%2C the United Nations,development needs%2C but with the (accessed Jan. 12, 2023).
[20] Rosenbaum and Vieira, "Definition of Sustainability," 1993. https://rdmc.nottingham.ac.uk/bitstream/handle/internal/287/Archaeology_final/definitions_of_sustainability.html (accessed Jan. 12, 2023).
[21] Inchainge, "The concept of the Tripple Bottom Line," 2023. https://inchainge.com/knowledge/sustainability/the-3ps-of-sustainability/ (accessed Feb. 10, 2023).
[22] The European parliment and the council of the European., "DIRECTIVE (EU) 2019/904 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL," 2019. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0904&from=EN.
[23] prof. dr. ir. R. ten Klooster, E. I. prof. (em. . dr. J. M. Dirken, prof. (em. . dr. F. Lox, and ir. A. A. Schilperoord, "Historische ontwikkelingen, Zakboek verpakkingen," in *Zakboek verpakkingen*, Doetinchem: Reed Business bv., 2008, p. 894.
[24] N. D. Steenis, E. van Herpen, I. A. van der Lans, T. N. Ligthart, and H. C. M. van Trijp, "Consumer response to packaging design: The role of packaging materials and graphics in sustainability perceptions and product evaluations," *J. Clean. Prod.*, vol. 162, pp. 286–298, 2017, doi: 10.1016/j.jclepro.2017.06.036.
[25] prof. dr. ir. R. ten Klooster, E. I. prof. (em. . dr. J. M. Dirken, prof. (em. . dr. F. Lox, and ir. A. A. Schilperoord, "Onderscheiden en ordenen van verpakkingsfuncties, Zakboek verpakkingen," in *Zakboek verpakkingen*, Doetinchem: Reed Business bv., 2008, p. 894.
[26] KIDV and M. Keukenhof, "Levensmiddelen," 2022. https://kidv.nl/levensmiddelen (accessed Jun. 08, 2022).
[27] Milieu Centraal, "Verpakkingen: Goed of slecht?," 2022. https://www.milieucentraal.nl/minder-afval/verpakkingen/verpakkingen-goed-of-slecht/ (accessed Jun. 16, 2022).
[28] prof. dr. ir. R. ten Klooster, E. I. prof. (em. . dr. J. M. Dirken, prof. (em. . dr. F. Lox, and ir. A. A. Schilperoord, "Definities en omschrijvingen, Zakboek verpakkingen," in *Zakboek verpakkingen*, Doetinchem: Reed Business bv., 2008, p. 894.
[29] Samen tegen voedselverspilling, "Samen tegen voedselverspilling - Feiten en Cijfers," 2022. https://samentegenvoedselverspilling.nl/voedselverspilling-feiten-en-cijfers/ (accessed Jun. 02, 2022).
[30] Two Sides, "European Packaging Preferences 2020," 2020. [Online]. Available: https://www.procarton.com.
[31] ING Economisch Bureau, "Plastic verpakkingen in de voedingssector Inhoud," 2019.
[32] M. Paolo, A. Kander, and P. Warde, "Pulp and Paper Industry | Definitions and Concepts," 2021. doi: 10.23943/princeton/9780691143620.003.0002.
[33] H. Holwerda, S. Tiekstra, and A. Hooimeijer, "Recycling van papier en karton in Nederland in 2019," 2019.
[34] Nedvang, "Van oud papier naar nieuw papier," 2022. https://www.nedvang.nl/recycling-nederland/oud-papier-karton/ (accessed May 12, 2022).
[35] prof. dr. ir. R. ten Klooster, E. I. prof. (em. . dr. J. M. Dirken, prof. (em. . dr. F. Lox, and ir. A. A. Schilperoord, "Materialen, Zakboek verpakkingen," in *Zakboek verpakkingen*, Doetinchem: Reed Business bv., 2008, p. 894.
[36] KIDV, "KIDV Recyclecheck Papier en Karton Verpakkingen," 2021.
[37] Stichting Duurzaam Verpakkingsglas, "Glasrecycling : het kán en het gebéurt."
[38] Nedvang, "De ontelbare levens van glas," 2022. https://www.nedvang.nl/recycling-nederland/glas/ (accessed May 12, 2022).
[39] Stichting Duurzaam Verpakkingsglas, "Alles over de duurzaamheid van glas," 2022. https://www.duurzaamglas.nl/informatie/verduurzamingsplan/.

[40] prof. dr. ir. R. ten Klooster, E. I. prof. (em. . dr. J. M. Dirken, prof. (em. . dr. F. Lox, and ir. A. A. Schilperoord, "Kunststoffen algemeen, Zakboek verpakkingen," in *Zakboek verpakkingen*, Doetinchem: Reed Business bv., 2008, p. 894.
[41] The European parliment and the council of the European Union., "Regulation (EC) No 1935/2004," no. EN, p. 14, 2004.
[42] The European parliment and the council of the European Union., "Regulation (EC) No 2023/2006," no. EN, p. 4, 2006.
[43] The European parliment and the council of the European Union., "Regulation (EC) No 10/2011," no. EN, p. 89, 2011.
[44] European Commission, "Commission Regulation (EU) 2022/1616," 2022.
[45] The European parliment and the council of the European Union, "Directive 94/62/EC," no. En, p. 14, 1994.
[46] The European parliment and the council of the European Union, "Directive 2004/12/EC," p. 6, 2004.
[47] The European parliment and the council of the European Union., "Directive 2005/20/EC," no. EN, p. 2, 2005.
[48] European Union, "Eur-Lex," 2022. .
[49] Recyclingnederland, "Hoe wordt papier gerecycled?," 2022. https://recyclingnederland.nl/artikelen/hoe-wordt-papier-gerecycled/ (accessed Dec. 14, 2022).
[50] B. Roeter and C. de Mol van Otterloo, "Verpakkingen in de circulaire economie," Leidschendam, 2018.
[51] M. Brouwer and U. T. Van Velzen, *Recyclebaarheid van verpakkingen op de Nederlandse markt Huishoudelijke kunststof verpakkingen in sorteerproducten onderzocht op*, no. December. 2017.
[52] Afvalfonds Verpakkingen, "Monitoring Verpakkingen," 2019, [Online]. Available: https://afvalfondsverpakkingen.nl/monitoring/monitoringsrapportage.
[53] K. Wilkinson, "Drawdown Review," p. 104, 2020, [Online]. Available: https://drawdown.org/drawdown-framework/drawdown-review-2020%0Ahttps://drawdown.org/sites/default/files/pdfs/TheDrawdownReview–2020–Download.pdf.
[54] H. Soethoudt and T. Timmermans, "Monitor Voedselverspilling," *Report*, p. 4, 2020, [Online]. Available: https://www.wageningenur.nl/upload_mm/e/2/d/ab1ed91f-5884-4ee4-ab50-e0e204a96877_2013-05-13 Rapport monitor Voedselverspilling.pdf.
[55] Wageningen University and Research, "Minder voedselverspilling in supermarkten," 2022. https://www.wur.nl/nl/onderzoek-resultaten/onderzoeksinstituten/food-biobased-research/show-fbr/nederlandse-supermarkten-maken-voedselverspilling-inzichtelijk-f00dwa5-1.htm#:~:text=Aan deze zelfrapportage werkten vijf,volgt verdeeld over vijf productcateg (accessed Jun. 02, 2022).
[56] G. Bergsma, M. Broeren, and M. Uijttewaal, "CO2-reductie met circulaire kunststoffen in Nederland CO 2 -reductie met circulaire kunststoffen in Nederland," Delft, 2021. doi: 21.210236.145.
[57] M. C. Heller, S. E. M. Selke, and G. A. Keoleian, "Mapping the Influence of Food Waste in Food Packaging Environmental Performance Assessments," *J. Ind. Ecol.*, vol. 23, no. 2, pp. 480–495, 2019, doi: 10.1111/jiec.12743.
[58] F. Silvenius, J.-M. Katajajuuri, K. Grönmna, R. S. H.-K. Koivupuro, and Y. Virtanen, "Role of packaging in LCA of Food Products," in *Towards Life Cycle Sustainability Management*, Springer Dordrecht Heidelberg London New York: Springer Science + Business Media B.V., 2011, pp. 391–410.
[59] KIVO, "Mechanical Recycling," 2022. https://www.kivo.nl/en/knowledge-base/mechanical-recycling/#:~:text=Mechanical recycling is the processing,are made from it again. (accessed Jul. 21, 2022).
[60] Nedvang, "Elke verpakking recyclen," 2022. https://www.nedvang.nl/recycling-nederland/ (accessed Jul. 21, 2022).
[61] Plastics Europe, "Publicatie e-paper; chemische recycling van plastics bruist," 2021. .
[62] A. Grant, V. Lahme, T. Connock, and L. Lugal, "How circular is PET?," 2022.
[63] Plastics Europe, "Introductie van chemische recycling: Plastic afval wordt een waardevolle hulpbron," 2021.
[64] M. Bijleveld, M. Beeftink, M. Bruinsma, and M. Uijttewaal, "Klimaatimpact van afvalverwerkroutes in Nederland," p. 76, 2020.
[65] Vereniging Nederlandse Glasfabrikanten, "Recycling van glas," 2022. https://www.nederlandseglasfabrikanten.nl/duurzaamheid/recycling-van-glas/ (accessed Jul. 06, 2022).
[66] Quest, "Moet je lege potjes en lessen schoon- maken voor je ze in de glasbak gooit ?," 2021.
[67] Nedvang, "Verdeelsleutel Plastic , Metaal en Drankenkartons," p. 1, 2017.
[68] Nedvang, "Kansrijk kunststof," 2022. https://www.nedvang.nl/recycling-nederland/kunststof-plastic/ (accessed May 12, 2022).
[69] Learning Center Kunststof Verpakkingsafval, "Samenstelling ingezameld kunststof / PMD verpakkingen," 2018.
[70] KIDV, "KIDV Recyclecheck Glazen Verpakkingen," 2021.
[71] Europese Commissie, "Een Europese strategie voor kunststoffen in een circulaire economie," Straatsburg, 2018.
[72] J. Turner, "A guide to environmentally friendly drinks packaging," 2020. https://www.ethicalconsumer.org/food-drink/guide-environmentally-friendly-drinks-packaging (accessed Jun. 30, 2022).
[73] Tetrapak, "Packaging material for Tetra Pak carton packages," 2022. https://www.tetrapak.com/solutions/packaging/packaging-material/materials (accessed Jun. 30, 2022).
[74] E. U. T. Van Velzen and I. W. Smeding, "Recycling van Nederlandse drankenkartons," 2022, [Online]. Available: https://afvalonline.nl/pdf/Recycling%2Bvan%2BNederlandse%2Bdrankenkartons.pdf.
[75] I. Borgman, M. Mulder-Nijkamp, and B. De Koeijer, "The influence of packaging design features on consumers' purchasing & recycling behaviour," Enschede, The Netherlands, 2018.
[76] G. Martinho, A. Pires, G. Portela, and M. Fonseca, "Factors affecting consumers' choices concerning sustainable packaging during product purchase and recycling," *Resour. Conserv. Recycl.*, vol. 103, pp. 58–68, 2015, doi: 10.1016/j.resconrec.2015.07.012.
[77] N. D. Steenis, I. A. van der Lans, E. van Herpen, and H. C. M. van Trijp, "Effects of sustainable design strategies on consumer preferences for redesigned packaging," *J. Clean. Prod.*, vol. 205, pp. 854–865, 2018, doi: 10.1016/j.jclepro.2018.09.137.
[78] University of Twente, "Conjoint Analysis Technical Lecture." Enschede, The Netherlands, p. 43, 2019.
[79] IBM Coperation, "IBM SPSS Conjoint 22," 2013. [Online]. Available: ftp://public.dhe.ibm.com/software/analytics/spss/documentation/statistics/22.0/en/client/Manuals/IBM_SPSS_Conjoint.pdf.
[80] Grow, "Beslisproces bij boodschappen." 2020.
[81] International Organization for Standardization, "Environmental management - Life cycle assessment - Principles and framework," 2006. [Online]. Available: http://www.springerlink.com/index/10.1007/s11367-011-0297-3.
[82] Nedvang, "Kansrijk kunststof," 2022. https://www.nedvang.nl/recycling-nederland/kunststof-plastic/ (accessed Jul. 21, 2022).
[83] Natureko, "Coffee cup details," 2022. https://www.natureko.nl/330301-fscr-kraft-pla-koffiebeker-8oz-240ml-

80mm-o?gclid=CjwKCAiAheacBhB8EiwAItVO26DzWPxkXjJ7ekDjPzot6uaPoCDmva6XmBT5JhV3taSR6hmRuIqfqBoCtf4QAvD_BwE (accessed Dec. 14, 2022).
[84] S. Haffmans, J. Nelissen, and J. Vlugter, “Koffiebeker recycling,” 2020.
[85] Glasverpakkingen.nl, “Glass jar,” 2022. https://glasverpakkingen.nl/webshop/370ml-hak-pot/ (accessed Dec. 17, 2022).
[86] M. A. J. Huijbregts *et al.*, “ReCiPe 2016 v1.1,” 2016. [Online]. Available: www.rivm.nl/en.
[87] M. B. Hocking, “Reusable and disposable cups: An energy-based evaluation,” *Environ. Manage.*, vol. 18, no. 6, pp. 889–899, 1994, doi: 10.1007/BF02393618.
[88] A. Gallego-Schmid, J. M. F. Mendoza, and A. Azapagic, “Environmental impacts of takeaway food containers,” *J. Clean. Prod.*, vol. 211, no. 2019, pp. 417–427, 2019, doi: 10.1016/j.jclepro.2018.11.220.
[89] A. Gallego-Schmid, J. M. F. Mendoza, and A. Azapagic, “Improving the environmental sustainability of reusable food containers in Europe,” *Sci. Total Environ.*, vol. 628–629, no. 2018, pp. 979–989, 2018, doi: 10.1016/j.scitotenv.2018.02.128.
[90] PetCore Europe, “Comparative LCA Analysis,” 2022.
[91] R. Fehringer, “Life cycle assessment of various ALPLA packaging units and alternative materials - COUNTRY,” 2019.

Private sources:
[S1] Lecture on Conjoint Analysis, from the Empirical Methods for Designing course, Master IDE, University of Twente 2021.
[S2] Visiting the recycling plant of Plastic Recycling Amsterdam (Umincorp) at 05-04-2022: Amerikahavenweg 42, 1045 AG Amsterdam | https://www.plasticrecyclingamsterdam.nl/
[S3] Visit to the recycling plant of ‘Van Gerrevink’ at 10-06-2022: Sint Maarten 2, 7332 BG Apeldoorn | https://vangerrevink.nl/
[S4] Meeting with contact person (packaging expert) of KIDV, via Microsoft Teams at 17-06-2022: www.kidv.nl
[S5] Information retrieved from the production process of Hordijk (i.e. datasheet containing all emissions and resources), 2022