Rethinking packaging at Aalberts Hydronic Flow Control

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aalberts

Acknowledgements

Before delving into the thesis, it's important to take a moment to acknowledge the individuals that have contributed to its completion. This section serves as a expression of gratitude to those who have offered their support, guidance, and encouragement throughout this journey.

Firstly, I would like to thank my supervisors, Lise Magnier and Pien Jager for guiding me throughout this project. You have supported and challenged me along the way of the creation of this thesis. Thank you for your effort and willingness to guide me through the journey to sustainable packaging.

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Thirdly, I want to thank all of my family and friends that have supported me during this project. Being able to discuss the project with others provided me valuable new insights and different views on the topic. Also, I would like to thank the ones that motivated me through the tough times during this project. You truly helped me to persevere, resulting in a thesis to be proud of.

Contents

Quick reading guide

This thesis aims to recommend on actions to be taken by Aalberts Hydronic Flow Control to reduce packaging. The thesis is built up as follows:

In order to read the thesis more easily, the following marks are applied throughout the report:

I Insights

Insights contributing to the proposed solution are shown in black

A Aims

Aims of different strategies to reduce packaging at Aalberts are shown in red

R Recommended actions

All recommended actions to reduce packaging at Aalberts are shown in green.

T Resulted targets

Targeted results of the recommended actions, packaging reduction results that can be achieved with the packaging changes are shown in blue

Executive summary

Aalberts Hydronic Flow Control has set the target to reduce their packaging material by 20% in weight by 2025. In this thesis will be looked into, and recommended on this target. In addition to this, the assignment has been established to develop a concept to reduce packaging waste for Aalberts through research on sustainable packaging, providing insights for improving business-to-business sustainable packaging practices.

Product categories using most packaging

In 2022, Aalberts Hydronic Flow Control introduced a total of 2739 tons of (registered) packaging to the market. This included 1807 tons of cardboard, 155 tons of plastic, and 777 tons of wooden packaging. The thesis focuses on the product categories PEX pipe, Expansion Vessels, Valves and Fittings that contribute most significant to packaging at Aalberts (54% of total packaging), representing 92 tons of plastic (59.4% of all plastic packaging), 872 tons of cardboard (48.3% of all cardboard packaging) and 520 tons of wood packaging (66.9% of all wood packaging).

Strategic roadmap

Based on, among others, findings from literature research, expert interviews, interviews with Aalberts' employees, competitor analysis, research into regulations, business economics and market trends, a strategic roadmap is designed showing all recommended actions for Aalberts to achieve packaging reduction based on three periods:

- The **first period (now-2025)** is focused on the implementation of most financially appealing packaging changes for Aalberts to reach the target of 20% reduction by 2025. Investments are needed, but are expected to be profitable within 2 years of implementation, leading to 20.7% reduction of all packaging (566 tons).
- The **second period (2025-2035)** is focused on reducing unnecessary packaging and redesigning packaging for recycled and less material use. In this period investments are needed to reduce packaging, contributing to more packaging reduction at Aalberts, leading to an accumulative reduction (of period I & II) of 25.8% of all packaging (707 tons).
- The **third period (>2035)** aims at eliminating single-use packaging through implementing the concept of packaging as a product. This requires further investments and a bigger change in packaging practices than the two periods before, which eliminates single-use packaging completely, leading to an accumulative reduction (of all periods) of 54.2% reduction of all packaging (1484 tons).

How to reach the target of 20% reduction by 2025?

In order to reach the target of 20% reduction by 2025, investment based packaging changes need to be made. Most financially appealing actions that are recommended to be implemented before 2025 are the following:

R 1. Reduce bag sizes Valves and Fittings by 50%

Reducing unnecessary packaging saves the company material and costs, a win-win scenario for Aalberts. It is advised to start with the reduction of plastic bag sizes for Valves and Fittings (46 tons, 1.7% of all packaging at Aalberts) since this provides the largest packaging reduction of unnecessary packaging.

R 2. Reusable pallets PEX pipe

Changing to reusable pallets for PEX pipe provides the largest reduction in packaging material with 520 tons (19% of all packaging at Aalberts). This change does require a one-time investment of €385,000 but saves €200,000 per year on single-use pallets. Therefore return on investment will be within 2 years. Since the packaging change offers a large reduction (close to the target of 20%) and saves costs in the long term, this action is recommended to be implemented as soon as possible to reach the target before 2025 (together with reducing bag sizes for Valves and Fittings).

New targets

Due to upcoming regulations on packaging, goals of Aalberts and the European Union to become net-zero by 2050, the following new targets are advised:

- Reduce all single-use plastics by 100% by 2040
- Reduce all single-use packaging by 100% by 2050

The new targets could be achieved with the concept presented in the third period of the strategic roadmap: *packaging as a product*. This concept aims to eliminate single-use packaging completely through redesigning packaging to replace another product by providing packaging with an additional function.

1. Project formulation & approach

Aalberts Hydronic Flow Control has set the target to reduce their packaging material by 20% in weight by 2025. This target follows the target of Techniek Nederland, a branche association where Aalberts is member of. Aalberts is a producer specialized in hydronic systems like PEX pipe, Multiskin fittings and Expansion Vessels selling in a business-to-business market. In this thesis will be looked into, and recommended on how to achieve the target of 20% reduction by 2025. In addition to this, the assignment has been established to develop a concept to reduce packaging waste for Aalberts Hydronic Flow Control through research on sustainable packaging, providing insights for improving business-to-business sustainable packaging practices.

Approach

To find out more on the current packaging status at Aalberts and investigate how to reduce packaging at the company, an analysis has been performed based on functions of packaging, current registered packaging figures, interviews with employees and a packaging journey.

Then, to explore the problem considering reducing packaging and implementing sustainable packaging in the industry, an analysis has been performed based on literature and expert interviews to find the current challenges in the industry. Also will be looked into (upcoming) regulations and material types involved with (sustainable) packaging.

Next, will be dived into how the targeted position of Aalberts to reduce 20% could be achieved. Challenges to change packaging at the company will be presented based on interviews with employees. An competitor and sustainable packaging analysis aims to compare Aalberts' competitors' goals and approaches to Aalberts. The Chapter will also dive into the influence of the circular economy on the targets of Aalberts considering packaging and greenhouse gas emissions.

From insights of the analyis phase, a roadmap will be presented showing recommended actions to reduce packaging at Aalberts. Various approaches will be discussed in periods to tackle the reduction of packaging and recommend Aalberts on how to achieve the target of 20% reduction by 2025. In addition to this, new targets will be presented when the current target is expected to be reached, focusing on future regulations and Aalberts' greenhouse gas emissions goals.

Lastly, will be dived deeper in a concept to reach the new targets of Aalberts established in the roadmap after reaching their current reduction target of 20%. This concept will be presented and validated with installers to demonstrate its feasibility, desirability and viability

Methods

Throughout this thesis multiple methods have been used for different purposes. The main used methods will be discussed below:

Firstly, the R-ladder has been used. This method guides in providing strategies based on different levels of circularity. The circular strategies can be used to pursue the principle of the circular economy. The higher a strategy is rated on the R-ladder, the more circular the strategy is, and thus the more resource extraction is prevented. More on the R-ladder will be discussed in Chapter 4.4.

Secondly, a roadmap has been created using the Three horizon model to guide the reduction of packaging at Aalberts. The method is a framework which helps to manage a goal in a coordinated way. In Chapter 6 the strategic roadmap created with the Three horizon model can be found.

Thirdly, the method of The Double Diamond has been used in this entire thesis. The method provides guidance through a creative process focused on problem solving. It makes use of diverging and converging processes to explore problems, possible solutions and eventually come to a detailled concept.

Also other methods have been used such as the Power-Interest matrix, Cost-Benefit analysis, Customer (packaging) journey, Life Cycle Analysis, How-to's, Product Concept Evaluations, Weighted Objectives and Cost Price Estimations.

2. Analysis - Aalberts' current packaging position

Aalberts goal is to reduce packaging by 20% by 2025. To reduce packaging and thereby reach this target, first an understanding of Aalberts current packaging status is required. To achieve this an analysis on current registered packaging data from Aalberts was performed. The following topics will contribute to understanding Aalberts' current packaging status.

First, will be looked into main functions and different types of packaging to guide with the generation process of possible solutions which reduce packaging at Aalberts.

Second, the Chapter will dive into the stakeholders involved in reducing packaging and sustainable packaging at Aalberts. This will be done to get a better understanding of who plays important roles in packaging practices.

Third, the Chapter will look into the current packaging journey at Aalberts to understand the context of the problem considering the reduction of packaging better. It will provide insights into current packaging practices which will be used to develop possible solutions later in this thesis.

Fourth, an analysis of the current packaging situation at Aalberts will be performed. This is based on the current packaging registered at the company. It will provide insights into which product categories should be focused on to reduce packaging material at Aalberts most significantly.

Fifth, there will be dived into current packaging figures in the EU to understand the problem better by providing insights into why packaging should be reduced.

2.1 Packaging functions

In order to determine how to reduce packaging at Aalberts Hydronic Flow Control, it first must be determined why packaging is used. In this Chapter will be discussed what the main functions of packaging are.

According to the European Union, packaging is described as the following: "Packaging shall mean all products made of any materials of any nature to be used for the containment, protection, handling, delivery and presentation of goods, from raw materials to processed goods, from the producer to the user or the consumer." (European Communities, 1994). Requirements of packaging can be divided into three categories:

1. **Product protection**: One of the primary functions of packaging is to protect the product from damage, contamination, or deterioration during transportation, storage, and handling. Packaging should be designed to withstand various environmental factors, such as temperature, humidity, and physical impact, ensuring the integrity and quality of the enclosed product.

2. **Product information**: Packaging serves as a means of communication between the product and the consumer. It should convey essential information about the product, including packaging recyclability, usage instructions, safety warnings, and any other relevant details. Clear and accurate labeling helps consumers to make informed choices and ensures compliance with regulatory requirements. (European Union, 2023). It is also a key element of branding and marketing strategies. It should visually communicate the brand identity, create a memorable impression, and differentiate the product from competitors. Colors, logos, and design elements play a crucial role in this aspect.

3. **Product handling**: Packaging should be designed to facilitate easy handling during transportation. This includes considerations for size, weight, and shape to optimize storage and shipping efficiency. Packaging should be user-friendly for both consumers and retailers. Easy-to-open features, clear instructions, and ergonomic design contribute to a positive user experience.

Additionally, packaging can be divided into three types (Escursell et al., 2021) (Figure 2.1.1):

1. **Primary packaging**, which encompasses the wrapping or containers handled by the consumer or end user and serves to protect and advertise the product (e.g., foil wrapped around a chocolate bar).

2. **Secondary packaging**, usually in the form of large cases or boxes that are used to group quantities of primary packaged goods for distribution and for display in shops (e.g. cardboard boxes containing large numbers of foil-wrapped chocolate bars).

3. **Tertiary packaging**, which comprises the containers used to gather packaging groups into larger loads for transport in order to facilitate loading and unloading of goods (e.g. wooden pallets and plastic wrapping).

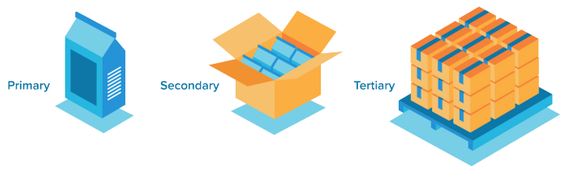


Figure 2.1.1: Primary, secondary and tertiary packaging (CRB, n.d.).

- Main functions of packaging: Protection, information and handling
- Three types of packaging: Primary, secondary and tertiary

2.2 Stakeholders

This Chapter explores sustainable packaging focusing on understanding stakeholders. A Power-Interest matrix is used to show the influence and interest of stakeholders in sustainable packaging at Aalberts (Figure 2.2.1). Difference in influence and power can make certain stakeholders play an important role in the process of developing sustainable packaging. Only the most involved stakeholders considering Aalberts' packaging are taken into account in this thesis.

2.2.1 Internal stakeholders

Marketing/Product Management

The marketing department plays a pivotal role in advancing sustainable packaging initiatives, impacting various stakeholders. Customers increasingly prioritize environmentally conscious products, making sustainable packaging a market differentiator. This department exists mainly out of Aalberts' product managers. The employees have high influence considering changing packaging practices. The department can influence sales of Aalberts with the type and design of the packaging, making it a high power and high interest stakeholder. Therefore the stakeholder should be engaged closely and influenced actively considering sustainable packaging practices. More information on Aalberts' attitude towards sustainable and reducing packaging can be found in Chapter 4.1.

R&D/Product engineers

These stakeholders are responsible for the type of packaging that is used. Material, infill and sizes are selected by this department. Because this department also develops the products, often it is preferred to package the product as safely as possible. This could provide contradictions with Aalberts' targets considering the reduction of packaging by 20%. Throughout this thesis, this stakeholder has been involved for (some) recommended actions considering the reduction of packaging and implementation of sustainable packaging. More on this can be found in Chapter 6.

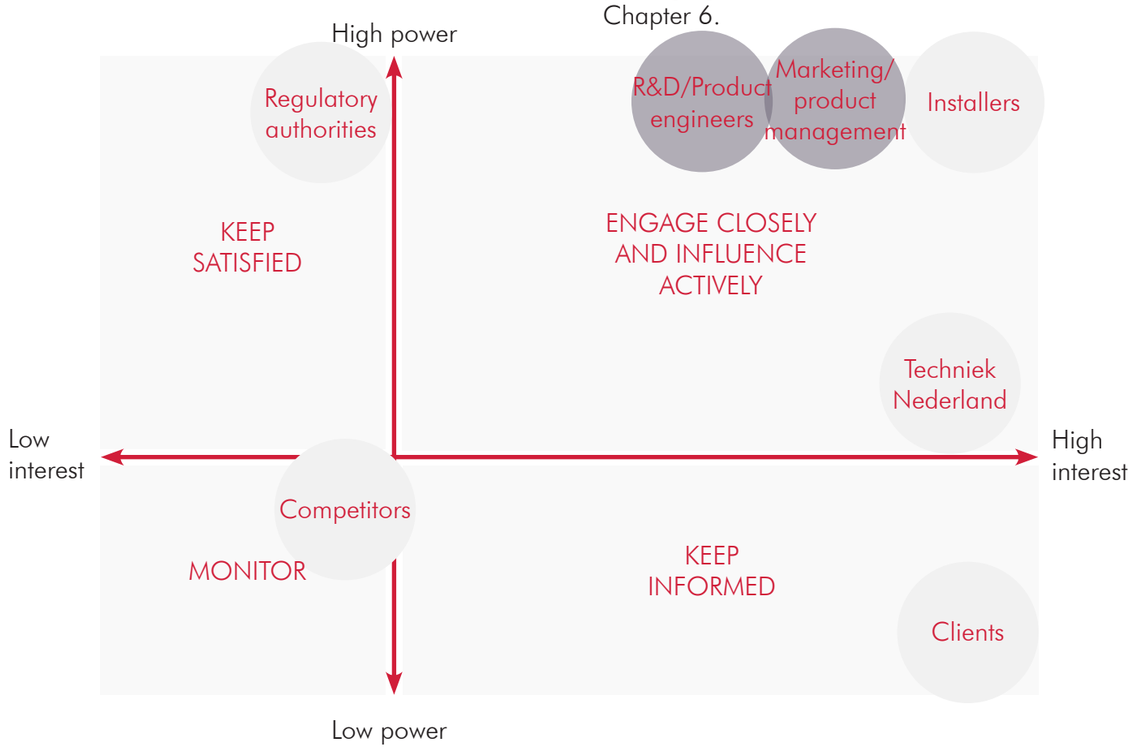


Figure 2.2.1: Stakeholder map - stakeholders are placed on the y-axis based on power and on the x-axis based on interest in reducing packaging and sustainable packaging. In grey are most important external stakeholders and in black are internal stakeholders presented.

2.2.2 External stakeholders

Regulatory authorities
Government agencies often set regulations and standards related to packaging and sustainability. Compliance with these regulations is crucial, and companies may also seek to influence policy decisions. As (new) regulations play a major role in changing packaging practices at Aalberts, this stakeholder is seen as one of the main drivers for packaging changes at the company. Nevertheless, Aalberts does not have direct influence on the formulation of new regulations and therefore has to keep the stakeholder satisfied. More on this topic will be discussed in Chapter 3.2.

Installers
Installers are the end-users of the products that Aalberts brings to market. These stakeholders are the ones that deal a lot with packaging. They are also the ones who determine the disposal of the packaging. The end-customers are a critical stakeholder as they could increasingly demand sustainable packaging options. They can influence the company's decisions by choosing to support businesses that prioritize sustainable packaging. As this stakeholder is the end-customer, it influences the sales of the company. Therefore is the stakeholder seen as high-power. The stakeholder needs to be engaged closely and influenced actively to keep sales to its target. In Chapter 4.1 will be discussed more on the influence of the end-customer.

Competitors
Companies within the same industry can influence each other by adopting sustainable packaging practices. They benchmark against each other to stay competitive. Competing businesses may drive each other toward adopting sustainable packaging as a means to distinguish themselves in the market. To stay competitive, Aalberts has to monitor its competitors packaging practices. More on competitor analysis will be explained in Chapter 4.2.

Clients
Aalberts direct clients are wholesalers. These stakeholders are a party inbetween the end-customer and Aalberts. Power of the direct clients is low as they are influenced by the end-customer (installers). Nevertheless, they do care about reducing packaging as will be mentioned in Chapter 4.1. For this reason, direct clients have to be informed by Aalberts considering their packaging practices.

Techniek Nederland
Techniek Nederland, a branche association where Aalberts is member of, is heavily involved in stimulating sustainable packaging in the industry. The branche association initiates sustainable packaging projects and half yearly meetings considering new packaging implementations in the industry (Techniek Nederland, 2023). The stakeholder does not have direct influence on the type of packagings used at Aalberts as it does not influence sales. Nevertheless, Techniek Nederland initiates sustainable packaging projects with other companies in the same branche and therefore should be engaged closely and influences actively to help Aalberts reduce packaging waste, together with other companies in the same branche. Because of the industry association, Aalberts can work together with the industry to reduce packaging waste. More on this stakeholder and sustainable packaging changes in the industry will be explained in Chapter 4.3.

I The most stakeholders involved in reducing packaging at Aalberts are: Marketing/product management, R&D, Regulatory authorities, Installers, Competitors, Clients and Techniek Nederland

2.3 Packaging journey

To understand more about how to reduce packaging, it needs to be researched how the current supply chain considering packaging looks like. This research aims to find out how the supply chain looks like by talking to Aalberts' supply chain employees to gain insights in the challenges of Aalberts' supply chain.

At Aalberts Hydronic Flow Control, the current packaging supply chain is linear: packaging is used only once before disposal, as opposed to circular, where the same packaging is used multiple times. First, when changing packaging, a packaging shape is selected at one of the packaging suppliers of the company. Then the packaging is graphically designed by the marketing department. Once the packaging is designed, the company will place an order at the packaging supplier. The supplier will produce the packaging and distribute it to one of Aalberts factories. The products will be packaged at one of these sites and then sent to one of Aalberts' clients. About 90% of all sales are channeled through wholesalers. At this point in the supply chain, Aalberts hands over the packaging (and its product) together with the responsibility of protecting the product. The company has no view on what happens in the next steps in the supply chain.

Next, the wholesaler internally ships the product and packaging to one of its retail locations. At these locations, the end-users (installers) can purchase the product. Once the product is installed, its packaging undergoes recycling, incineration, or ends up in a landfill.

In practice, Aalberts primarily sells its products in Europe, resulting in lengthy supply chains that involve multiple distribution steps. According to the supply chain manager at Aalberts (2023), it's common for products to be transported from one warehouse to another several times by wholesalers as they distribute their products across Europe. This results in a complicated supply chain that varies for each client of Aalberts.

I Aalberts' supply chain is linear and complex: it involves a lot of stakeholders

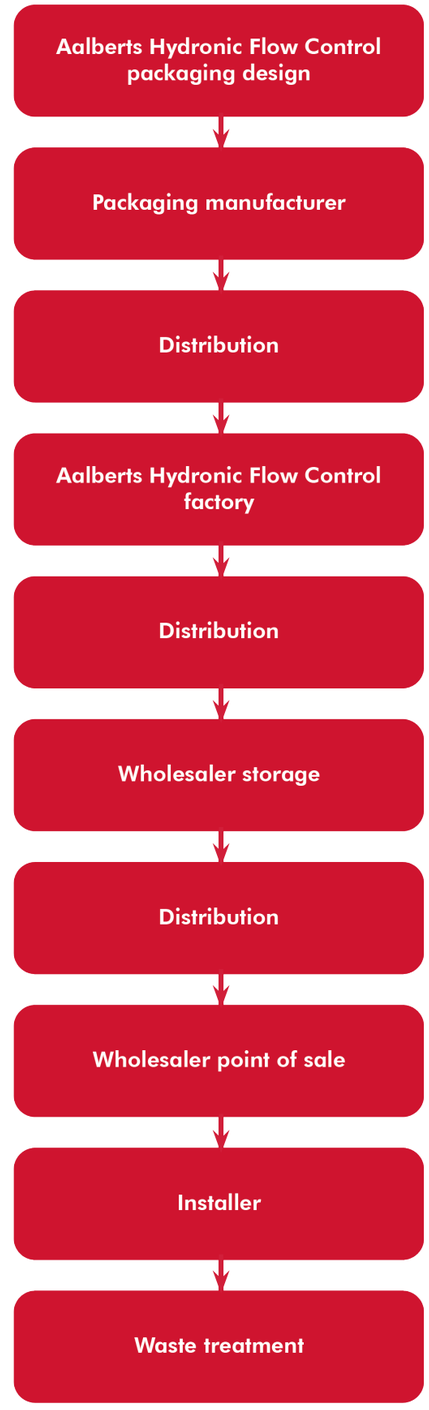


Figure 2.3.1: Packaging journey for Aalberts Hydronic Flow Control packaging and products.

2.4 Packaging analysis at Aalberts

In order to find out where most packaging material can be saved, an analysis on internal data has been performed on the current packaging consumption per product category. The analysis has been based on the registered packaging weights that are known at Aalberts. In Aalberts' packaging registration a distinction is made between three types of materials; cardboard, plastic and wood. In this Chapter, the packaging consumption analysis will be presented.

Product categories using most packaging materials

Aalberts has a catalog of 60.000 products (Appendix 9.4). By focussing on product categories that contribute most packaging material, the largest packaging reductions at Aalberts can be realised. To perform the analysis we looked at which factories currently bring most packaging material to the market. As stated before, in 2022 Aalberts brought 2739 tons of packaging material to the market.

In scope

The product categories that contribute most to packaging materials are PEX Pipe, expansion vessels, fittings (both multiskin and brass) and valves (balancing and normal valves). The factories where these products are produced represent 2311 tons of packaging material (approximately 84% of all packaging used at Aalberts). Since the product categories above contribute to most packaging material consumption at Aalberts in this thesis will be focused on these product categories. By focussing on the product categories that generate the greatest amount of packaging waste, this thesis aims to identify the greatest opportunities for packaging reduction at Aalberts. In Figure 2.4.1 - 2.4.6 main products contributing to most packaging material consumption can be seen.

Out of scope

It must be noted that the categories Separation, Boiler equipment, Multilayer PEX pipe and Panels are out of scope due to the fact that these categories are the minority of all packaging represented at Aalberts. In addition to this, the packaging of these categories exist of different sizes and types of products, requiring different types of packaging. For these categories, there is no clear representative product that represents the majority of the packaging use for this category. The complete list of products belonging to these categories can be found in Appendix 9.4.

Types of primary packaging

All products from Aalberts can generally be divided into two types of primary packaging: plastic bags (Polyethylene) and corrugated cardboard boxes. Generally can be said that for smaller products (e.g. fittings and valves), plastic bags are used. For bigger products (PEX pipe and expansion vessels), cardboard is mainly used as packaging material. Main packaging materials for the main product categories can be found in Figure 2.4.7.

Figure 2.4.1: PEX pipe.

Figure 2.4.2: Expansion vessel.

Figure 2.4.3: Balancing valve.

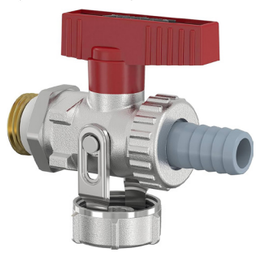


Figure 2.4.4: Valve.

Figure 2.4.5: Brass fittings.

Figure 2.4.6: Multiskin fittings.

Amount of packaging used per factory at Aalberts

Factory	Amount of packaging per factory (incl. wood)	%	Main product category per factory	Main packaging material per product category	
FLAMCO NL	942 tons	34.4	Expansion vessels	Cardboard box	In scope
COMAP Nevers	740 tons	27.0	PEX pipe	Cardboard box	
COMAP Abbeville	296 tons	10.8	Brass fittings	Plastic bags	
COMAP Brescia	120 tons	4.4	Multiskin fittings	Plastic bags	
Nexus	75 tons (2021)	2.7	Balancing valves	Plastic bags	
Simplex	138 tons	5.0	Valves	Plastic bags	
Total PEX pipe, expansion vessels, fittings and valves	2311 tons	84.4			
Meibes	200 tons	7.3	Boiler equipment	Cardboard box	Out of scope
Flamco UK	60 tons	2.2	Separation	Cardboard box	
Henco	59 tons	2.2	Multilayer PEX pipe	Cardboard box	
HAKA	75 tons	2.7	Multilayer PEX pipe	Cardboard box	
HEWING	27 tons	1.0	Multilayer PEX pipe	Cardboard box	
HIRSCH	7 tons	0.3	Panels	Cardboard box	
Total Separation, boiler, multilayer PEX and panels	428 tons	15.6			
Total Aalberts	2739 tons	100			

Figure 2.4.7: Packaging consumption of all types of packaging materials (plastic, cardboard and wood) at Aalberts per factory - Colours in red represent the product categories in scope, colours in grey are out of scope for this thesis.

When diving deeper into the amount of packaging for the two common types of primary packaging, the following can be concluded.

Plastic packaging

By focussing on fittings and valves, which are mostly packaged in plastic bags, 92 tons of plastic is involved. In total, Aalberts required 155 tons of plastic packaging in 2022. Therefore, it can be said that by focussing on fittings and valves, 59% of all plastic packaging is represented (Figure 2.4.8).

Cardboard packaging

Additionally, by targetting on PEX pipe and expansion vessels which are largely packaged in cardboard boxes, 872 tons of cardboard is taken into account. In 2022, Aalberts used 1807 tons of cardboard packaging. Therefore by targetting PEX pipe and expansion vessels, 48% of all cardboard consumption is represented (Figure 2.4.9).

Plastic packaging use Aalberts

Main product categories	Main packaging material product category	Plastic packaging	%
Multiskin fittings	Plastic bags	21 tons	13.5
Brass fittings	Plastic bags	35 tons	22.5
Balancing valves	Plastic bags	8 tons (2020)	5.2
Valves	Plastic bags	28 tons	18.1
Total Valves & Fittings		92 tons	59.4
Total plastic Aalberts		155 tons	100

Figure 2.4.8: Plastic packaging consumption at Aalberts per main packaging material.

Cardboard packaging use Aalberts

Main product categories	Main packaging material product category	Cardboard packaging	%
PEX pipe	Cardboard box	198 tons	11.0
Expansion vessels	Cardboard box	674 tons	37.3
Total PEX pipe & Expansion vessels		872 tons	48.3
Total cardboard Aalberts		1807 tons	100

Figure 2.4.9: Cardboard packaging consumption at Aalberts per main packaging material.

Wood packaging

Aside from primary packaging materials, tertiary packaging is used. Wood is the third registered type of packaging at Aalberts used for tertiary packaging, mostly in the form of pallets. Registered wooden packaging is used as single-use packaging and therefore is recommended to be reduced as well. In Figure 2.4.10 can be seen for which products most single-use wood is used.

When looking at the single-use pallet consumption of all product categories, it can be concluded that PEX pipe (produced in Nevers) contributes most to all single-use wood consumption with 520 tons of wood per year. By targetting PEX pipe tertiary packaging 67% of all single-used wood is represented.

Wooden packaging use Aalberts

Main product categories	Wood packaging	%
PEX pipe	520 tons	66.9
Total wood Aalberts	777 tons	100

Figure 2.4.10: Single-use wood packaging consumption at Aalberts per product category.

Conclusion

In conclusion, in 2022 Aalberts brought 2739 tons of packaging material to the market. The product categories PEX Pipe, expansion vessels, fittings (both multiskin and brass) and valves (balancing and normal valves) represent most packaging material use at Aalberts accounting for approximately 1484 tons (54%) of all packaging.

The types of primary packaging for these categories can be divided into two categories: plastic polyethylene bags and corrugated cardboard boxes. The product categories Valves and Fittings account for approximately 92 tons (59%) of all plastic packaging at Aalberts. The product categories PEX pipe and Expansion vessels represent 872 tons (48%) of all corrugated cardboard consumption at the company. This thesis focuses on these product categories in order to have the most significant impact of packaging reduction at Aalberts.

In addition to this, the third and last type of material used for packaging at Aalberts is wood. This material is mostly used for tertiary packaging in the shape of pallets. Most single-use pallets are used for the product category PEX pipe, representing 520 tons (67%) of all single-use wood use. In this thesis will also be looked at how to reduce single-use wood packaging in addition to reducing the packaging materials for the product categories PEX pipe, expansion vessels, valves and fittings.

- PEX pipe, Expansion vessels, Fittings and Valves contribute most (54%, 1484 tons) to packaging waste at Aalberts
- Main packaging materials: Plastic, cardboard (primary) and wood (tertiary packaging)

2.5 EU packaging waste figures

To gain a better understanding in the common types and amounts of packaging materials used, research has been done on packaging waste in the European Union.

The European Union (EU) experienced an overall increase in packaging waste generation from 2010 to 2021. In 2021, the EU produced an estimated total of 84.3 million tonnes of packaging waste, marking a 6.0% rise (equivalent to 4.8 million tonnes) compared to 2020. (Eurostat, 2023).

Over the 11-year period, paper and cardboard emerged as the primary packaging waste material, contributing 34.0 million tonnes to the total generated in 2021. This waste stream grew by 23.5% since 2010. Plastic packaging amounted to 16.1 million tonnes, making it the second most significant packaging material with a 29.9% increase compared to 2010. Glass packaging waste reached 15.6 million tonnes (up by 18.1%), wood amounted to 14.4 million tonnes (a rise of 32.7%), and metal packaging totaled 4.2 million tonnes in 2021 (a 10.6% increase). (Eurostat, 2023) (Figure 2.5.1).

In addition to this, in 2020 only 38% of all plastic packaging waste is recycled. (Eurostat, 2022). The limited percentage of plastic recycling in the EU results in substantial losses for both the economy and the environment. It's estimated that approximately 95% of the value of plastic packaging material is lost to the economy (European Parliament, 2018). Between 2010 and 2021, plastic recycling hit a peak at 42.4% in 2016 but has generally been on a declining trend since that time (Statista, 2024b).

In contrast, in 2021, the European Union achieved a recycling rate of 82.5% for paper and cardboard packaging waste. The recycling rate for paper and cardboard packaging waste has consistently stayed above 80% in the European Union since 2008 (Statista, 2024).

In 2022, Aalberts Hydronic Flow Control introduced a total of 2739 tons of (registered) packaging to the market. This included 1807 tons of cardboard, 155 tons of plastic, and 777 tons of wooden packaging. A detailed analysis on what packaging is used for what type of products was presented in Chapter 2.4.

- Packaging waste is increasing in EU
- Recycling rate paper & cardboard: 83%
  Recycling rate plastics: 42%

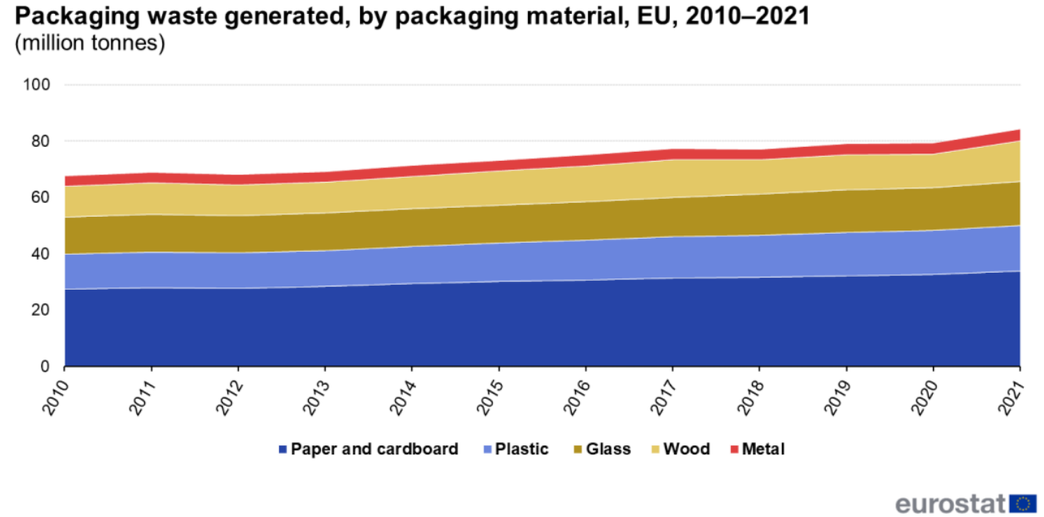


Figure 2.5.1: Packaging waste generated by packaging material in the European Union (Eurostat, 2023).

2.6 Conclusion

Packaging can be divided into three main functions; product protection, product information and product handling. Additionally, packaging can be divided into three types; primary, secondary and tertiary packaging.

From the stakeholder analysis can be concluded that there are two types of main stakeholder involved in packaging reduction and sustainable packaging at Aalberts. Firstly, marketing and R&D are seen as important internal stakeholders in decision making processes of packaging practices at Aalberts. Secondly, regulatory authorities, installers (end-customer), competitors, clients (wholesalers) and Techniek Nederland (branche association) are seen as important external stakeholders involved in reducing and changing packaging practices at Aalberts.

It can be concluded from the packaging journey analysis that Aalberts' supply chain involves a lot of stakeholders and is complex. The current supply chain of the company is linear.

From the analysis on Aalberts' current packaging status can be concluded that the product categories PEX pipe, Expansion vessels, Valves and Fittings contribute most to packaging used at Aalberts, representing 1484 tons (54%) of all packaging. Current packaging material at Aalberts can be divided into three categories: Cardboard, Plastic and Wood.

The analysis on current packaging figures in the EU provided the insight that packaging waste is increasing. Cardboard packaging is recycled on a bigger scale than plastic packaging (83% vs 42%).

All insights mentioned above will be used later on during the ideation of possible packaging solutions, enabling most significant packaging reduction at Aalberts.

3. Analysis - Industry current position and regulations

To gain a better understanding on sustainable packaging in the industry, an analysis has been performed based on literature research and expert interviews to find current challenges and approaches to reducing and implementing sustainable packaging in the industry. The following topics will contribute to understanding the current industry's challenges.

Firstly, will be looked into the current challenges of the industry to reduce and transition to more sustainable packaging through expert interviews and literature research.

Second, will be dived into regulations considering packaging based on literature research. This is done to gain a better understanding on how changing policies affect packaging practices at companies.

Third, will be looked into the various common material types used for packaging applications in the market. Recommendations will be given to Aalberts considering the type of materials used for packaging.

3.1 The packaging industry

To learn more about the packaging industry and its challenges, explorative interviews with packaging experts were conducted. In total, four experts with various backgrounds were interviewed: a B2B packaging researcher, a packaging consultant, a business developer circular packaging and a packaging technologist. Results from these interviews are divided in three main challenges, perception of policies and regulations, lack of impact knowledge and prevention of risks and investments, and are described in this Chapter. One hour long interviews were conducted online via videocalls (n=3) and via phone (n=1). Interviewees were approached via LinkedIn and were not associated with Aalberts, this thesis nor the interviewer. More detailed information on the interview procedure can be found in Appendix 9.6.

3.1.1 Perception of policies and regulations

Perception of policies and regulations - Interviews

Policies and regulations are the first bottleneck when it comes to sustainable packaging. According to the B2B packaging researcher, "Policies might not be completely aligned with each other. There might be a clash of regulations; while fixing one thing might cause major issues on another thing. You cannot improve every aspect of sustainability in the supply chain. For example a reverse logistics implemententation requires a complete new logistics system as well. If reverse logistics are implemented without a properly thought through logistics system, you will likely increase the environmental footprint of the supply chain" (B2B packaging researcher, 2023).

Moreover, it was discovered that many companies are unsure about regulations. "This often leads to choosing business as usual over changing packaging. Uncertainties over regulations can be led to the fact that regulations are not formed yet (e.g. PPWR). "Uncertainties over regulations can also lead to skepticism at companies. This group does not know how to react to these policies that become stricter and stricter." (packaging consultant, 2023).
In addition to this, "Regulations tend to give too much space for alternative packaging options with no positive change in environmental impact. This leads to changing regulations without having any impact. Since the introduction of the Single Use Plastic (SUP) regulations some producers of single use plastics started to produce heavier, more sturdy plastic products so that it could pass the tests for reusable items, while in practice these products are only used one time, leading to more use of plastic overall." (packaging technologist, 2023)

Another observation that emerged from the interviews is the explanation for the concentration of regulations primarily on plastics. "These regulations are based on recycling rates of the type of packaging; metal, paper and glass have high recycling rates, whereas plastic recycling is lagging behind." (packaging consultant, 2023). In 2020 plastic packaging waste had a recycling rate of 38% in EU (Eurostat, 2022). Recycling rates are even decreasing: in 2016 it reached a high of 42.4 percent, but has been in decline ever since (Statistica research department, 2023).

Perception of policies and regulations - literature

From literature can be concluded that new regulations could be effective to reduce the demand for packaging. Results from a research performed on environmental taxes on industrial packaging in Denmark show that these environmental taxes were effective in reducing the quantity imported (Cela & Kaneko, 2011). In addition to this, it is recognized by Dace et al. (2014) that packaging tax is an effective policy instrument for increasing the material efficiency. It ensures the decrease of the total consumption of materials and waste generation. The tax also stimulates for eco-design of packaging. This shows that packaging taxes are effective to reduce packaging material. Therefore governments are likely to implement new regulations considering packaging taxes to reduce the increase of packaging material in the EU as stated in Chapter 2.5.

In addition to taxes, Extended Producer Responsibility (EPR) policies considering packaging are seen as effective. An analysis of waste management policies in Portugal and Spain shows that the implementation of EPR policies have had a positive impact throughout the years in both countries. The policies have been able to promote material usage reduction and increase recycling rates throughout the years (Rubio et al., 2019). Furthermore, it is stated in a research of Pietro Colelli et al. (2022) that a mix of policy schemes focused on EPR can be effective for increasing the recycling rates of the waste streams that need more intervention, most notably plastic packaging. This shows that regulations considering producer responsibilities are effective as well.

Conclusion

In conclusion, policies and regulations have an influence on reducing packaging waste and increasing recycling rates of packaging as shown in literature research. The implementation of packaging taxes and Extended Producer Responsibility policies both do lead to reduced packaging and increased recycling rates. As these are seen as effective, it is likely that more governments will implement new regulations considering packaging. However, in practice it seems that these new regulations are not well received by the industry. It would be very likely that this is partly because the industry does prefer not to change packaging practices. Since these type of (upcoming) packaging regulations are new, not everyone is entirely aware of them and their impact.

- Policies and regulations influence (future) packaging practices
- Companies are not always aware of new regulations considering packaging
- Governments are likely to introduce more policies regarding reducing packaging waste

3.1.2 Lack of impact knowledge

Lack of impact knowledge - Interviews

Another challenge identified during the interviews is the lack of awareness regarding the impact of changes in packaging. "Many factors such as the length of the supply chain, weight and material of the package, type of transport are dependent on the environmental impact of a packaging. All these factors can make it hard for a company, researcher or policymaker where to decide on. The choice of packaging depends on the specific case and the company's focus area." (packaging technologist, 2023).

All packaging experts interviewed agree that there isn't a single approach to making packaging more sustainable. "There is always a trade-off that a company has to make to change their packaging. For example, circular packaging does not always mean that the CO2 impact of that packaging is lower as well. This might result in companies being uncertain about how to diminish the environmental impact of their packaging." (business developer circular packaging, 2023).

Moreover, the interview revealed the understanding that Life Cycle Assessments (LCAs) are not flawless. "Although the method can provide a general insight of the environmental impact of a product, the outcome of an LCA depends on which emission factors you focus on. Hence, the optimal choice in terms of environmental impact varies depending on the specific case. As a consequence, most companies make decisions about a particular type of packaging before it is scientifically validated through a LCA. In many instances, these decisions are made based on the company's intuition or instinct. Once the results of the LCA are known, they are mainly used for marketing purposes." (packaging technologist, 2023).

Based on his experience, the packaging technologist explains that LCAs are frequently manipulated to portray a positive image for a company. “LCA’s are only partially presented: only positive facts are shown to the public. Due to this, for instance, a packaging that initially prioritized carbon footprint reduction may be presented to the public as if “we are saving x amount of plastic”, when results from the LCA do not support the packaging decision that was previously made by the company.” (packaging technologist, 2023).

Furthermore, it became evident that customers are the primary force behind the demand for sustainable packaging. “Perception contributes to the paperification of the market, where customers may favor a solution based on intuition.” (business developer circular packaging, 2023)

Lack of impact knowledge - Literature

Literature research shows that during recent years a range of tools for improvement of reliability in LCA have been presented, but despite this there is still a lack of consensus about how these issues should be handled (Björklund, 2002). In addition to this, drawbacks of the LCA are related to the incomplete inclusion of environmental impacts related to littering, as well with the missing indicators to measure packaging circularity (Pires, 2021). These two findings show that LCA’s and their reliability are not perfect.

In addition to this, according to Stark & Matuana (2021), there are 20 trends in the current sustainable paper- and bioplastic-based materials packaging market. Also, according to Ibrahim et al. (2022) sustainable packaging is made possible by using bio-based and recyclable materials. These findings show that there could be multiple approaches to make packaging more sustainable.

Conclusion

In conclusion, lacking reliability, chosen focus for emission factors and neglecting down-sides of an LCA outcome could contribute to a lack of awareness among the industry considering what needs to be done to reduce the environmental impact of packaging. The availability of multiple options of sustainable packaging could also contribute to complicating decisions for companies regarding sustainable packaging. Not one solution or method is provided as the environmental impact depends on lots of factors and differs per packaging practice, leading to most companies not entirely knowing the impact of the packaging changes that are to be made.

I Companies have a lack of impact knowledge on sustainable packaging practices

I The lack of impact knowledge is (partly) caused by the availability of multiple sustainable packaging options differing per product

3.1.3 Prevention of risks and investments

The prevention of risks and investments - Interview

The final challenge highlighted in the interviews is the need for risk prevention and investments. “Industries are hesitant to be pioneers primarily due to the high levels of associated risk. There is not enough evidence to show that another way of working will succeed. This leads to a conservative attitude. Reusables are often seen by companies as too much hassle for the benefits.” (packaging consultant, 2023).

In the interviews, it was also noted that the primary reason for products being “overpacked” is companies’ fear of the products getting damaged during transportation. “Damaged products can cost companies’ profits, making them act careful to their products and thus overpacking them.” (business developer circular packaging, 2023). “When minimizing packaging, it should be taken into account that there is an elevated risk of causing damage to the product” (B2B packaging researcher, 2023).

Apart from avoiding risks, the decision to stick with the current type of packaging is also influenced by investment considerations. From the interviews, it was revealed that companies frequently make investments in packaging machines with a perspective of the next 10 or 20 years. “It is more cost-effective for them to keep the machines running, rather than going for another packaging and thus changing packaging machines.”(packaging consultant, 2023).

Additionally, “When considering reusable packaging, it works better with standardized packaging. Using individualized packaging is more challenging for reusability because any change in the product may make the packaging unusable.” (B2B packaging researcher, 2023). Furthermore, “Reusable packaging is seen as more risky than single-use packaging due to the fact that the company is also responsible for the return of the packaging. This is not the case for single-use packaging where the supply chain is linear.” (packaging consultant, 2023). This shows that reusable packaging also has its limitations.

The final challenge brought up in the interviews is the expenses associated with using more environmentally friendly packaging materials. All packaging experts agreed that the primary obstacle in B2B packaging is frequently the cost. “Resellers are not willing to pay more for a sustainable packaging, leading to less margins when using a more expensive packaging material. Currently chemical recycled plastics, which have the same properties as virgin plastics, are 3x as expensive. Eco-friendly packaging materials are frequently pricier than new plastics, putting companies at a cost disadvantage compared to competitors who use virgin plastics. “ (business developer circular packaging, 2023).

The prevention of risks and investments - Literature

Research from Cammarelle et al. (2021) shows that manufacturers are only willing to invest in sustainable packaging solutions which show a demand. Additionally research from Wandosell et al. (2021) shows that manufacturers choose packaging based on costs and consumer preferences. It is indicated that green packaging involves issues of high production costs. Also research from Lau and Wong (2024) states that the adoption of sustainable packaging incurs relatively high costs and operational challenges. Firms face difficulties in balancing between organisational needs (e.g. profitability), consumer preferences and environmental concerns in strategy development related to packaging. This shows that increased costs of sustainable packaging do have an influence on the type of packaging used by companies.

Research by Herrmann et al. (2022) on consumers’ perception and willingness-to-pay for alternative plastic packaging reveals that consumers are willing to pay for packaging that they perceive to be sustainable and are not willing to pay for packaging that they perceive to be non-sustainable or about which they are uncertain. In addition to this, research from Zwicker et al. (2021) shows mixed evidence in the effect of attitudes towards sustainable packaging on willingness to pay. The research suggests that other psychological factors may

also play a role. It appears that willingness to pay for more sustainable packaging strongly depends on the type of customer.

Conclusion

The willingness to pay for sustainable packaging is strongly connected to the type of customers and their perceived attitude towards sustainable packaging. It would be safer for a company to assume that customers are not willing to pay extra for sustainable packaging over traditional packaging. Also, increased costs for greener packaging alternatives and required investments for new packaging machines are seen as challenges for companies considering sustainable packaging practices.

- Aalberts should not assume that customers are willing to pay extra for sustainable packaging
- Increased costs and required investments for sustainable packaging are seen as a challenge to implement sustainable packaging
- Reusable packaging is seen as more risky than single-use packaging due to the fact that the company is also responsible for the return of the packaging

3.2 Packaging regulations

To gain a better understanding of upcoming regulations, an analysis has been performed on literature on packaging regulations. Only relevant regulations for Aalberts hydronic flow control will be discussed in this Chapter.

EU Green Deal

The basis of all upcoming packaging regulations is found in the Green Deal of the European Union. The goal of this overarching policy is to guide Europe to the first climate-neutral continent on the planet by 2050 (European Commission, 2021) (Figure 3.2.1).

Circular Economy Action Plan

One of the pillars described in the EU Green Deal is the Circular Economy Action Plan. The pillar is Europe's new agenda for sustainable growth. The new action plan announces initiatives along the entire life cycle of products. It targets how products are designed, promotes circular economy processes, encourages sustainable consumption, and aims to ensure that waste is prevented and the resources used are kept in the EU economy for as long as possible (European Commission, n.d.). More information on the circular economy and Aalberts can be found in Chapter 4.4.

Packaging and Packaging Waste Directive

The Packaging and Packaging Waste Directive is part of the pillar Circular Economy Action Plan (Anthesis, 2023). The directive was established in the early nineties and has undergone multiple revisions. Member states of the EU adopt measures from these directives into their national legislation on waste and packaging (KIDV, n.d.).

Packaging and Packaging Waste Regulation

At the end of 2022, the European Commission published the proposal for a new packaging regulation, the Packaging and Packaging Waste Regulation based on the Packaging and Packaging Waste Directive (PPWR) (KIDV, n.d.). Unlike under the current packaging directive, under the new packaging regulation, EU countries are not allowed to implement it in their own way. The playing field is equalized for all member states in the proposal (KIDV, 2023).

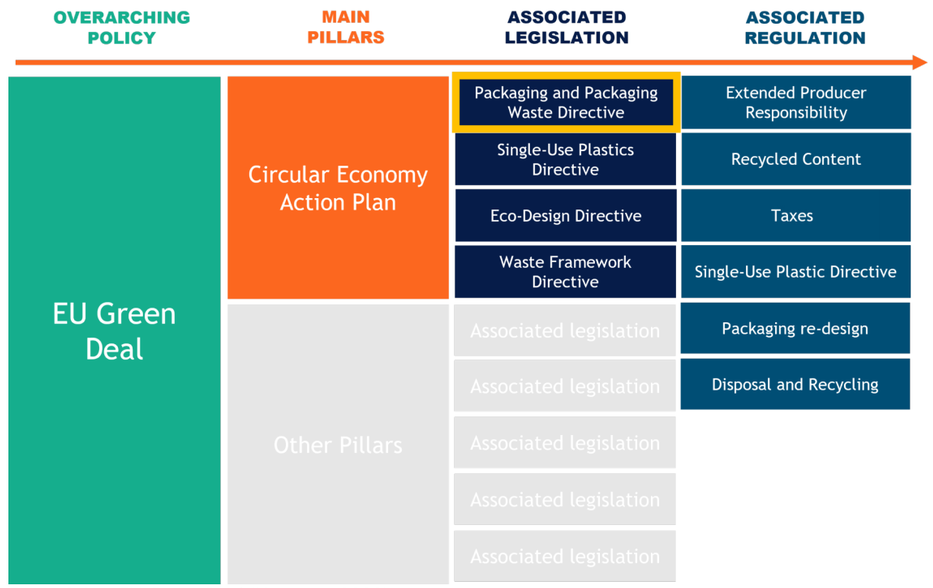


Figure 3.2.1: EU Green Deal (Hampsey, 2023)

"The intended overarching objective of the Regulation is to reduce packaging waste in the first instance, improve recyclability and grow the market for recycled content" (Hampsey, 2023).

Although the PPWR seems to be part of the new packaging regulations, it still needs to be approved; *"The proposal for the PPWR by the European Commission must be approved by the European Council and the European Parliament before it can come into effect. There are various negotiation rounds between the European Parliament, the European Council, and the European Commission. The outcomes of these discussions will determine the final form of the PPWR." (KIDV, 2023)*. If everything goes as scheduled, the PPWR will be published end of 2024.

Associated regulations

There are two associated regulations that are relevant for Aalberts at this moment due to its rapid expected implementation: Extended Producer Responsibility (EPR) and Taxes. These will be discussed in this Chapter. Regulations that will play a role in future packaging decisions at Aalberts will be explained in Chapter 6.3.2 and 6.4.2.

Extended Producer Responsibility

The PPWR includes measures that specifically apply to producers/importers, as well as measures affecting the implementers of extended producer responsibility (EPR). Producers that bring products to market, like Aalberts, will be held responsible for the packaging brought to market as well.

Packaging registration

Part of the EPR is that companies will soon have to compile a file (with the implementation of the PPWR) for each packaging including information on the type of product and packaging, the composition of materials, recyclability and compostability, and the proportion of recycled content applied. The European Commission requires from every producer and importer a 'packaging passport' for each packaging, including a list of materials used and their weights. (European Commission, 2023).

Label

In addition to the registration of packaging, producers, like Aalberts, are responsible for labelling of the packaging. When the PPWR is implemented, the following needs to be presented on every packaging brought to market in Europe (Ragonnaud & European Parliamentary Research Service, 2023):

- **Material composition**: 3.5 years after entry of the PPWR all packaging must have labels containing information on its material composition (Ragonnaud & European Parliamentary Research Service, 2023). As of this moment, it is not yet determined how this information should be showed exactly on every packaging. However, it is very likely that the label on the composition of the packaging materials will be comparable to the current labelling requirement of the textile industry, where the composition of the fabric is explained written in decreasing percentage order (European Union, 2023) (Figure 3.2.2).

Figure 3.2.2: Material composition label textile (Limited, n.d.).

- **Recycling codes:** 4 years after the implementation of the PPWR it is required to label packaging with its recyclable content (Ragonnaud & European Parliamentary Research Service, 2023). Currently there are recycling codes available to identify the materials out of which the item is made, to facilitate an easier recycling process. The presence on an item of a recycling code, a chasing arrows logo, or a resin code, is not an automatic indicator that a material is recyclable; it is an explanation of what the item is made of. (Wikipedia contributors, 2024) (Figure 3.2.3).

Figure 3.2.3: Recycling codes (Recycling Codes, n.d.)

- **Recycled material:** 4 years after the implementation of the PPWR, packaging is required to have recycled contents labelled on it (Ragonnaud & European Parliamentary Research Service, 2023). It is recommended to use the current logo, which is used internationally to show the recycled contents as showed in Figure 3.2.4.

Figure 3.2.4: Recycled material symbols (Recycling, n.d.)

Taxes

Taxes on packaging are also part of the new associated legislation PPWR. Member States of the European Union will have to pay contributions for packaging waste. The States are developing different approaches on how to finance the levy (European Commission, 2023). These upcoming taxes aim to incentivize businesses to adopt eco-friendly packaging solutions, promoting a shift towards sustainability (KIDV, n.d.). The type of tax system differs per Member State of the European Union and it is recommended for Aalberts to look more into in detail.

I With the implementation of the PPWR (end of 2024), the following needs to be registred considering packaging information:
- Type of product and packaging
- Composition of materials for the packaging
- Recyclability and compostability of packaging
- Proportion of recycled content applied of packaging
- Weight of the packaging brought to market

I Producers, like Aalberts, will be held responsible for the packaging they bring to market

I It is recommended for Aalberts to look deeper into the tax regulations on packaging per country in the EU

I Taxes on packaging will be implemented to stimulate the use of eco-friendly packaging

3.3 Materials in the market

This Chapter will discuss the current trend in the packaging industry. It provides an overview which can be used for inspiration when adapting packaging strategies to reduce its environmental footprint.

Recyclable materials

Reyclable packaging is made of materials that can be used again, usually after processing. Recyclable materials include glass, metal, cardboard, paper and some plastics. Currently the most common form of recyclable packaging is corrugated cardboard. (GWP Group, 2023)

Recycled materials

A recycled material is a material that has been reprocessed from a recovered material, by means of a manufacturing process, and then, included in a final product or component (Green trade world, 2023). The definition of recycled materials is often confused with recyclable materials (business developer circular packaging, 2023). It must be recognized that recycled materials are made from recyclable materials only whereas recyclable materials could be made from both recycled or virgin resources.

Recycled materials can be divided into mechanical recycled and chemical recycled materials. Mechanical recycling is processing plastics waste into secondary raw materials or products without significantly changing the material's chemical structure. In principle, all types of thermoplastics can be mechanically recycled with little or no impact on quality. (Plastics Europe, 2024)

Chemical recycling is the process of converting polymeric waste by changing its chemical structure and turning it back into substances that can be used as raw materials for the manufacturing of plastics or other products. The benefit of using chemical recycling over mechanical recycling is that it can deal with complex plastic waste streams, like films or laminates, which would otherwise result in incineration or landfill. In contrast, chemical recycling is much more costly than mechanical recycling. (Plastics Europe, 2024b). In addition to this, the environmental impact of chemical recycled plastics is greater than for mechanical recycled plastics.

- Mechanical recycled pellets rPE or rPP 0.57kg CO2 equiv./kg
- Chemical recycled pellets PE 2.02kg CO2 equiv./kg
- Chemical recycled pellets PP 1.85kg CO2 equiv./kg (Idemat, 2024)

Biodegradable materials

Biodegradable packaging is generally defined as any form of packaging that will naturally disintegrate and decompose. "Biodegradation is the biochemical material conversion process in the water, biomass, carbon dioxide or methane in terms of the action of microorganisms." (Ivankovic et al., 2017). Biodegradable materials can be made from biomass or fossil based resources. To demonstrate complete biodegradability, the level of biodegradation of at least 90 % must be achieved in less than 6 months (Ivankovic et al., 2017). Biodegradable plastic is tested to make sure that it breaks down under controlled conditions in a lab, including factors such as oxygen levels, UV exposure, temperatures, and others. However, since nature lacks controlled conditions, there is no certainty that biodegradable plastic will truly decompose in the natural environment if it is discarded. (WWF, 2022). Biodegradation is very much dependant on the environment and it can be different from one environment to another. The standards (EN 13432) are mainly about industrial composting and they cannot be applied to other environments, such as soil, marine, etc. (Rujnić-Sokele & Pilipović, 2017). When using biodegradable materials, it is adviced to use materials that are degradable in all conditions. In Figure 3.3.3 can be seen that only a few biodegradable polymers biodegrade in all conditions (PHA and chemical pulp) (Rujnić-Sokele & Pilipović, 2017).

Compostable materials

Compostable plastics are plastics that are biodegradable in the conditions and within the time frame of the cycle of composting. During industrial composting temperature can reach temperatures up to 70 °C. Composting occurs in humid conditions, the composting process takes place for months (Ivankovic et al., 2017). Compostable plastic must be recovered in either home or commercial compost, depending on what that specific item is designed for. (WWF, 2022). When using compostable materials, it must be communicated that disposal is different than for non-compostable packaging. For this reason, one could argue that implementing compostable packaging makes the disposal of packaging more complex.

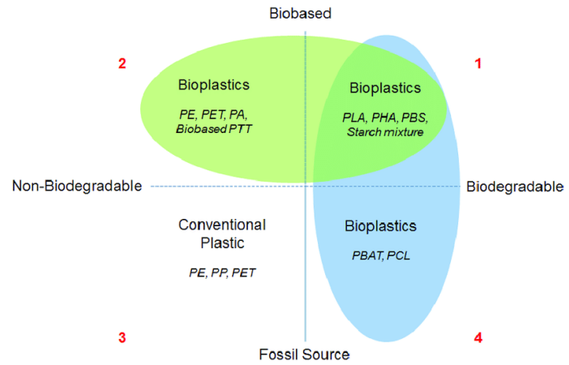


Figure 3.3.1: Coordinated system of bioplastic material (Ottoni et al., 2018).

Biobased materials

Biobased packaging is packaging made from biobased materials. These are defined as those materials derived from biological sources instead of petroleum (fossil fuel) sources (Borras, n.d.). Bio-based packaging could be seen as the solution to fossil resource depletion (Figure 3.3.2). Much of the driving force behind the circular bioeconomy has been directed at reducing petroleum-based plastics packaging (Stark & Matuana, 2021). The goal of a circular economy for plastic packaging implements that the plastics must constantly flow around a 'closed loop' system, rather than being used once and then discarded. According to the Ellen MacArthur Foundation, achieving this shift will involve gradually disconnecting plastic packaging materials from finite (fossil) resources (Stark & Matuana, 2021). A list of most commonly used biobased packaging materials can be found in Appendix 9.13 (Figure 3.3.1).

When comparing biodegradable PE against mechanical recycled rPE, it can be concluded that the carbon footprint of rPE is much smaller than for bio-PE. Additionally, when comparing Bio-PE to Virgin LDPE, it can be concluded that the virgin material has a smaller carbon footprint. Nevertheless, it's essential to highlight that conventional LDPE is derived from fossil sources, leading to increased greenhouse gas emissions. In contrast, bio-PE does not contribute to these emissions and aligns with the principles of the circular economy.
- Mechanical recycled pellets rPE or rPP 0.57kg CO2 equiv./kg
- Bio-PE 1.87kg CO2 equiv./kg
- Virgin LDPE 1.84kg CO2 equiv./kg (idemat, 2024)

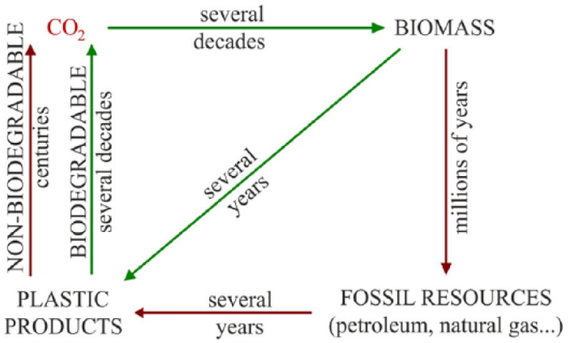


Figure 3.3.2: Global carbon cycle (Rujnić-Sokele & Pilipović, 2017).

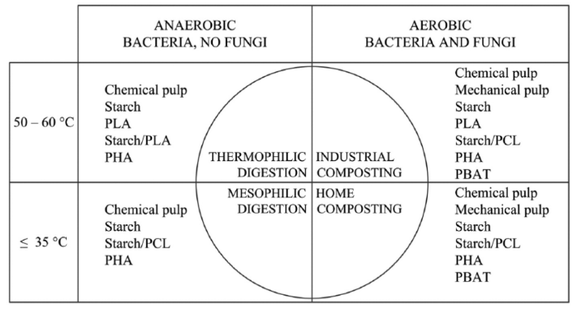


Figure 3.3.3: Biodegradable materials per environment (Rujnić-Sokele & Pilipović, 2017).

- Compostable materials are not recommended due to making disposal more complex
- Biodegradable materials should only be used when polymers can degrade in all conditions (PHA and chemical pulp)
- Recycled and biobased materials are recommended as they do not contribute to fossil resource extraction.
- Mechanical recycled materials are recommended over chemical recycled materials due to a lower CO2 footprint per kg of material

3.4 Conclusion

To gain a better understanding on sustainable packaging in the industry, an analysis has been performed based on literature research and expert interviews to find current challenges and approaches to reducing and implementing sustainable packaging in the industry.

It can be concluded that there are three main challenges for the industry to implement sustainable packaging:

First of all, the perception of policies and regulations is seen as a challenge. Implementation of new regulations do have an impact on the generated packaging waste. However, companies are not in favour of changing regulations and are not always aware of the new regulations. Nevertheless, governments are likely to introduce new policies regarding reducing packaging waste due to their positive impact.

Secondly, companies have a lack of impact knowledge on sustainable packaging practices. The lack of impact knowledge is partly caused by the availability of multiple sustainable packaging options, all differing per product.

Third of all, increased costs and required investments for sustainable packaging are seen as a challenge to implement sustainable packaging. Aalberts should not assume that customers are willing to pay extra for sustainable packaging since it depends on the type of customer. Reusable packaging is seen as more risky than single-use packaging due to the fact that the company will be also responsible for the return of the packaging.

From literature research on (new) packaging regulations can be concluded that producers like Aalberts will be held responsible for the packaging they bring to market. They will have to register a lot of information on packaging brought to market with the implemention of the PPWR. In addition to this, taxes on packaging will be implemented to stimulate the use of eco-friendly packaging by companies. It is recommended for Aalberts to look deeper into the tax regulations on packaging per country in the EU.

From literature research on common packaging material types the following can be concluded:

Firstly, using compostable materials is not recommended for Aalberts due to making disposal of packaging more complex for users than for current packaging.

Secondly, biodegradable materials should only be used when the polymers can degrade in all conditions. This is only applicable for the materials PHA and chemical pulp.

Thirdly, the use of recycled and biobased materials are recommended to be used as packaging material as they do not contribute to fossil resource extraction.

Fourthly, mechanical recycled materials are recommended over chemical recycled materials due to a lower CO2 footprint per kg of material.

Insights and findings mentioned above will be taken into account when designing a solution for Aalberts to reduce their use of packaging material.

4. Analysis - Aalberts' targeted position

This Chapter will focus on Aalberts' challenges and targets considering the reduction of packaging material.

As is mentioned in Chapter 1, Aalberts currently has the target to reduce 20% of their packaging by 2025. This is initiated by Techniek Nederland, called "Brancheplan Verpakkingen". As Aalberts is member of the association, it also has taken over the goal of "Brancheplan Verpakkingen" to reduce packaging by 20% by 2025.

To validate whether the goal of 20% reduction is possible for Aalberts, first needs to be found out what the current challenges are regarding the reduction of packaging material. This will be discussed in this Chapter.

Also, as competing businesses may drive each other towards adopting sustainable packaging as a means to distinguish themselves in the market, the Chapter will dive into the current set targets considering the reduction of packaging at Aalberts' competitors.

Next, the Chapter will look into what is currently being done in the market to achieve the packaging reduction targets to validate how companies aim to achieve current packaging reduction targets.

Finally, the Chapter discusses how the reduction of packaging is related to the reduction of greenhouse gas emissions, the circular economy and Aalberts scientific greenhouse gas emission targets.

4.1 Sustainable packaging at Aalberts

To find out more on sustainable packaging practices at Aalberts, interviews were conducted with a wide variety of employees (interview template can be found in Appendix 9.7). In total 6 people were interviewed in the area of supply chain (n=1), procurement (n=1) and product management (n=4) due to the fact that these stakeholders are closely involved with packaging practices. In this Chapter results from the interviews will be discussed. Overall findings can be formulated into four areas. Examples of current packaging practices can be found in Appendix 9.3.

Knowledge on sustainability

Firstly, it was found that knowledge on sustainability is lacking. "Often decisions are based on gut-feeling. No checks are being done whether one type of packaging performs better in terms of sustainability than the other. This is for example the case for plastic bags versus cardboard boxes." (product manager, 2023). In addition to this, the lack of knowledge is often blamed on having too little time to investigate what the best option is in terms of environmental performance (product manager, 2023). It is highlighted that currently a packaging is chosen on what exist at the packaging supplier (product manager, 2023). This might be viewed as counter productive since packaging suppliers typically strive to maximize product sales. Additionally, the majority of information on (sustainable) packaging is provided by these suppliers (procurement manager, product manager, 2023), potentially resulting in biased advice.

In addition to this, the majority of the interviewees is not aware of the current packaging reduction goals. As of today, the company has set a goal for 2025 to reduce 20% of its packaging (Aalberts, 2022). Nevertheless, in the interviews, it was evident that only 1 out of 6 employees was cognizant of this objective (product manager, 2023). This shows that communication on sustainable packaging within the company should be improved upon.

Customer focus

During the interviews it was mentioned that the perceived quality of the packaging is important. "According to our customers a packaging should be of high quality and align with policy regulations" (product manager, 2023). On the other hand, during the interviews it was mentioned that "the customer prefers as little packaging as possible" (product manager, 2023). These findings potentially show that packaging criteria differ per product manager. Also, "packaging requirements often depend on the type of product that is packaged. If it is a fragile product, more packaging is needed. If it is not, less packaging would be sufficient." (product manager, 2023). In addition to this, it was also said that "sustainability awareness among customers is increasing" (product manager, 2023). This demonstrates a trend towards increasing customer influence in the market of Aalberts. Last but not least, in all interviews was mentioned that the packaging has a strong customer focus. In some cases it was recognized that "the customer should receive another benefit than sustainability to increase the willingness to choose for our product over other products" (product manager, 2023).

Costs and investments

Another important topic when it comes to sustainable packaging that was brought up during the interviews is costs. Multiple times it was mentioned that "the pricing of packaging depends on the product" (product manager, 2023). In addition to this, "extra costs of a more expensive packaging reduce the margin of the product" (product manager, 2023). Because Aalberts competes in a very cost-competitive market, costs of packaging (and product) usually are kept as low as possible to sell as much volume as possible. Nevertheless, half of the product managers stated that they are prepared to lose a bit of their margin if implementing more sustainable packaging (product manager, 2023). Last but not least, "different packaging materials or sizes require adaptations to current production lines. The main challenges for these adaptations arise from the phase-in and phase-out trajectory. Transferring from the old to the new packaging in automated machines, can lead to (temporarily) reduced production output or even set the production line to a complete stop, resulting in increased costs." (supply chain manager, 2023).

Types of packaging

In addition to the previously mentioned topics, during the interviews it was brought up by all product managers that "every production facility of Aalberts Hydronic Flow Control has its own challenges considering sustainable packaging. The type of packaging depends on the product and thus differs per location". (product manager, 2023).

Conclusion

All in all, four main topics considering packaging are seen as important to Aalberts arised from six interviews with employees at Aalberts. First of all, most decisions considering packaging changes at Aalberts are based on intuïtion and the majority of Aalberts' employees is not aware of current packaging reduction targets. This demonstrates a lack of knowledge on sustainability at Aalberts. Second of all, it can be said that sustainability awareness among customers is increasing and that Aalberts' packaging is strongly customer focused. This shows a trend on increasing customer influence at Aalberts. Third of all, costs and investments are seen as a threshold for Aalberts to change to more (expensive) sustainable packaging. For this reason it is recommended to keep investments low to increase chances of implementation of sustainable packaging changes at the company. Fourth of all, it is recognized that for every factory of Aalberts different packaging solutions to reduce packaging material are needed.

- Communication on sustainable packaging within the company should be improved upon
- Keep investments low to increase chances of implementation of sustainable packaging changes
- Trend on increasing customer influence at Aalberts
- For every factory different packaging solutions to reduce packaging material are needed

4.2 Competitor analysis

To explore sustainable packaging initiatives in the hydronic flow industry, an analysis has been conducted on published sustainable packaging initiatives of Aalberts' competitors. Additionally, goals mentioned in the competitors' annual reports are compared to gain insights into their perspectives on sustainable practices. The following competitors were taken in consideration:

- *Uponor*
- *Danfoss*
- *IMI*
- *Giacomini (no sustainable packaging initiatives could be found)*
- *Oventrop (no sustainable packaging initiatives or sustainability goals could be found)*

4.2.1 Published initiatives

Uponor - paper fillings

Uponor makes use of paper fillings to replace plastic air pillow packing. However, the company claims that it is used as void fill, not for protection. Uponor has made the decision to use paper fillings to align with their core values. (Uponor North America, 2024).

Danfoss - honeycomb cardboard |redesigned packaging

Danfoss started using cardboard instead of polystyrene to protect small VLT drives during shipment. Implementing this change saves 300 tons of plastic foam annually. Danfoss states that switching from plastic foam to cardboard increases costs because foam is more affordable. Customer requests for plastic alternatives drive the change, aligning with Danfoss' updated Packaging Standard prioritizing sustainability in new packaging selection and design (Danfoss, 2023).

Danfoss redesigned his service nozzle packaging. The new packaging is using fewer materials. The new service nozzle packaging eliminates the sleeve, reducing material use. The one-piece stamped box is easily opened with a perforated tear strip, providing a sturdier container for improved storage. (Major, 2023).

IMI - recyclable cardboard and new packaging methods

IMI plans to cut plastic use by packaging actuators in recyclable cardboard tubes instead of bubble wrap. The tubes not only decrease plastic use but also provide an increase in protection for actuators during transit as stated by IMI (2023).

IMI has discovered a method cutting plastic use by 26%, maintaining package protection, volume, and packing time. The method is applied to U-vessels and the Zeparo range. (IMI, 2023a)

IMI is decreasing plastic pallet packaging, shifting from plastic to cardboard wrapping in one Climate Control facility, resulting in a 5.5-ton reduction in plastic use over recent months (IMI, 2023c).

4.2.1 Targets

By examining the annual reports of the previously mentioned companies, a comparison has been drawn regarding their sustainability targets on carbon and packaging reduction. Findings on industry competitors sustainable packaging annual reports can be found in Appendix 9.12.

Aalberts Hydronic Flow Control

- Carbon zero by 2050.
- Reduce packaging by 20% by 2025.

(Aalberts, 2022).

Uponor

- Carbon zero by 2040.
- Minimize packaging and phase out single use plastic packaging.

(Uponor, 2022).

Danfoss

- Carbon zero by 2030.
- 25 % decrease in 'purchased goods'. (packaging is part of this category).

(Danfoss, 2022a).

IMI

- Carbon zero by 2040.
- Fully recyclable packaging by 2025.

(IMI, 2022).

Giacomini

- At the moment, the company does not have clear goals to reduce or replace their packaging by more sustainable alternatives.

(Giacomini, 2023).

Oventrop

- No objectives could be found.

Conclusion

In conclusion, the analysis on published sustainable packaging initiatives shows that 3 out of 5 direct competitors of Aalberts are working on implementing sustainable packaging. From the packaging changes can be concluded that all competitors have packaging initiatives focussing on replacing plastics with paper based alternatives. When 3 out of 5 competitors are implementing and publishing sustainable packaging initiatives, it can be said that commercializing sustainable packaging changes and minimizing waste by reducing packaging is promoted by the majority of Aalberts' competitors, demonstrating two trends in the market where Aalberts is participating in.

From the sustainability targets comparision considering carbon and packaging reduction can be concluded that 3 of 5 competitors of Aalberts have developed goals in sustainability. Of which 2 out of 5 have clear goals on their packaging strategy. These strategies are focussing on making packaging fully recyclable, minimizing packaging and phazing out single use plastics.

It can also be concluded that all competitors strive to achieve carbon neutrality. This demonstrates the trend that sustainability is seen as a core value to Aalberts and its competitors in this market.

- Trend on commercializing sustainable packaging
- Trend on minimizing waste by reducing packaging
- Trend on sustainability as a core value
- Aalberts wants to reach net-zero by 2050

4.3 Current initiatives to reduce packaging

As of currently, competitors are working on multiple initiatives to reduce their packaging waste. It is recognised that packaging itself is only used because of its function of protection, as an installer mentioned during an interview:

"Packaging itself is not neccessary. Delivering damage free products is. In essence, we do not need packaging" (Installer, 2024).

In this Chapter, current sustainable packaging initiatives are discussed.

Prefab

Currently, within the industry there are initiatives to reduce packaging waste by prefabricating parts before installing the products on the build site. By prefabricating products before arrival, the total amount of packaging can be saved; products will be preassembled, and therefore require less packaging material per assembled product since the complete product only needs to be protected with packaging compared to all parts separately. By preassembling the parts into a product, the total surface of the object is decreased, requiring less packaging material per preassembled product over packaging components seperately. This new way of shipping products often saves installers time in handling and installing the product as well (Techniek Nederland, 2023).

In addition to this, prefab is seen as one of the solutions to solve the issue of packaging as mentioned by Batenburg, one client of Aalberts.

"Prefab solves the packaging issue. It also makes it easier for us to install. We save time on unboxing the products. Wasco is already providing prefab products." (Batenburg, 2024).

Bulk packaging

Another initiative to reduce packaging is bulk packaging. By delivering products in bulk, less packaging is needed in total. This method, however, is dependent on the demand of the amount of products and only applicable to large batches (Techniek Nederland, 2023).

Moreover, Aalberts Hydronic Flow Control is also working on bulk packaging initiatives. In the factory of Brescia, bulk packaging offers a way to reduce the total amount of packaging at the factory. One of the downsides, however, is that the customer needs to be willing to purchase more products as well. This is not applicable to all products. Currently only a small part of the type of product that is produced in this factory is shipped out in bulk (product manager, 2023).

Redesiging packaging

Currently in the industry there is a focus to reduce packaging. While interviewing a customer of Aalberts, the following considering this trend was mentioned.

"All our customers are working on reducing packaging materials as well. It becomes a hot topic". (Batenburg, 2024)

Furthermore, in the competitors analysis focused on sustainable packaging (Chapter 4.2), it can be concluded that some competitors are working on reducing the amount of packaging per product by redesigning its packaging.

Reusable packaging

Reusable packaging also is an upcoming trend when it comes to packaging in the industry. As mentioned by Installer Batenburg:

"The Technische Unie has developed reusable packaging, which we use for some applications because it is more convenient. We are getting more enthousiastic on reusable packaging. We tend to ask for more applications to use reusable packaging because of its convenience over traditional packaging." (Batenburg, 2024).

In addition to this, Aalberts Hydronic Flow Control has already implemented a reusable packaging solution with OEM-customers. However, the main advantage of this supply chain is that it is very simple. There is a direct connection between the producer and the client. This is not the case for all other products which are sold via the wholesaler (Aalberts, 2023).

I Prefab, bulk, redesigning and reusable packaging are common ways to reduce packaging

4.4 Circular economy & Aalberts

This Chapter will explain what the effects of the circular economy are on reducing greenhouse gas (GHG) emissions for the packaging industry and Aalberts.

Circular economy

In our current economy, we extract materials from the Earth, manufacture products, and ultimately discard them as waste in a linear process. In a circular economy, on the other hand, the aim is to prevent the generation of waste right from the beginning. (Ellen MacArthur Foundation, 2023)

Kirchherr et al. (2017) provide a precise definition of the circular economy by consolidating 114 different definitions:

"An economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/ distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations." (Kirchherr et al., 2017)

Circular economy and greenhouse gas emissions

Currently, material extraction and use amount to 70% of global greenhouse gas emissions (Circular Gap Report, 2021). This indicates, by reducing material extraction, emissions can be drastically reduced. The circular economy aims to prevent the generation of waste from the beginning. And therefore, by applying the circular economy, less material extraction is needed, leading to less greenhouse gas emissions.

Circular economy and the packaging industry

The circular economy could lead to less GHG emission for the packaging industry as well. As stated in a study focussing on the Chinese plastic recycling industries, it was concluded the following: "Integrating the concepts of circular economy in this industry could be deemed an effective strategy, one which not only reduces post-consumer waste pollution, but also mitigates GHG emissions." (Liu et al., 2018). This shows that applying the circular economy to the industry of packaging would help to reduce GHG emissions.

Circular economy and policy

Also regulations are based on the principles of the circular economy. As the European Commission adopted the new circular economy action plan (CEAP). It is seen as one of the main building blocks of the European Green Deal (as mentioned in Chapter 3.2). According to the EU (2015) the transition to a circular economy will reduce pressure on natural resources and help to achieve 2050 climate neutrality targets. The CEAP aims to ensure that waste is prevented and the resources used are kept in the EU economy for as long as possible (European Commission, 2015). This shows that regulations are based on principles of the circular economy as well to help reduce waste and GHG emissions.

Circular economy and Aalberts

Applying the circular economy to Aalberts can help the company to reduce both waste and GHG emissions as well. Especially considering the targets for 2050 of the company to become net-zero, it is advised for Aalberts to apply the principles of a circular economy to reduce its GHG emissions.

R-ladder

The R-ladder (circularity ladder) contains a wide range of hierachically arranged strategies in the process towards a circular economy (CBS, 2023). There are various strategies to enhance circularity and reduce the use of natural resources while minimizing waste production. These strategies can be prioritized based on their circularity levels (Figure 4.4.1).

In general, more circularity in a product chain leads to reduced consumption of natural resources and materials, and consequently to fewer environmental effects brought about by that product chain, as well as in related product chains (Potting et al., 2017).

All in all, by applying the R-ladder to packaging at Aalberts, the principle of a circular economy can be pursued. By implementing the circularity strategies, waste and greenhouse gas emissions (GHG) can be reduced at Aalberts.

I	By implementing circular strategies (R-ladder), waste and greenhouse gas (GHG) emissions can be reduced at Aalberts
I	Implementing circular strategies can lead to a reduction in GHG emissions

R-ladder (circularity ladder): ladder on circular strategies

Circular economy	Strategies		
Increasing circularity	Smarter creation and use of products	R0 Refuse	Turning a product redundant by cancelling its function, or by substituting it with a radically different product.
		R1 Rethink	Intensifying product use (e.g. via product sharing or multifunctional products).
		R2 Reduce	More efficient use and/or manufacture of products through the use of fewer natural resources and materials.
Rule of thumb: More circularity = fewer natural resources and less environmental pressure	Extending the lifespan of products and parts	R3 Reuse	Reuse of discarded yet still usable product, for the same purpose, by a different user.
		R4 Repair	Repair and maintenance of broken or malfunctioning product, to enable continuation of its original function.
		R5 Refurbish	Refurbishing and/or modernising an older product, so that the improved version can be used in the product's original function.
		R6 Remanu-facture	Using parts of a discarded product in a new product of the same function.
		R7 Repurpose	Using discarded products or their parts in new products with a different function.
	Usefull application of materials	R8 Recycle	Processing of materials to achieve the original high-quality or reduce to low-quality.
		R9 Recover	Incineration of materials, recovering their energy.
Linear economy			pbl.nl

Figure 4.4.1: R-ladder with circular strategies (Bassens et al., 2020)

4.5 Conclusion

From interviews with employees of Aalberts can be concluded that there are three major topics considering changing packaging practices.

Firstly, most packaging change decisions at Aalberts are based on intuïtion, demonstrating a lack of knowledge on sustainability at Aalberts.

Secondly, Aalberts is strongly customer focused considering packaging and sustainable awareness among customers is increasing. This shows a trend on increasing customer influence at Aalberts.

Thirdly, costs and investments are seen as a bottleneck to change to sustainable (more expensive) packaging. Therefore it is recommended to keep investments low to increase chances of implementation of sustainable packaging.

When looking at Aalberts' competitors, the majority is implementing and publishing sustainable packaging initiatives, indicating a trend towards commercializing sustainable packaging changes and a trend towards minimizing waste for customers by reducing packaging. It can also be concluded that all competitors strive to achieve carbon neutrality, demonstrating a trend for sustainability as a core value in this market.

In the current industry four main types of packaging reduction initiatives can be seen: Prefab, bulk, redesigning and reusable packaging. These are the current approaches for companies in the same industry as Aalberts to reduce packaging material.

Finally, it is recommended to Aalberts to apply the R-ladder to packaging to pursue the principle of the circular economy. The implementation of the circular strategies can reduce waste and greenhouse gas emissions at Aalberts, helping to achieve their goal to become net-zero by 2050.

5. Analysis - Conclusion

In order to recommend on how to achieve the target of 20% reduction and develop a concept to reduce packaging waste for Aalberts, research has been performed on the current packaging status of Aalberts, the industrys current position and regulations and Aalberts targeted future position. From this research the following can be concluded.

Packaging has three main functions: product protection, product information and product handling. Aalberts Hydronic Flow Control used 2739 tons of packaging in 2022. From the analysis on Aalberts' current packaging status can be concluded that PEX pipe, Expansion Vessels, Valves and Fittings contribute most to Aalberts' packaging use with 1484 tons (54% of all packaging), representing 59% of all plastic (92 out of 155 tons), 48% of all cardboard (872 of 1807 tons) and 67% of all wood (520 of 777 tons) packaging. To have most significant impact on packaging reduction at Aalberts, it was decided to focus on these product categories.

In addition to this, the current supply chain of Aalberts is very complex and involves a lot of stakeholders. This has to be taken into consideration when recommending on new packaging practices influencing Aalberts' supply chain. Reusable packaging, for example, is often seen as more risky than single-use packaging due to the fact that Aalberts will be also responsible for the return of the packaging.

Also, from the analysis can be concluded that there are three main challenges when implementing sustainable packaging.

Firstly, the perception of policies and regulations is seen as a challenge to the industry. Due to its positive impact on reducing packaging waste, governments are very likely to introduce new policies. However, companies are not in favour of changing regulations and are not always aware of the new regulations. The solution of this thesis should prepare Aalberts for upcoming packaging regulations.

The European Union and governments in Europe are targetting for less packaging waste. Upcoming regulations show that producers like Aalberts will be held responsible for the packaging they bring to market. They will have to register information on the packaging that they have shipped. Also, packaging taxes will be implemented to encourage packaging reduction and the implementation of eco-friendly packaging. Using less packaging will be stimulated by regulations, encouraging companies to reduce their packaging brought to market.

Secondly, companies deal with a lack of impact knowledge on sustainable practices, partly caused by the availability of multiple sustainable packaging options differing per product. From interviews with Aalberts' employees can be concluded that most packaging change decisions at the company are based on intuïtion, also demonstrating a lack of knowledge on sustainability at Aalberts. Therefore, the solution should provide Aalberts with a clear plan on the recommended steps to reach their targets.

Thirdly, increased costs and investments are seen as a challenge in both the industry and at Aalberts. Costs and investments are seen as a bottleneck to change to sustainable (more expensive) packaging. Therefore it is recommended to keep costs and investments low to increase chances of implementation of sustainable packaging. In addition to this, it is recognized by Aalberts that its customers' sustainable awareness is increasing. This, in combination with the strong customer focus of Aalberts considering its packaging, indicates a trend on increasing customer influence. But research also shows that the willingness to pay for sustainable packaging depends on the type of customer, showing that it will be safer for Aalberts to assume that customers are not willing to pay for sustainable packaging. Costs and investments need to be kept to its minimum to increase chances of implementation by Aalberts.

Furthermore, results from literature research on common packaging material types show the following four findings:

Firstly, using compostable materials is not recommended for Aalberts due to making disposal of packaging more complex for users than for current packaging.

Secondly, biodegradable materials should only be used when the polymers can degrade in all conditions, only being applicable for the materials PHA and chemical pulp.

Thirdly, the use of recycled and biobased materials are recommended to be used as packaging material as they do not contribute to fossil resource extraction.

Fourthly, mechanical recycled materials are recommended over chemical recycled materials due to a lower CO2 footprint per kg of material.

When looking at Aalberts and its competitors, it can be concluded that there is a trend on commercializing sustainable packaging and a trend on minimizing waste for customer due to the fact that the majority is implementing and publishing sustainable packaging initiatives. In addition to this, because of all competitors' have goals to achieve carbon neutrality, it can be concluded that there is a trend on sustainability as a core value in Aalberts' market.

To add, pursuing the circular economy will reduce packaging waste and greenhouse gas emissions. By implementing circular strategies by applying the R-ladder to packaging can help Aalberts to achieve packaging and greenhouse gas emissions reductions. This contributes to achieving Aalberts' goal of becoming net-zero by 2050.

All in all, insights from the analysis will contribute to the development of a clear and achievable plan for Aalberts to reduce their packaging in the future. The plan will be based on both current and new, future oriented, targets for the company.

6. Aalberts' future packaging position

6.1 Strategic roadmap

In the analysis phase it was found that there are multiple approaches to reduce packaging as mentioned in Chapter 3.1. It is not reasonable to tackle all packaging reduction options at the same time. Therefore a roadmap has been created, dividing the approaches into three different periods. The roadmap tackles two of the three bottlenecks formulated earlier: the lack of impact knowledge and the risks of investing (as mentioned in Chapter 3.1).

Lack of impact knowledge

Firstly the roadmap tackles the lack of impact knowledge by providing examples and recommendations on how to reduce single-use packaging. It does this by providing objectives, supported by actions (providing examples on how to reduce packaging). For example, reducing plastic bag sizes and using different shapes of cardboard packaging. In addition to this, the roadmap shows targeted results which can be reached by following the objectives and actions, demonstrating what is needed to achieve Aalberts' current goal of 20% packaging reduction.

Risks of investing

Secondly, the roadmap adresses the bottleneck of risks of investing. During research it was found that the need for making investments increases the barrier for companies to move towards more sustainable packaging. Therefore, it is necessary to explore solutions which are associated with a low level of investment risk.

Policy and regulations

Although the roadmap does not explicitly tackle challenges related to policy and regulations it must be noted that the bottleneck can be addressed by basing packaging decisions on future upcoming regulations. This could prevent a company from making last-minute, not well thought out decisions. Therefore it would be key to use future regulations as one of the drivers for certain packaging changes.

Periods

The roadmap can be divided into three periods. To establish the roadmap, the Three Horizons model is used, comprehending three parallel scenarios based upon three different life cycles of strategic business innovation (Simonse, 2018). The periods are based on Aalberts target of 20% reduction by 2025 and incoming regulations established by the European Union according to the PPWR.

- The **first period (now-2025)** is focused on the implementation of most financially appealing packaging changes for Aalberts to reach the target of 20% reduction by 2025. Investments are needed, but are estimated to be profitable within 2 years of implementation.
- The **second period (2025-2035)** is focused on reducing unnecessary packaging and redesigning packaging for recycled and less material use. In this period investments are needed to reduce packaging, contributing to even more packaging reduction at Aalberts.
- The **third period (>2035)** aims at eliminating single-use packaging through implementing the concept of packaging as a product. This requires a bigger change in packaging practices than the two periods before, but eliminates single-use packaging completely.

Reduce, reuse and rethink

The first period is based on the circular strategies of "Reduce" and "Reuse" (more efficient use of products through the use of fewer natural resources and materials, and reuse of discarded yet still usable product, for the same purpose, by a different user) according to the R-ladder (Chapter 4.4). The second period is based on the circular strategy of "Reduce". The third period is based on a different circular strategy than reducing and reusing. The aim of this period is based on the circular strategy of "Rethink", since the packaging will receive an additional function, making it a multi-functional product on the market (Chapter 4.4). This type of solution can be seen as the long-term vision of packaging at Aalberts due to the fact that the solution offers a completely different approach to packaging than is currently the case. Because the concept of packaging as a product scores

higher on the R-ladder than reducing, reusing and eliminates single-use packaging completely, more packaging material can be saved by following the concept of packaging as a product, thus reducing packaging at Aalberts even more than in the first two periods. Reducing packaging can only be done to a certain amount, limiting the potential of reducing single-use packaging. In the end, packaging is still used as a single-use product. Rethinking packaging by giving it another function can have a much greater impact on the reduction of single-use packaging.

Pillars

Recommended targeted results on the reduction of packaging at Aalberts of the roadmap are based on objectives and actions. These objectives and actions are built on three pillars.

Regulations

Firstly, the pillar of regulations will have an impact on the recommended actions in the three periods showcased in the roadmap. Since all companies are required to follow regulations, so is Aalberts. Changing regulations regarding packaging forces the company to change packaging practices. This pillar will have a large impact on the formulated objectives and actions.

Business economics

Secondly, the pillar of business economics does have influence on the packaging practices of Aalberts, since increasing or decreasing material prices or taxes can stimulate the company from focussing on reducing certain types of packaging materials. Business economics do have a direct impact on the profit a company makes and is therefore seen as an important foundation for the recommended actions and objectives.

Market trends

Thirdly, market trends play a role on the actions and objectives recommended in the roadmap. Market trends predict future customer behaviour and will therefore influence on the number sales of the company. By taking market trends into account, Aalberts is likely to respond well on the requirements and wishes of his clients. Additionally, by following the trends, Aalberts decreases risks of losing customers to competitors which are following these trends.

For the reasons mentioned above, the three pillars, regulations, business economics and market trends are taken into account in the roadmap. These pillars will form the foundation of the recommended actions and objectives for Aalberts.

Chapter 6 will delve into the details of the timeline, while Chapter 7 will provide an in-depth exploration of packaging as a product. All packaging reduction figures (%) are based on current (2022) figures to allow for equal comparison.

Strategic roadmap for Aalberts packaging reduction

			Period I now-2025	Period II 2025-2035	Period III >2035
PRODUCT	A	Aim	**Achieving 20% reduction by 2025 - current target (Chapter 6.2)**	**Reduce unnecessary packaging and redesign single-use packaging for recycled and less material usage (Chapter 6.3)**	**Eliminate single-use packaging (Chapter 6.4)**
	R	Recommended actions	• Target of 20% reduction by 2025 • Reduce bag sizes Valves & Fittings by 50% (-/-46 tons) • Reusable pallets PEX pipe (-/-520 tons)	• Reduce unnecessary packaging • Reduce feuillard PEX pipe by 50% (-/-4 tons) • Replace outer boxing with tape PEX pipe (-/-12 tons) • Minimize printing* (0 tons) • Implement brown boxes over white* (0 tons) • Redesign primary packaging closer to products • Octagon & hexagon packaging Vessels (-/-103 tons) • Hexagon packaging PEX pipe (-/-8 tons) • Octagon (pallet) packaging PEX pipe (-/-14 tons) • Eliminate virgin fossil-based materials primary packaging • 100% recycled plastic bags Valves & Fittings* (0 tons)	• Packaging as a product • Fittings (-/-56 tons) • Valves (-/-36 tons) • Expansion vessels (-/-674 tons) • PEX pipe (-/-198 tons)
	T	Plastic reduction	-/- 46 tons (30% of plastic)	-/- 4 tons (3% of plastic)	-/- 92 tons (59% of all plastic)
		Cardboard reduction	-	-/- 137 tons (8% of cardboard)	-/- 872 tons (48% of all cardboard)
		Wood reduction	-/- 520 tons (67% of wood)	-	-
		Reduction results	**-/- 566 tons (21% of all packaging)**	**-/- 141 tons (5% of all packaging)**	**-/- 964 tons (35% of all packaging)**
		Accumulative results	**-/- 566 tons (21% of all packaging)**	**-/- 707 tons (26% of all packaging)**	**-/- 1484 tons (54% of all packaging)**
		R-ladder strategy	Reduce & Reuse	Reduce	Rethink
REGULATIONS		Regulations	-	• 55% GHG emissions reduction EU • Implementation PPWR • EPR • Packaging taxes • Packaging minimized weight & volume • Minimum recycled contents	• Net zero GHG emissions EU • Ban single use plastics UK & France • Eliminate avoidable waste
BUSINESS ECONOMICS		Pulp prices increase Packaging taxes increase Recycled plastic prices decrease			
MARKET TRENDS		Commercializing sustainable packaging Minimizing waste in construction Sustainability as a core value Increasing customers influence Availability of alternative materials Sustainable consumption Zero waste			
		Recommended stakeholder involvement actions for packaging as a product (Chapter 7.7)	Smaller scale involvement 1. Via pilots	Smaller scale involvement 2. Via techniek Nederland 3. Via product managers Larger scale involvement 4. Via media 5. Via trade fairs	

** For recommended actions providing 0 tons reduction, a CO2 reduction can still be achieved by implementing this action.*

Targeted results per recommended action

Recommended actions	Plastic	Cardboard	Wood	Total	% of all packaging (2739 tons)	% of all plastic packaging (155 tons)	% of all cardboard packaging (1807 tons)	% of all wood packaging (777 tons)	One-time investments	Yearly investments	savings per year
Reduce bag sizes Valves & Fittings by 50%	46 tons				1.7%	29.7%			€0	€0	€120,000
Reusable pallets PEX pipe			520 tons		19.0%			66.9%	€385,000	€0	€200,000
Period I results (now-2025)	**46 tons**		**520 tons**	**566 tons**	**20.7%**	**29.7%**	**0%**	**66.9%**	**€385,000**	**€0**	**€320,000**
Reduce feuillard PEX pipe by 50%	4 tons				0.1%	2.6%			€0	€0	€13,000
Replace outer boxing with tape PEX pipe		12 tons			0.4%		0.7%		€0	€0	€17,000
Minimize printing*					0%*						
Implement brown boxes over white*					0%*						
Octagon packaging 18L vessels & hexagon packaging 25L vessels**		103 tons			3.8%		5.7%		€0	€456,000**	-
Octagon packaging PEX pipe**		8 tons			0.3%		0.4%		€0	€46,000**	-
Octagon (pallet) packaging PEX pipe**		14 tons			0.5%		0.8%		€0	€81,000**	-
100% recycled plastic bags Valves & Fittings*					0%*				€0	-	€60,000
Period II results (2025-2035)	**4 tons**	**137 tons**		**141 tons**	**5.1%**	**2.6%**	**7.6%**	**0%**	**€0**	**€583,000**	**€90,000**
Packaging as a product: Fittings	56 tons				2.0%	36.1%			T.B.D.	T.B.D.	T.B.D.
Packaging as a product: Valves	36 tons				1.3%	23.2%			T.B.D.	T.B.D.	T.B.D.
Packaging as a product: Expansion vessels		674 tons			24.6%		37.3%		T.B.D.	T.B.D.	T.B.D.
Packaging as a product: PEX pipe		198 tons			7.2%		11.0%		-	€1,500,000	T.B.D.
Period III results (>2035)	**92 tons**	**872 tons**		**964 tons**	**35.2%**	**59.4%**	**48.3%**	**0%**	**€0**	**€1,500,000**	T.B.D

** For recommended actions providing 0 tons reduction, a CO2 reduction can still be achieved by implementing this action.*
*** The implementation of octagon and hexagon packaging does reduce packaging at Aalberts, but requires yearly investments due to increased packaging prices.*

How to reach the target of 20% reduction by 2025?

In order to reach the target of 20% reduction by 2025, investment based packaging changes need to be made. Most financially appealing actions that are recommended to be implemented before 2025 are the following:

R 1. Reduce bag sizes Valves and Fittings by 50%

It is recommended to reduce unnecessary packaging because it saves the company material and costs, a win-win scenario for Aalberts. It is advised to start with the reduction of plastic bag sizes for Valves and Fittings (46 tons, 1.7% of all packaging at Aalberts) since this provides the largest packaging reduction of unnecessary packaging.

R 2. Reusable pallets PEX pipe

Changing to reusable pallets for PEX pipe provides the largest reduction in packaging material with 520 tons (19% of all packaging at Aalberts). This change does require a one-time investment of €385,000 but saves €200,000 per year on single-use pallets. Therefore return on investment will be within 2 years. Since the packaging change offers a large reduction (close to the target of 20%) and saves costs in the long term, this action is recommended to be implemented as soon as possible to reach the target before 2025 (together with reducing bag sizes for Valves and Fittings).

A 6.2 Achieving 20% reduction by 2025 - current target

The first period is from now to 2025. The focus is on actions to achieve the target of 20% reduction by 2025.

6.2.1 Product

A Aim

As mentioned before in Chapter 3.1.3 it was concluded that one of the bottlenecks of sustainable packaging is the risk of increased costs and investments. Since the target of 20% reduction is only achievable with investment based changes, it has been decided to recommend actions which are financially rewarding for Aalberts, in addition to reducing single-use packaging. By making the packaging changes financially rewarding for the company, chances of implementation will be increased.

Target of 20% reduction by 2025

The following actions are recommended for Aalberts to be implemented to reach the current target of 20% packaging reduction by 2025:

R - Reduce bag sizes Valves & Fittings by 50% (46 tons reduction)

Currently plastic polyethylene bags are the common way to package valves and fittings. As stated in Chapter 2.4, a total of 92 tons of plastic bag packaging is used to package these type of products.

The bags which these type of small components are shipped in, are usually a lot bigger than needed. Typically, a bag is 2-4 times bigger than the components inside (Figure 6.2.1.1 & 6.2.1.2). By decreasing the size of the polyethylene bags, a total in unnecessary packaging materials can be reduced. The amount of packaging material that can be reduced by decreasing its size differs per product that is packaged. Nevertheless, it can be said that per product, plastic packaging can be saved by approximately 50%-75%, as supported by R&D in the factory Brescia (where Multiskin fittings are produced). Currently the reason for not reducing these bags is based on having no priorities to look over current packaging (2023).

It should be encouraged by management to reduce plastic bag sizing to increase priority considering reducing packaging.

Research shows that other products (pipe brackets) produced by Aalberts HFC are sold in tightly packaged PE bags (Figure 6.2.1.3). In addition to this, in the fashion industry, clothes are often packaged very closely to the product (Figure 6.2.1.4), also demonstrating that packaging plastic bags close to its product is feasible.

It is estimated with current procurement figures of Aalberts, that for the product categories Valves and Fittings €240,000 is spend on plastic bags yearly. By saving 50% on plastic bags, €120,000 can be saved yearly.

If plastic bag consumption for the product categories valves and fittings can be reduced by 50%, a total of 46 tons of plastic can be saved per year.

Figure 6.2.1.1: Press fitting in PE bag (current packaging).

Figure 6.2.1.2: Nexus Valve in PE bag (current packaging).

Figure 6.2.1.3: Tightly packaged products by Aalberts HFC.

Figure 6.2.1.4: Efficient packaging by Patagonia (Patagonia, 2021).

R - Reusable pallets PEX pipe (520 tons reduction)

At the factory in Nevers, 520 tons of single-use wooden pallets is used every year. By implementing reusable pallets, a large reduction in single-use packaging material can be realized. For this change an investment is required in reusable pallets. With a constant exchange value of €7 per pallet in Europe (Epal, 2023), it is expected that Aalberts has to invest in approximately 55.000 reusable pallets (according to supply chain of the factory of Nevers) worth €385,000. Currently the factory buys in single-use pallets worth €200,000 every year. Therefore it is estimated that return of investments could be achieved within 2 years. Due to the international deposit system of reusable EUR-pallets (Epal, 2023) and the versatility of these pallets (as pallets are used as standard in the transport sector), it could be viable for Aalberts to implement this type of reuse system over specific product category related reuse systems. Additionally, reusable pallets are already used in other factories of Aalberts' (Netherlands & Belgium), demonstrating that these pallet systems are already used. All in all, by implementing the change to reusable pallets, 520 tons of single-use wooden pallets can be saved.

Targeted results

When implementing all actions mentioned above the following results can be achieved by 2025.

T - Plastic reduction of 46 tons (30%)

As of this moment, Aalberts Hydronic Flow Control used 155 tons of plastic packaging in 2022. By focussing on the product categories Valves and Fittings, 92 tons of plastic bag packaging is represented. Reducing the amount of plastic per bag by approximately 50% could lead to savings of 46 tons of plastic per year, taken into account that future production is similar to current production. By implementing this action, on a total of 155 tons plastic, 30% of all plastic packaging at Aalberts can be saved.

T - Single-use wood reduction of 520 tons (67%)

Currently Aalberts uses 777 tons of single-use wood per year. By replacing single-use pallets by reusable ones in the factory of Nevers, a reduction of 520 tons of single-use wood can be realised. A total of 67% of single-use wood can be reduced when implementing reusable pallets in Nevers. It is also recommended to perform more research in single-use wooden pallet use for other product categories or factories of Aalberts, to stimulate a greater reduction of single-use pallets by replacing them with reusable ones.

Alignment current Aalberts target (2025 -20%)

By implementing all recommended actions mentioned in the first period, a total of 566 tons of packaging material can be saved. The total consumption of packaging material at Aalberts was 2739 tons in 2022. Therefore, it can be concluded that these changes can reduce all packaging at Aalberts by approximately 21%.

Currently Aalberts has set the goal to reduce packaging by 20% by 2025. It can be concluded that the goal can be achieved by implementing these two recommended actions. The goal cannot be achieved by implementing only no-investment packaging reduction changes. Packaging changes requiring investments are needed to reach the target.

In order to increase chances of implementation, investments have to be financially appealing to Aalberts (in the long term) as increased costs for sustainable packaging is seen as a bottleneck (as mentioned in Chapter 3.1.3 and 4.1). By implementing the two recommended actions, a one-time investment of €385,000 is needed. Nevertheless, due to saving €320,000 per year on single-use packaging, it is expected that the return on investment is within 2 years for Aalberts after implementation of the recommended actions.

The current reduction target is set for 2025. Due to the fact that less than a year is left to reach the target, it is recommended to start with the implementation of the actions as soon as possible. It is expected that investment based packaging changes require a longer period to be implemented, due to the fact that these changes require greater packaging practices adaptations.

Period I alignment current Aalberts target (2025 - 20%)

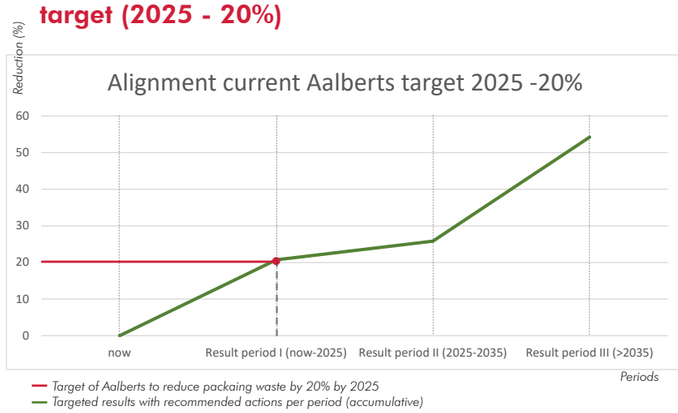


Figure 6.2.1.5: Alignment current Aalberts target - in red the current target and in green the expected targeted result is shown.

I Period I (now-2025) reduces all packaging at Aalberts by 21%

I Return on investment (ROI) is expected to be within 2 years after implementation

I Investments are needed for packaging changes to achieve 20% reduction for 2025 target

A 6.3 Reducing unnecessary single-use packaging and redesign single-use packaging for recycled and less material usage

The second period is from 2025 to 2035. During this wave unnecessary packaging will be reduced and single-use packaging will be redesigned for recyled materials and minimized in weight and volume.

6.3.1 Product

A Aim

As mentioned before in Chapter 3.1.3 it was concluded that one of the bottlenecks of sustainable packaging is the risk of investments. For this reason it has been decided to start reducing packaging at Aalberts by reducing unnecessary packaging (for the product categories PEX pipe, Expansion vessels, Valves and Fittings). These recommended actions are based on reducing packaging by leaving out material without compromising packaging functions significantly as described in Chapter 2.1. Therefore, the changes do not require investments and thus lowering the risk of implementation.

In addition to reducing unnecessary packaging, during the second period it is recommended to redesign single-use packaging for recycled and less material usage (for the product categories PEX pipe, Expansion vessels, Valves and Fittings). These packaging changes will be recommended to be implemented after unnecessary packaging reduction changes. In order to reduce packaging even more at Aalberts, additional investments are required.

Figure 6.3.1.1: coiled PEX pipe in packaging, a roll of feuillard and the coiling machine used for PEX pipe packaging.

Reduce unnecessary packaging

Unnecessary primary packaging can be reduced by the following actions:

R - Reduce feuillard PEX pipe by 50% (4 tons reduction)

Currently a polypropylene strap is used to keep a coil of PEX pipe together before placing the product in a cardboard box (Figure 6.3.1.1). In 2022 8160kg of the packaging material is used. As of this moment, €26.025,- is spent on straps made of polypropylene in the factory of Nevers every year.

By reducing the amount of straps per coil of PEX pipe from 6 to 3 straps, 50% can be saved on both material and costs. This results in a material saving of 4080kg of polypropylene and €13.013,- in costs. Changing from 6 to 3 straps does not involve any significant changes in the production process. According to R&D at the factory of Nevers (2023), a simple programming change can be made in the coiling machine to reduce the amount of straps used per coil. All in all, this results in no investment costs. Furthermore, according to the department, the change in packaging does not affect (perceived) quality of the product drastically and therefore would be viable (2023).

R - Replace outer boxing with tape PEX pipe (12 tons reduction)

As of this moment, outer boxing (secondary packaging) is used for the product category PEX pipe to keep individual packaging of the coils on the pallet. According to the supply chain of the factory, 12 tons of cardboard is used for this packaging application every year (2023).

By replacing the outer boxing by an alternative like (paper based) tape, less cardboard material can be used. In order to succeed in the implementation it is adviced to use water based tape, which is recycleble with cardboard (Gallagher, 2021). With €5,- per roll on tape expenses (RS, 2024), 50m of tape per roll and 2 stokes of tape for one pallet, 6 pallets can be taped per roll of tape. In total 940 rolls of tape are needed every year, accumulating to a price of €4700,- on tape. With this implementation, 12.000 kg of cardboard can be saved leading to €17.000,- in financial savings.

Figure 6.3.1.2: outer boxing for PEX pipe.

Minimize processing

The carbon footprint can be reduced by minimizing processing of Aalberts' packaging by implementing the actions below. This does not directly align with the goal of reducing packaging material, however, does also have an effect on the environmental footprint of Aalberts. Additionally, the client of this thesis asked for a clarification of the environmental impact of printing and white cardboard boxes. Based on the requests, the following actions are recommended:

R - Minimize printing

It is recommended to keep the amount of (surface) printing on packaging as little as possible. In the following paragraphs will be explained why this recommendation is listed.

Printing can have a negative effect on the environmental impact of packaging. Printing inks, varnishes, lacquers, moistening solutions and washing solvents contain volatile organic compounds (VOCs) and air pollutants (HAPs) (Aydemir & Özsoy, 2020). Solvent-based inks, which are commonly used in flexographic, gravure, and screen printing, as well as in offset printing dampening solutions and cleaning solvents, typically have a high concentration of volatile organic compounds (VOCs). During the production process, VOCs will evaporate, causing harm to the environment (Aydemir & Özsoy, 2020).

VOCs and HAPs contribute to the formation of photochemical smoke, air particles and ground level ozone emission in the atmosphere. Additionally, VOCs can lead to soil and water pollution when left in landfill. Flexo, gravure, and screen-printed products typically retain only 3-4% of the total ink solvent used in their composition. The rest of the solvent in the printed ink content evaporates in its own environment after the printing process, causing negative effects on health and environment (Aydemir & Özsoy, 2020). Figure 6.3.1.3 shows the in- and output of VOCs during the printing process.

To reduce the pollutants released to the environment, the Environmental Protection Agencies in US, Europe, Canada, and many other countries have restricted the amount of

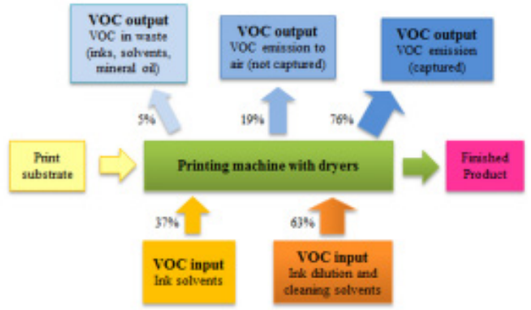


Figure 6.3.1.3: VOC input and output during the printing process. (Aydemir & Özsoy, 2020).

solvent that can be released into the air (Saad, 2007).

To decrease the VOC output, mineral oils and hydrocarbon solvents used in production of cold-set, heat-set and sheet-fed ink should be minimized or should be replaced with the solvents with low aromatic content (linseed–soybean oil-based). In addition to this, the release of volatile solvents used in producing flexographic and gravure inks is minimized by utilizing fully enclosed or covered systems.

Because no single ink technology or printing process provides a universal environmental friendly solution, the most suitable production and ink option should be determined by considering factors such as substrate absorptivity, energy source, energy consumption, and carbon footprint. But generally it can be said that using too much ink can harm the environment by increasing the consumption of energy resources. To promote environmental sustainability in printing, it's crucial to keep ink consumption at a minimum level throughout the production process. It should be considered not using solvents or replacing them with harmless or less harmful alternatives. When possible, water and plant-based systems should be prioritized, reducing the release of volatile organic compounds (VOCs) into the atmosphere and minimizing hazardous waste. (Aydemir & Özsoy, 2020). Furthermore, it is advised to use as little ink as possible. It is even preferred by the KIDV to have no ink to increase the recyclability of the packaging. If it is not possible to reduce the ink consumption, producers should consider using inks that are easily deinkable (KIDV, 2020).

As of the current situation, the main type of printing used at Aalberts is flexography, which

is a very common to use solvent-based ink (Sumitomo Riko Company, 2014). This shows that printing should be kept to a minimum to have the least environmental impact as possible (Figure 6.3.1.4).

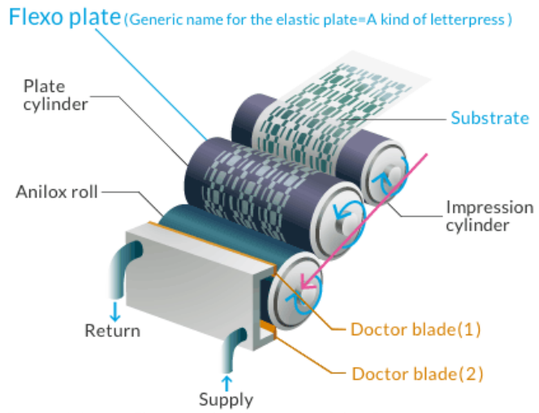


Figure 6.3.1.4: Flexography (Sumitomo Riko Company, 2014).

R - Implement brown boxes over white

Currently a lot of cardboard that is used at Aalberts HFC, is a white type of cardboard. Multiple examples can be found in Figure 6.3.1.5. It is recommended to switch from white to brown cardboard. In these paragraphs will be discusses why this change in packaging is recommended.

In order to produce white cardboard, cellulose fibres are bleached. The bleaching process is a sequence of different oxidising processes utilising different chemicals and conditions in each stage. Typically, washing is done between the stages. The bleaching process, including the production of bleaching chemicals from cradle to gate, transportation of these chemicals to the pulp mill, and the actual bleaching process, forms 15-41% of the overall carbon footprint (Jour et al., 2013). The increase in carbon footprint can be mostly referred to the large amount of electricity that is needed to produce sodium chlorate and sodium hydroxide, which is used for bleaching pulp (Jour et al., 2013). In addition to this, pulp bleaching belongs to one of the main subsystems contributing to the overall environmental impact (Jawjit, 2006).

Moreover, the company Camfil changed to brown boxes, reducing 13% of their CO2 impact per box compared to the previous white version (Camfil, n.d.).

In conclusion, in the recycling process cardboard needs to be bleached when produced in white. This is not the case for brown cardboard, which is unbleached, reducing it's carbon footprint by 15-41%. Therefore, by replacing white, bleached, cardboard by brown cardboard, CO2 emissions can be reduced.
Given the fact that white cardboard is used for expansion vessels mainly (Packaging designer Aalberts, 2023), approximately 674 tons of white cardboard is used in the factory of Almere. In total, this accounts for 488 tons of CO2 equiv. if only using brown cardboard. When mainly bleached, white cardboard is used, the CO2 impact is increased from 488 tons to 560 tons of CO2 equiv. Therefore, by changing from white to brown cardboard, 72 tons of CO2 equiv. can be saved by the factory of Almere (taking a increase of 15% CO2 equiv. for white cardboard versus brown cardboard).

As of this moment, the decision to use white cardboard is mainly because of marketing reasons. It is believed by Aalberts that white boxes stand out more than brown cardboard boxes, leading to more sales. Therefore it is recommended to validate multiple brown cardboard alternatives with Aalberts' clients. During this thesis, due to time constraints, this recommendation has not been validated with clients.

Figure 6.3.1.5: White cardboard use at Aalberts.

Redesign primary packaging closer to products

Primary packaging should be designed closer to products to reduce the amount corrugated cardboard packaging weight by eliminating as much unused space as per packaging as possible. This recommended action is based on a comparison between four ways to reduce corrugated cardboard packaging (Figure 6.3.1.6). In this comparison the following four categories are validated; using thinner cardboard, providing partly protection, pulp moulded paper and different shapes of packaging.

Thinner cardboard

Firstly, to reduce cardboard packaging use it could be considered to use thinner (non-corrugated) cardboard. Instead of using three layers, for corrugated cardboard, only one layer can be used. When discussing the option with one of the product managers at Aalberts it was stated that the type of cardboard already has been optimized considering the type of cardboard. Using less layered cardboard types increases the risk of the packaged product getting damaged. According to the product manager, the thin cardboard already causes for damaged products and/or packaging and therefore could not be reduced (2023).

Partly protection

Secondly, to reduce cardboard packaging consumption, it was considered to protect the products on only its most vulnerable spots, allowing for less cardboard to be used per packaging. By implementing this change, the risks of damaging the product increases a lot. Doubtlessly, this change in packaging is seen as riskier than using thinner cardboard as some parts of the product are exposed during transport, increasing the risks of product damage. For this reason, reducing packaging by protecting products only on its most vulnerable places would not be desirable for Aalberts.

Pulp moulded paper

Thirdly, using pulp moulded paper as packaging material instead of corrugated cardboard could reduce the weight of the packaging. Due to its low density compared to cardboard, pulp packaging could reduce the total packaging weight (Munari, 2017). Nevertheless, the production of pulp packaging requires a mould (Dey et al., 2020). Producing moulds for pulp paper packaging requires investments of approximately €20.000 per mould, whereas no investments are needed for corrugated options (Stratasys, 2023). Per unit of pulp moulded packaging costs are expected to be €0.10-€1.50 (Lian Pack, 2024). As concluded from the research in Chapter 3.1, investments are seen as a treshold to swithch to sustainable packaging practices. For this reason it will not be recommended to produce pulp paper packaging to reduce packaging weight at Aalberts.

Different shapes

Fourthly, by packaging closer to products with different packaging shapes, material can be reduced (as shown on the next page in this thesis). Thus, by using different shapes the volume (and thus weight) of a packaging can be reduced. When looking at various packaging shapes available on the market, it can be concluded that round, octagon and hexagon shapes can be used over (traditional) rectangular shapes to reduce cardboard packaging. These packaging shapes offer a packaging closer to the product, reducing its weight. In addition to this, corrugated packaging is more affordable as pulp moulded packaging as it uses more mass production (Kubbinga, 2023). When looking into alternative shape packagings to package closer to the product, round, octagonal and hexagonal packagings have been considered. Out of the three, octagon and hexagon packaging offer better stackability when placed on its sides than round shapes due to its shape (which is currently the case for transport applications). This is essential for transport purposes, making octagon and hexagon packaging more suitable options. Nevertheless, octagon and hexagon packaging is expected to be more expensive than traditional rectangular boxes. Based on a comparison of octagon and hexagon versus squared boxes via off-the-shelf corrugated boxes, it can be concluded that octagon and hexagon boxes are to be expected to be 1.5 times more expensive as squared boxes (Alibaba, 2024). Therefore, although corrugated cardboard options are more affordable than pulp moulded packaging options, investments are still needed to implement the recommended packaging practices. Per unit of corrugated packaging, costs are expected to be €0.10-€0.75 (Lian Pack, 2024). This indicates a comparable price to pulp packaging per unit, while not needing investments to produce moulds, making it the most appealing option for Aalberts.

All in all, packaging material per product can be reduced when packaging products closer to its packaging. A comparison between four options was made, considering using thinner cardboard, partly protecting products, pulp moulded paper and packaging closer to products with different shapes (Figure 6.3.1.6). The last option, considering the shapes octagonal and hexagonal was found to be most promising for Aalberts. Recommendations considering reducing packaging material by packaging closer to its products with octagonal and hexagonal shapes can be found on the next pages.

Validated options to reduce corrugated cardboard

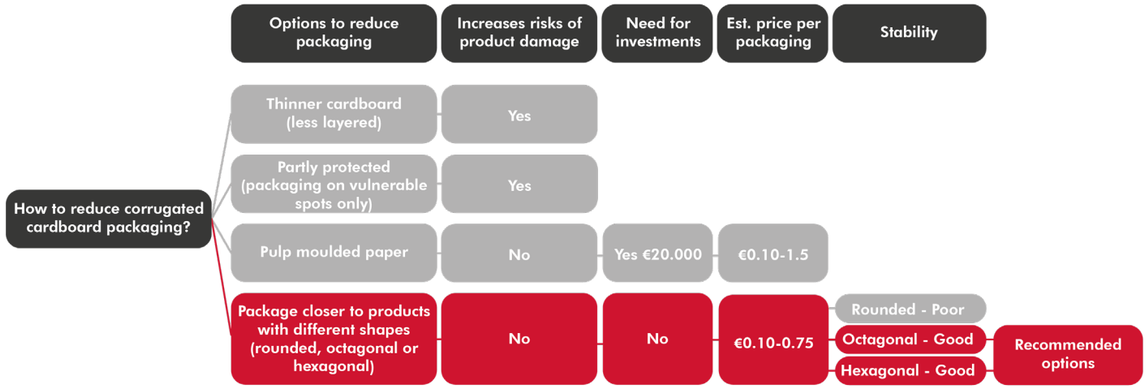


Figure 6.3.1.6: Four options to reduce corrugated cardboard packaging at Aalberts - the chosen direction is shown in red, other validated directions are shown in grey.

R - Octagon & hexagon packaging 18L & 25L Vessels (103 tons reduction)

As of this day, expansions vessels are packaged in squared cardboard boxes. Every year, a total of 674.000 kg of white cardboard is used for the packaging of expansion vessels. The two sizes which are sold most are 18L and 25L expansion vessels (Figure 6.3.1.7).

Figure 6.3.1.7: Expansion vessels on a pallet in the factory of Almere, left 18L right 25L vessels.

Octagon expansion vessels

For 18L expansion vessels it is recommended to use octagonal packaging. Per product, a total of 17.2% of packaging material can be saved by implementing this change (Table 6.3.1.9, Figure 6.3.1.8).

Figure 6.3.1.8: Section cut expansion vessel packaging shapes.

18L expansion vessels	Size lxbxh (mm)	Top & bottom (mm2)	Sides (mm2)	Total (mm2)	Total reduction (%)
Current packaging	289x289x423	167.042	488.988	656.030	0
Octagonal packaging	289x289x423	138.382	405.064	543.446	17.2

Table 6.3.1.9: 18L expansion vessel packaging material savings calculations.

Hexagon expansion vessels

For the 25L expansion vessels it is also recommended to package closer to the round product. However, in this case it would be best to package the product in hexagonal packaging since it provides an additional benefit over saving packaging material.

Currently 25L expansion vessels are packaged in rectangular cardboard corrugated boxes as can be seen in Figure 6.3.1.7. By changing to hexagonal packaging, more products can be loaded onto one pallet. The capacity of 1 pallet can be raised from 25 to 32 products if the vessels are packaged in hexagonal boxes. This results in 28% more efficiency if using hexagonal boxes over rectangular boxes (Table 6.3.1.12).

Total dimensions are 832mm by 1249mm. Note that the dimensions are slightly larger than the size of an Euro pallet (1200mm by 800mm). However, currently 18L vessels are packaged on a pallet in such a way that the overall size is 67mm too big for the pallet. In addition to this, the layout of the packaged products on the pallet is in such a way that the protruding parts can be overlapped during transport so no trailer capacity is lost (Figure 6.3.1.10, Table 6.3.1.11). This currently happens with transport for expansion vessels as well, as can be seen in Figure 6.3.1.7.

Currently it is estimated that €909,000 is spent on expansion vessels at Aalberts yearly. Since it is expected that octagon and hexagon packaging is 1.5 times more expensive (as mentioned in Chapter 6.3.1), it is expected by implementing this change, yearly costs will rise to €1,365,000 with and increase of €456,000 yearly.

All in all, by packaging expansion vessels in octagonal and hexagonal corrugated cardboard boxes, it is expected to have a packaging reduction of 15.3% on average. In 2022 674 tons of corrugated cardboard is used for expansion vessel packaging. Therefore it can be concluded that the implementation of this action could result in a packaging reduction of approximately 103 tons cardboard.

Hexagonal boxes during transport

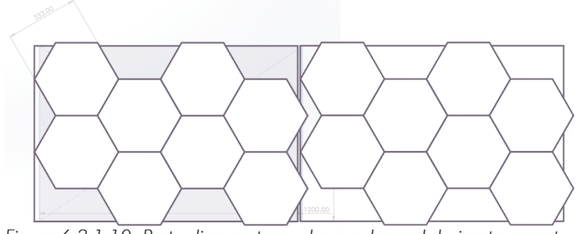


Figure 6.3.1.10: Protruding parts can be overlapped during transport to prevent trailer capacity loss.

25L expansion vessels	Size lxbxh (mm)	Top & bottom (mm2)	Sides (mm2)	Total (mm2)	Total reduction (%)
Current packaging	333x333x440	221.778	586.080	807.858	0
Hexagonal packaging	333x333x440	192.066	507.566	699.632	13.4

Table 6.3.1.11: 25L expansion vessel packaging material savings calculations.

25L expansion vessels	Size lxbxh (mm)	Maximum layers (limit 2200mm) (Eurosender, n.d.)	Products per layer (pce)	Height incl. pallet (144mm) (mm)	Total products per pallet (pce)	Increase products per pallet (pce)	Total increase in efficiency (%)
Current packaging	333x333x440	5	5	1904	25	0	0
Hexagonal packaging	333x333x440	4	8	1799	32	7	28

Table 6.3.1.12: 25L expansion vessel packaging pallet dimensions calculations.

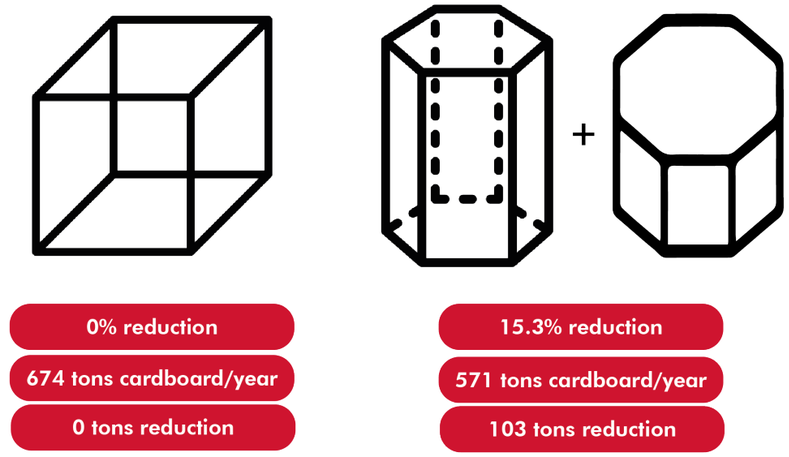


Figure 6.3.1.13: Comparison packaging reduction rectangular versus hexagon and octagonal packaging.

R - Octagon packaging PEX pipe (8 tons reduction)

To reduce the amount of packaging material per packaged product, a packaging needs to be as tight as possible to its product. Therefore, the least amount of material is used to protect the product during its handling. Since coils are a round product, space and material is not used to its full potential by having a rectangular packaging. To package for a round product it is recommended to use an octagon packaging since these shapes are stackable (more easily than round shapes) while being most efficient compared to hexagonal boxes looking at material efficiency. In Table 6.3.1.16 can be seen how much material can be saved when implementing the change from rectangular to octagon packaging. These figures on packaging material are supplied by supply chain from the factory of Nevers (where PEX pipe is produced). By implementing octagonal packaging for PEX pipe, approximately 8 tons of cardboard can be saved per year (currently 56 tons is used yearly for these products). On average 14.65% cardboard can be saved per sold product.

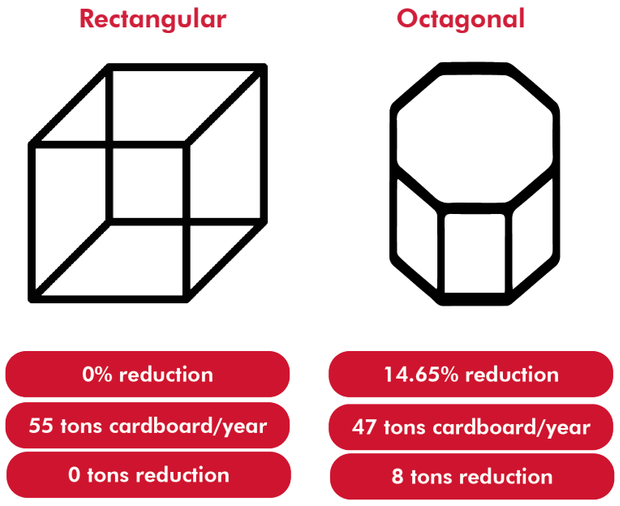


Figure 6.3.1.14: Comparison packaging reduction rectangular versus octagonal packaging.

Since octagon packaging is expected to be 1.5 times more expensive as rectangular packaging (like mentioned in Chapter 6.3.1), costs are expected to rise from €91,000 to €137,000 per year. Extra investments of €46,000 are required for this packaging change.

Figure 6.3.1.15: Cardboard boxing for PEX pipe.

In total, by implementing octagonal packaging for PEX pipe, 8 tons of cardboard can be saved per year.

Current size(mm)	Current weight (g)	Amount used 2022 (pce)	Potential savings (%)
800x190x800	1165	29.985	14.6
800x110x800	928	12.840	14.2
800x230x800	1039	6.360	14.8
800x285x800	1636	1.524	15
			14.65 (avg)

Table 6.3.1.16: Cardboard savings per box.

R - Octagon (pallet) packaging PEX pipe (14 tons reduction)

Currently loose coils are shipped in boxes of 120x80 cm. Per box on a pallet, 4 coils can be shipped. Using these types of boxes and pallets, in total 99 pallets with 396 coils fit in 1 trailer. In 2022 119.568kg of 120x80 are used at the factory of Nevers (Figure 6.3.1.17).

Figure 6.3.1.17: outer boxing for PEX pipe.

By changing from 120x80 to 80x80cm packaging, 63 coils can be loaded more per truckload. In this calculation the following dimensions of a truck were taken 245x1360cm (Truck Dimensions, n.d.). However, implementing a change from 120x80cm boxes to 80x80cm boxes does influence the amount of packaging negatively; 8011kg of packaging is used more. Nevertheless, by changing from squared 80x80 packaging to octagonal packaging, a total of 13.870 kg cardboard can be saved compared to 120x80 packaging. In Figure 6.3.1.18 and Table 6.3.1.19 the changes of the implementation can be seen.

Currently, according to the figures of supply chain Nevers, €163,000 is spent on this type of cardboard every year. Since octagon packaging is expected to be 1.5 times more expensive (like mentioned in Chapter 6.3.1), it is expected that costs increase with €81,000 to €243,000 per year.

In conclusion, approximately 14 tons of cardboard can be reduced by implementing octagonal (pallet) boxes, while increasing the total amount of coils transported per truck load.

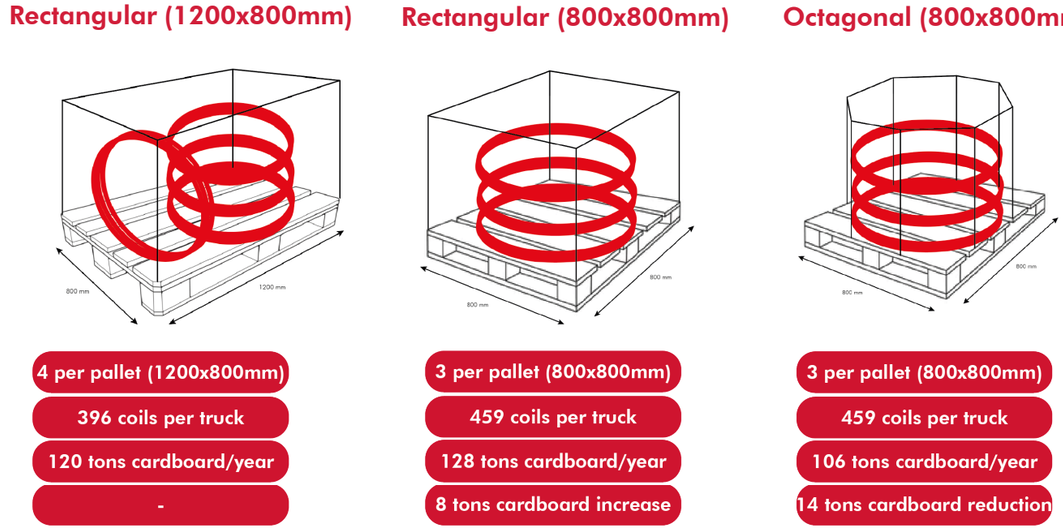


Figure 6.3.1.18: Comparison in material of cardboard boxing 1200x800 (4 coils), 800x800 (3 coils) & 800x800 octagonal (3 coils).

Outer boxing size (mm)	Pallets per truck (pce)	Coils per box (pce)	Coils per truck (pce)	Packaging comparison per 396 coils (%)	Packaging savings per 396 coils (%)	Packaging savings (kg)
1200x800	99	4	396	100	0	0
800x800	153	3	459	106.7	-6.7	-8.011
800x800 octagonal	153	3	459	88.4	11.6	13.870

Table 6.3.1.19: Comparison in material of cardboard boxing 1200x800 (4 coils), 800x800 (3 coils) & 800x800 octagonal (3 coils).

Eliminate virgin fossil-based materials primary packaging

R - 100% recycled plastic bags Valves and Fittings

With the upcoming regulations stating that in 2030 packaging needs to have a certain amount recycled content, it would be recommended to prepare for these packaging changes.

Furthermore, it is expected that the use of alternative materials becomes mainstream by 2030. Recycled materials are referred to with alternative materials. (Deloitte, 2023). Also, it will be more cost-efficient to implement recycled materials over virgin materials due to the fact that material prices are expected to be lower, while not compromising quality (to a great extent) of the packaging (as mentioned in Chapter 3.3). Mechanical recycled plastics are expected to be €954/tonne, whereas virgin plastics are expected to be €1278/tonne by 2030 according to Deloitte (2023). This means a decrease in price per tonne of 25% when using mechanical recycled plastics over virgin plastics by 2030.

Currently approximately €240,000 is spent on plastic bags every year according to Aalberts. When material prices of packaging decrease with 25%, material costs of plastic bags can decrease with €60,000 to €180,000 when implementing recycled materials over virgin materials.

It would be recommended to implement the use of 100% recycled plastic packaging to prepare for the upcoming regulations considering minimum recycled contents. For this reason, is the packaging change placed in the second period. Although the packaging change is not directly connected to reducing packaging material, it does contribute to a decrease in carbon footprint as stated earlier in Chapter 3.3. Also, because of the goal of Aalbert to be net-zero in 2050 (Chapter 4.2), it is recommended to implement the packaging change to recycled plastic packaging.

Figure 6.3.1.20: Plastic bag packaging produced by Aalberts.

Figure 6.3.1.21: Plastic bag packaging produced by Aalberts.

Figure 6.3.1.22: Plastic bag packaging produced by Aalberts.

Targeted results

When implementing all actions mentioned above the following results can be achieved by 2035.

T - Plastic reduction of 4 tons (3%)

Aalberts used 155 tons of plastic in 2022. By implementing the packaging changes in the second period, a total of 4 tons of plastic packaging can be reduced. Compared to 2022 figures, 3% of all plastic packaging at Aalberts can be reduced if the recommended actions are implemented.

T - Cardboard reduction of 137 tons (8%)

In 2022, Aalberts used 1807 tons of cardboard as mentioned in Chapter 2.4. By implementing the recommended redesigns of packaging and reducing unnecessary packaging in this period, a total of 137 tons of cardboard can be reduced. This amount accounts for 8% of all cardboard use at Aalberts compared to 2022 figures.

Alignment current Aalberts target (2025 - 20%)

By implementing all recommended packaging changes discussed in the second period, a total of 141 tons of single-use packaging can be reduced. This represents 5% of all of Aalberts' packaging use in 2022.

The second period accounts for packaging reduction changes, reducing packaging even more after the first period changes. When accumulating the targeted results of both periods, a total of 26% reduction of all packaging at Aalberts can be reduced compared to 2022 figures. A total of 707 tons of packaging can be reduced after this period.

It is recommended in this period to start with packaging changes that reduce unnecessary packaging and implement recycled materials. This is because these type of changes reduce both packaging and costs for Aalberts. After these implementing these actions it is recommended to reduce packaging even more by redesigning for less material usage. These changes are based on investments, but reduce packaging at the company even more.

Period II alignment with current Aalberts target (2025 - 20%)

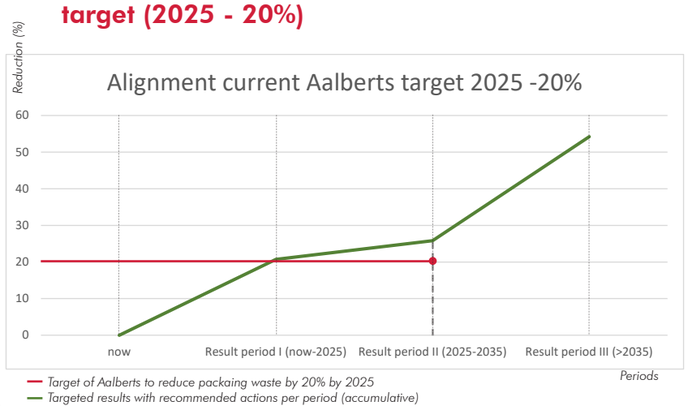


Figure 6.3.1.23: Alignment current Aalberts target - in red the current target and in green the expected targeted result is shown.

- **Period II (2025-2035) reduces all packaging at Aalberts by 5%**
- **Period I & II represent a reduction of 26% of all packaging at Aalberts**

6.3.2 Regulations

Reducing packaging materials is partly driven by regulations becoming stricter.

In 2025 the Packaging and Packaging Waste Regulations will be introduced (European Parliament, 2023). As explained in Chapter 3.2 the new regulations will be implemented in the European Union (and therefore influencing packaging practices at Aalberts because most of their factories are based in countries belonging to the European Union). There are two main reasons for Aalberts to reduce unnecessary packaging.

First being the introduction of the Extended Producer Responsibility (EPR). Companies will become responsible for the environmental consequences of the packaging of their products brought to market. EPR will lead to more transparancy on packaging materials. Companies will be required to register information considering used packaging amounts and label packaging on material composition (European parliament, 2023).

Second being the implementation of packaging taxes. All member states of the European Union will have to pay for packaging waste. Member states are developing different approaches to how finance the levy (CMS, n.d.). In countries like the Netherlands, France, Germany and the United Kingdom, packaging taxes are already taking shape. Companies are required to pay waste management fees to governments for the packaging brought to market (European Parliament, 2023).

With the packaging taxes upcoming, it will be recommended for Aalberts to reduce packaging as much as possible, to limit the amount of taxes needed to be financed.

The European Union has set a goal for 2030 to reduce greenhouse gas emissions by 55% compared to 1990 levels (European Parliament, 2023). To achieve this goal, new regulations will be implemented. The need to redesign packaging for recycled and less material usage copes with the following regulations.

Firstly, packaging will be required to be minimized in weight and volume. Although not being specified what is exactly meant by to be minimized in weight and volume at the moment (European Parliament, 2023), it indicates that there will be new regulations upcoming considering the design of current packaging. This will encourage the company to redesign packaging closer to its product so that volume (and therefore weight) will be reduced.

Secondly, the PPWR shows a regulation considering minimum recycled contents for packaging. Although not specified at this moment, regulations considering recycled contents will be implemented in the near future (CMS, n.d.). By implementing fully recycled packaging Aalberts can already prepare for the incoming regulation, lowering the risks for late-minute packaging adjustments potentially leading to downtimes in busy production periods, since transferring from old to new packaging in automated machines can lead to (temporarily) reduced production output as mentioned by the supply chain manager of Aalberts (2023).

- Because of upcoming packaging taxes, it is recommended for Aalberts to reduce packaging (weight) as much as possible
- Implementation of packaging taxes in period I
- Introduction of the Extended Producer Responsibility in period I
- Packaging will be required to be minimized in weight and volume in upcoming regulations
- Packaging will be required to have minimum recycled contents in upcoming regulations
- Targets on reusable transport packaging (pallets) will be implemented in upcoming regulations

6.3.3 Business economics

Business economics are expected to play a big role for Aalberts to reduce packaging. Due to rising taxes on packaging, the company will be encouraged to reduce packaging. The UK government announced that taxes on plastic packaging will increase by 2024 by 3% to 217 pounds per tonne (UK Government, 2023). Also in the Netherlands, packaging taxes are increasing from 2016 to 2024, plastic packaging tax increased from €0.12 to €0.23 per kg of material. Additionally, packaging taxes on cardboard increased from €0.011 to €0.015 per kg of material from 2016 to 2024 in the Netherlands (Verpact, n.d.). Also in Germany taxes are increasing. A new plastic packaging tax will be implemented, requiring companies to pay €0.876 per kg of plastic bag packaging (Laird, 2023). In Italy, plastic packaging taxes are implemented as well. The rate has been set at €0.45 per kg of plastic (KPMG, 2021). Additionally, Member States of the European Union will have to pay contributions of €0.80 per kg for non-recycled plastic packaging waste. As all factories of Aalberts are based in countries being part of the EU, it is expected that Aalberts has to pay for these taxes as well.

Governments are likely to increase their taxes considering packaging to motivate corporates to reduce the environmental impact of packaging, as is currently also the case (as mentioned in Chapter 3.1.1). These regulations could stimulate Aalberts to reduce packaging.

In addition to increasing packaging taxes, material prices are expected to change over time. As projected by Deloitte (2021), prices of recycled materials are expected to decrease (Figure 6.3.3.1). Since prices of packaging materials have an effect on the margins of a product (as mentioned in Chapter 4.1), decreasing material prices could encourage a company to switch over packaging materials. Since recycled materials are expected to decrease in price, it is recommended for Aalberts to switch to this type of packaging material (in addition to upcoming regulations considering recycled contents as mentioned in Chapter 6.3.2).

Also, in the future, due to increasing material prices, the difference between traditional shaped packaging and unconventional packaging (requiring less material) might decrease. Since traditional packaging requires more material per packaging for its product than unconventional (closely to the product designed) packaging, like explained in the recommended actions above, prices for these two packagings could be less than expected in first instance. The increasing material prices, as can be seen in Figure 6.3.3.1, (of cardboard) could encourage companies to redesign packaging for less materials use.

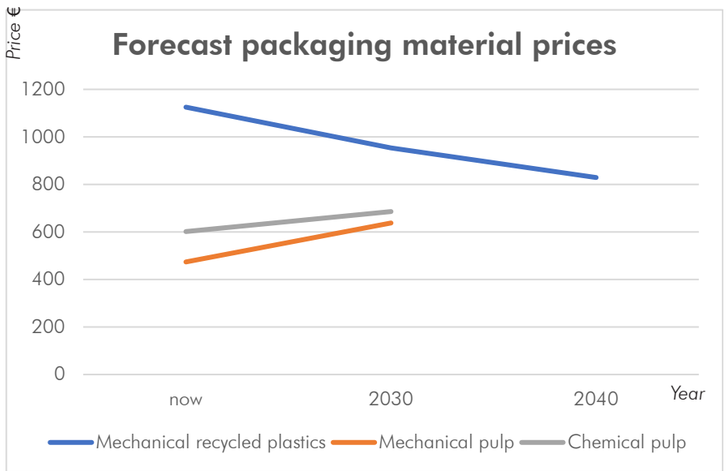


Figure 6.3.3.1: Mechanical recycled plastics, mechanical pulp and chemical pulp price forcasts (Deloitte, 2021) (Johnston, 2016).

- Packaging taxes are expected to increase over time
- Recycled materials are expected to decrease in price
- Pulp is expected to increase in price

6.3.4 Market trends now-2035

The following market trends will play a role in the need to reduce unnecessary packaging and redesign single-use packaging for recycled and less material usage at Aalberts in period II.

Commercializing sustainable packaging

Currently, and in the future, where companies invest their money will depend more on how sustainable and effective those businesses are. Companies will be focussing on three lenses: decreased leakage, improved circularity and a reduced carbon footprint. As a result of this, there are stronger efforts to commercialize packaging innovations, as well as better marketing of their performance (Feber et al, 2022). For the industry of Aalberts, this can be seen by the marketing actions of competitors by showcasing reductions or material changes in packaging (as discussed in the competitor analysis). It can be concluded that sustainable packaging is valuable to be advertised by the marketing departments. To prevent Aalberts from falling behind on sustainable practices on their competitors, it is essential for the company to reduce packaging, for all types: primary, secondary and tertiary packaging (as mentioned in Chapter 2.1).

Increasing customer influence

In the current trend, there is a significant emphasis on bringing sustainable packaging into the commercial sphere. Customers play a pivotal role in influencing how brand owners navigate the market. This has led to a surge in the adoption of sustainability targets and concrete actions (Feber et al., 2022). Within the industry of Aalberts, customer focus is seen as an important factor in changing packaging practices. As discussed in the interviews with employees of Aalberts (Chapter 4.1) it can be concluded that customers have a large role in packaging decisions for the company. Since customers prefer to have as little packaging as possible, as mentioned in Chapter 4.1, it is key to reduce packaging material as much as possible.

Minimizing waste in construction

In this phase, there is a growing prevalence of eco-friendly construction, driven by a demand to reduce emissions and waste (Feber et al., 2022). Since the main target group of Aalberts are installers, working in the construction industry, packaging needs to be reduced to facilitate a reduction in waste in the construction industry. As discussed earlier in (Chapter 4.3) it can be concluded that the industry of Aalberts is reducing packaging waste via initiatives of Techniek Nederland. The branche organisation also has set goals together with competitors and clients of Aalberts to reduce packaging waste by 20% (Techniek Nederland, 2023).

Sustainability as a core value

As governments and society pay more attention to sustainability, people are starting to see that only companies actively embracing sustainable practices will have lasting value. Investors are getting more involved in political talks and are gaining more influence on what companies do regarding sustainability. Both internal and external stakeholder will play a significant role in making sure companies stick to their sustainability goals and actions (Deloitte, 2023). As investors of Aalberts Hydronic Flow Control also have sustainability as one of their values, it is important for the company to focus on reducing packaging waste. Additionally, overpackaging products could often lead to higher packaging costs, potentially leaving less margin on products sold, since extra packaging costs reduce the margin of the product as mentioned in Chapter 4.1 by a product manager. To keep the sales margin to the targeted level, products need to be packaged with minimum packaging. Also, for this reason it is recommended to reduce unnecessary packaging in the first phase.

- Trend on commercializing sustainable packaging
- Trend on minimizing waste in construction
- Trend on increasing customer influence
- Trend on sustainability as a core value

Sustainable consumption

In this period, customers will become more aware of how their consumption and lifestyle choices affect the environment, resulting in a higher demand for sustainable packaging. They are also inclined to research the sustainability practices of companies before making purchases and are willing to pay a premium for products that are environmentally and socially responsible. This forces companies to be more transparent, adopt sustainable practices, and fulfill the growing demand for eco-friendly products (Feber et al., 2022). During the conversations with Aalberts employees discussed in Chapter 4.1 it was concluded that packaging is strongly customer focused. It will therefore be important for Aalberts to align with the desires from customers considering sustainable packaging, showing the need to redesign packaging to be more eco-friendly.

Availability of alternative materials

Ongoing efforts in material development involve exploring options like biodegradable plastics derived from plant materials and recycled waste. These emerging materials present promising opportunities for creating innovative products with both eco-friendly and highly functional attributes. Advancements in material technology are expected to drive the development of products and functionalities that contribute to a more sustainable future (Deloitte, 2023). The new emerging materials can offer Aalberts more possibilities in sustainable packaging. Materials that are recycled offer better environmental performance as virgin materials (as explained in Chapter 3.3), offering the company other possibilities considering sustainable packaging.

I Trend on sustainable consumption

I Trend on availability of alternative materials

A 6.4 Eliminate single-use packaging with packaging as a product

The third period is from 2035. The period focuses on eliminating single-use packaging with the concept of packaging as a product.

6.4.1 Product

A Aim

The aim for the third period is to eliminate single-use packaging (for the categories PEX pipe, Expansion vessels, Valves and Fittings). This could be done by implementing the concept of packaging as a product.

Packaging as a product

Using less material per packaging can only save a limited amount of packaging. In the end, single-use packaging is still used to transport products. There are multiple approaches to eliminating single-use packaging. Three directions considering the packaging (based on the R-ladder like mentioned in Chapter 4.4) have been validated; refuse, reuse and rethink.

Refusing packaging

Firstly, the direction of refusing packaging is validated. According to the R-ladder the following is meant considering the strategy of Refuse: *"Turning a product redundant by cancelling its function."* (Bassens et al. 2020). Only refusing packaging is not possible due to the main functions of packaging: protection during transport, providing product information and providing product handling. Implementing this direction could lead to more damaged products, since no protection during transport of the product is offered. This is likely to lead to more discarded products, leading to more harm than good considering the environmental footprint of this direction. For this reason, the direction would not be desirable for Aalberts.

Reusing packaging

Secondly, the direction of reusing packaging has been considered. According to the R-ladder the strategy of reuse is described as: *"Reuse of discarded yet still usable product, for the same purpose, by a different user."* (Bassens et al. 2020). As mentioned in Chapter 3.1 & 2.3, during the analysis of challenges in the industry and the supply chain at Aalberts, we discovered that one of the three obstacles for a company to transition to more environmentally friendly packaging was the risks of increased costs and investments. Reusable packaging is seen as a risky packaging change compared to single-use packaging according to interviews with experts as mentioned in Chapter 3.1. In addition to this, as the supply chain of Aalberts is complex (with reference to Chapter 2.3), it would be an uncertain move for Aalberts to implement reusable packaging since a lot of stakeholders are involved. The more stakeholders are involved in the supply chain, the harder it will be for Aalberts to get their reusable packaging returned, increasing the risk of implementation. In addition to this, during a conversation with the company, it is believed by Aalberts that reusable packaging wouldn't be a viable solution due to the great risk involved (2023). For these reasons has been decided that reusable packaging wouldn't be favourable for Aalberts.

Rethinking packaging

Thirdly, the direction of rethinking the packaging was considered. According to Bassens et al (2020), the strategy means: *"Intensifying product use via multifunctional products."* For this direction, the packaging is still used in a linear supply chain (from producer to installer), but also used for an additional function than offering protection during transport. The direction offers the least amount of risks when implemented compared to refusing and reusing packaging for Aalberts. As companies tend to mitigate risks as much as possible (as mentioned in Chapter 3.1), this direction offers most chance of implementation of the three for Aalberts. The following vision has been formulated:

Vision: "Design a packaging with a double function in a way that the packaging acquires another additional function by replacing another product."

Requirements

The direction of rethinking packaging can be applied to all product categories that contribute most to packaging material at Aalberts. Rethinking packaging must eliminate single-use packaging as mentioned in Chapter 6.4.1. Multiple rethinking packaging concepts have been generated to demonstrate the possibilities of the concept. To guide the initial concepts, the following requirements have been set up:

1. The packaging must replace another product

As mentioned in Chapter 6.4.1, rethinking packaging requires the packaging to be intensified via multifunctional use and must eliminate single-use packaging. Therefore, the packaging must replace another product.

The packaging of PEX pipe, Expansion vessels, Valves and Fittings can be redesigned so that it replaces another product. The additional function of the new packaging differs per product category as different products will be replaced with the new packaging. For this reason, underfloor heating pipe will likely have a different function for its packaging as for expansion vessels, valves or fittings.

2. The size of the packaging must not exceed the size of a pallet of 800x800

In order to make chances of implementation of the packaging change as large as possible at Aalberts, the size of the packaging cannot be bigger than a pallet size of 800x800 (Chapter 6.3.1). In this way, transport of the product does not have to be changed, thus lowering the threshold of implementation.

Context analysis

When designing a packaging with a double function that should replace another product, the context in which the original product is used, should be analysed to determine which products could be replaced. Due to the fact that every context is different for each product category, it is likely that for different product categories different packaging concepts are required. For example, expansion vessels are mainly used closely to central heating boilers, whereas fittings could be used in other hydronic applications, which do not have to be related to heating systems. The difference in context will have an influence on the function of the packaging. Additionally, it's worth noting that the installer isn't obligated to install the packaging right away. Alternatively, they can carry it to their next customers and install it there if the initial customer either already has the product in place or doesn't require it.

Selected concept direction

One of the four product categories (PEX pipe, expansion vessels, Valves and Fittings) has been selected for further development to demonstrate its feasibility, desirability and viability. The deep dive is based on the rate of automatisation of the packaging process in current factories. While talking to R&D and Supply chain and visiting factories where these products are produced, it was found that packaging of Expansion vessels, Valves and Fitting was all done automatically. For the product categories PEX pipe packaging was still executed by manual labour. Changing packaging practices at a factory with only manual packaging could increase chances of implementation due to the non-automated packaging process. As mentioned in Chapter 4.1, transferring from the old to the new packaging in automated machines can lead to reduced production output resulting in increased costs. Although slightly decreased production output is also temporarily expected for manual packaging processes when changing packaging, changing practices will have less influence overall for manual labour than for automatic packaging practices according to Aalberts R&D (2023). For this reason has been decided to further develop the concept of rethinking packaging for PEX pipe.

On the following pages the product categories contributing to most packaging material at Aalberts will be discussed regarding the topic rethinking packaging: packaging as a product. For each product category a recommendation on packaging as a product was made based on the context analysis of the product. The product category PEX pipe will be briefly discussed in this Chapter, but will be discussed in more detail in Chapter 7.

- Expansion vessels

Since expansion vessels are installed in heating related environments and bound to the central heating boiler, an application for its packaging can contribute to increasing the efficiency of the central heating boiler. For example by implementing a packaging which helps to insulate heating pipes entering and exiting the boiler, efficiency of the system can be increased, also cutting down on heating costs (Regionaal Energieloket, 2023). This shows that the packaging functions as insulation, replacing insulation material which would currently be bought seperately. In addition to this, the average house in the Netherlands still has 10 to 20 meters of pipe which can be isolated. A meter of insulation saves approximately 3m3 of natural gas consumption every year (Regionaal Energieloket, 2023). Therefore, packaging for expansion vessels could be used to isolate heating systems to increase efficiency of the system.

Context analysis expansion vessels

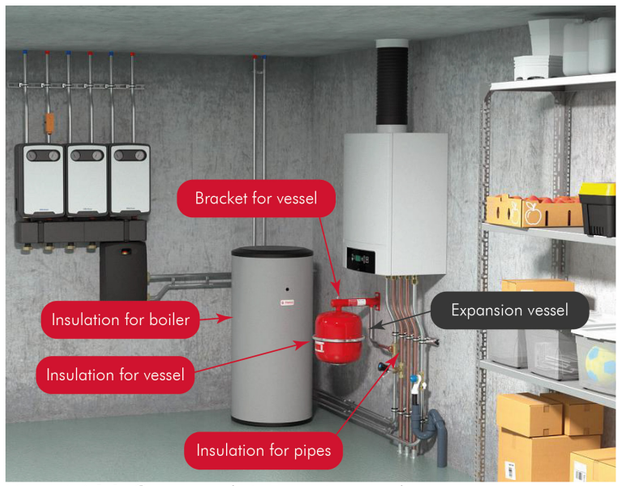


Figure 6.4.1.1: Context analysis Expansion vessels.

Limitations & advantages

	Limitations	Advantage	
Bracket for vessel	Not used if vessels only needs to be replaced		
Insulation for boiler	Boilers are already insulated		
Insulation for vessel	-	Insulation could increase efficiency	Potential option
Insulation for pipes	-	Insulation could increase efficiency	Potential option

Figure 6.4.1.2: Limitations & advantages for packaging as a product Expansion vessels - the potential options are shown in red, other validated directions are shown in grey..

Packaging as pipe insulation

Figure 6.4.1.3: Proposed concept packaging as a product Expansion vessels.

- Fittings

The product category Fittings has a wide variety on locations of installation. Nevertheless it can be said that these products are bound to hydronic pipes. The use of multiskin fittings for example varies from sanitary water to heating applications (Comap, 2024). For this reason, the context of application is less specific than for expansion vessels. Nevertheless, in can be said that in all applications, fittings (and hydronic pipes) need to be secured in place. As of this moment, this is done with pipe brackets needed to be bought seperately. By designing a packaging which can be used as pipe brackets, packaging of both pipe brackets fittings can be eliminated.

Context analysis fittings

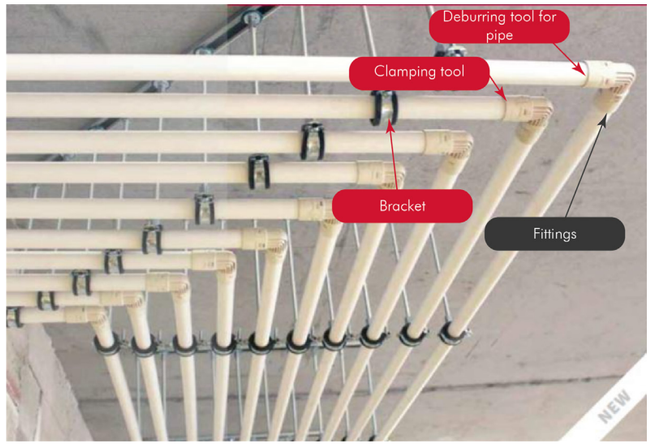


Figure 6.4.1.4: Context analysis Fittings.

Packaging as a bracket

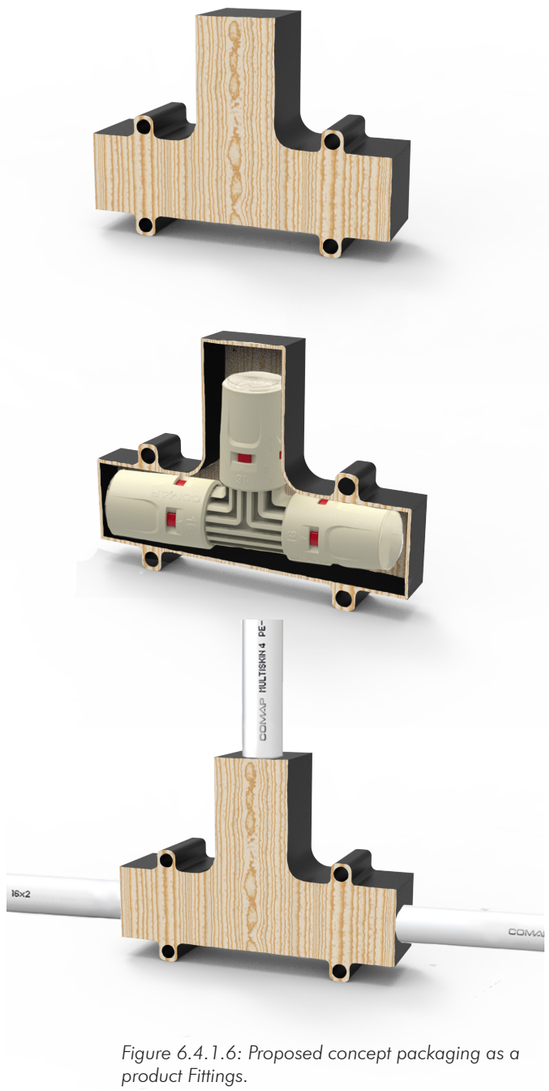


Figure 6.4.1.6: Proposed concept packaging as a product Fittings.

Limitations & advantages

Limitations	Advantage
Deburring tool for pipe	Deburring tool is already used multiple times by installer
Clamping tool	Clamping tool is already used multiple times by installer
Bracket	-
	Clamps are needed anyways
	Potential option

Figure 6.4.1.5: Limitations & advantages for packaging as a product Fittings - the chosen direction is shown in red, other validated directions are shown in grey.

- Valves

Valves are commonly installed in heating related environments. For this reason it is recommended to produce the packaging out of insulation material. The packaging of Valves can therefore contribute to increasing the efficiency of the heating system. The principle works the same as for packaging as a product Expansion vessels (as mentioned in Chapter 6.4.1). The packaging can be used as insulation material for heating pipes.

In addition to this, since Valves are installed on heating circuits for central heating systems, it can decrease thermal losses when insulated. Therefore it could also be an option to insulate the valves itself with the packaging.

Context analysis Valves

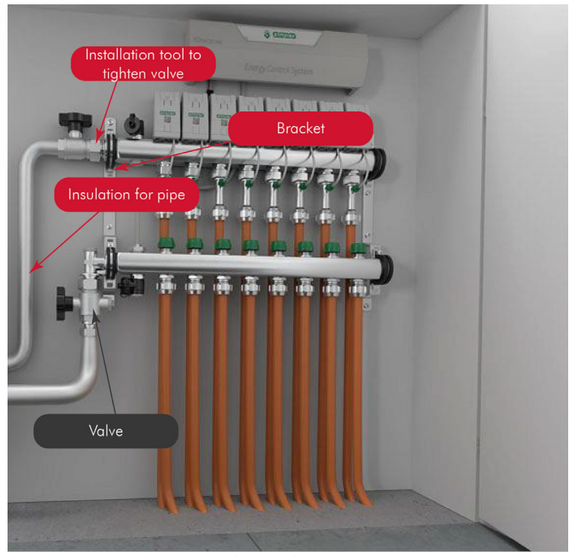


Figure 6.4.1.7: Context analysis Valves.

Packaging as valve insulation

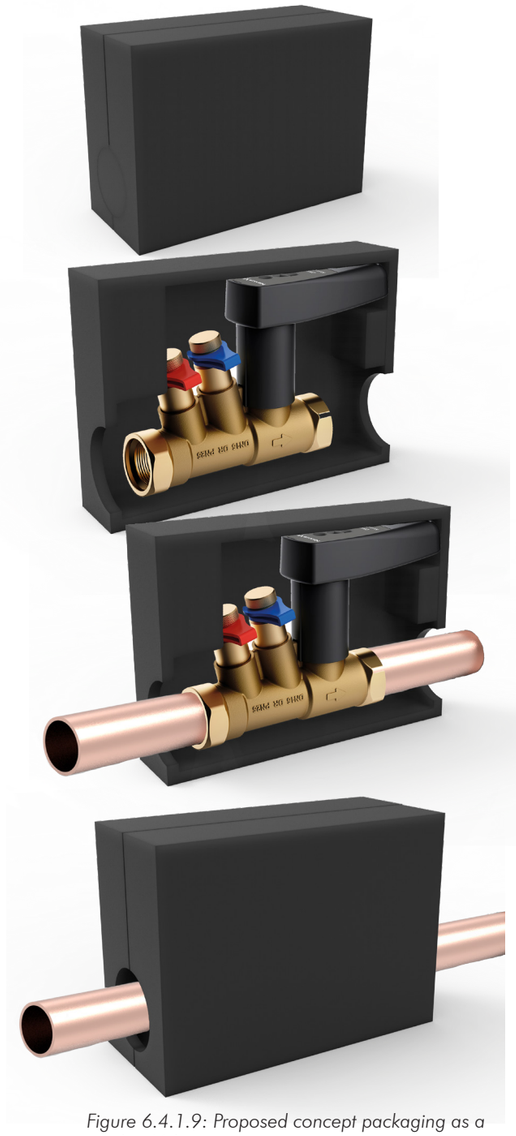


Figure 6.4.1.9: Proposed concept packaging as a product Valves.

Limitations & advantages

Limitations	Advantage
Installation tool to tighten valve	Deburring tool is already used multiple times by installer
Bracket	Not needed as often as with fittings
	Valves and backets are both placed during installation
	Potential option
Insulation for pipe	-
	Insulation could increase efficiency
	Potential option
Insulation for valve	-
	Insulation could increase efficiency
	Potential option

Figure 6.4.1.8: Limitations & advantages for packaging as a product Valves - the potential options are shown in red, other validated directions are shown in grey.

- PEX pipe
PEX pipe produced in Nevers is used for underfloor heating applications. When attaching the pipe to the floor, a type of attachment system is needed in all applications of underfloor heating. In this case, packaging can be used to function as an attachment system. Therefore the packaging eliminates all single-use packaging which is currently used for the pipe, while replacing the attachment system. A context analysis has been made for PEX pipe and products needed for its installation (Figure 6.4.1.10).

Four products that are used for the installation of underfloor heating were considered to be replaced by rethinking a packaging.

Firstly, the distribution block has been considered to be replaced with a packaging. This product is very complex and fragile and therefore would not be suitable to be replaced by a packaging.

Secondly, insulation was considered to be replaced by a packaging. Nevertheless, 20m2 of insulation is needed for 100m of PEX pipe, the maximum amount of pipe that could be installed in one go (Uheat, 2023). Since current insulation is approximately 100mm thick, 2m3 of insulation is needed per packaging (100m of pipe). This means that the total volume of the packaging from insulation would be 2m3. This volume would not fit on a pallet sized 800x800mm, a height of 3.1m is required for all insulation and therefore does not fit the requirement (Chapter 6.4.1). Even when less insulation is used so that the PEX pipe and insulation could fit on one pallet, extra insulation would have to be bought additionally by the installer, making the installation of underfloor heating more complex. Since the required amount of insulation does not fit on one pallet, replacing insulation with packaging for PEX pipe would not be feasible.

Thirdly, brackets have been considered to be replaced by its packaging. These brackets are currently used to guide the PEX pipe close to the distribution block (Aalberts, 2023). It was found that the size of the brackets was significantly smaller than the product PEX pipe. For this reason, replacing brackets with PEX pipe is not feasible.

Fourthly, the attachment system has been considered to be replaced by its packaging. Due to the size of the rails elements (a type of attachment system currently used for underfloor heating installation), the fact that the product is also needed during installation and it would be used in the same context (for underfloor heating), the product has been selected for further development. A more extensive explanation and visualization on rethinking packaging for underfloor heating will be given in Chapter 7.

Context analysis PEX pipe

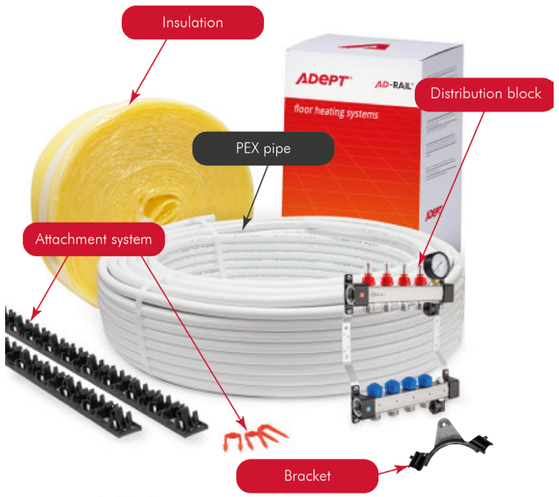


Figure 6.4.1.10: Context analysis PEX pipe.

Limitations & advantages

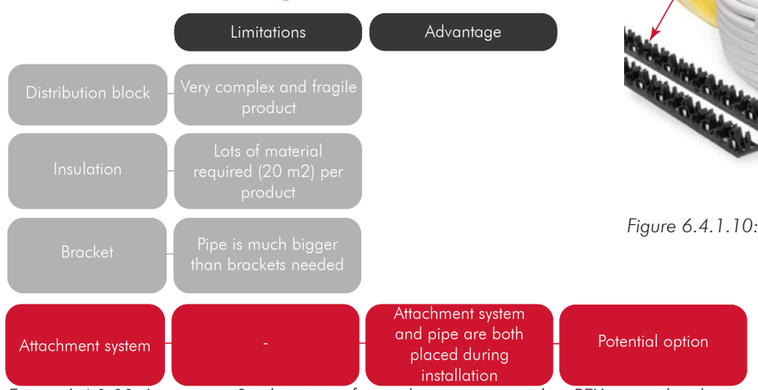


Figure 6.4.1.11: Limitations & advantages for packaging as a product PEX pipe - the chosen direction is shown in red, other validated directions are shown in grey.

Targeted results

If the concept of packaging as a product is applied to the product categories contributing most to packaging material at Aalberts (PEX pipe, Expansion vessels, Valves and Fittings), all single-use packaging could be eliminated. This has the following effects on the total packaging use at Aalberts.

T - Plastic reduction of 92 tons (59%)
In 2022, Aalberts Hydronic Flow Control used 155 tons of plastic as mentioned in Chapter 2.4. By getting rid of all single-use plastic packaging for the product categories Valves and Fittings, a total of 92 tons of plastic can be reduced. Compared to all plastic consumption at Aalberts, a total reduction of 59% of plastic packaging can be realised when implementing packaging as a product.

T - Cardboard reduction of 872 tons (48%)
Aalberts used a total of 1807 tons of cardboard in 2022. When eliminating all single-use cardboard for the product categories PEX pipe and Expansion Vessels, a reduction of 872 tons could be made. This amount accounts for 48% of all cardboard consumption at Aalberts. By implementing the concept of packaging as a product, 48% of cardboard use at Aalberts can be reduced.

Total reduction

A total reduction of 35% can be realised if eliminating all single-use packaging for the categories PEX pipe, Expansion vessels, Valves and Fittings. The reduction of 35% represents 964 tons (eliminated packaging) of 2739 tons of total packaging use at Aalberts in 2022. When including the recommended impact of packaging reduction of the first two periods, a total packaging reduction of 54% can be realised at Aalberts.

Although the third period packaging as a product could be seen as more challenging as the first two periods, it does provide the opportunity to reduce more packaging material than all recommended packaging changes combined in period I and II. This shows that the direction of rethinking packaging with packaging as a product could potentially realise much greater packaging reductions for Aalberts.

Alignment with current reduction targets

As mentioned in Chapter 6.3.1, if all recommended actions are implemented in period one and two, a total reduction of 26% of all packaging at Aalberts can be realised. In period III a total 35% of all packaging could be achieved. When accumulating all packaging reduction from period I, II and III, a total of 54% of single-use packaging reduction could be achieved.

New reduction targets

Critics could say that no more reduction of packaging material is needed after achieving the goal of 20%. Nevertheless, it is recommended for Aalberts to set up long-term goals considering the reduction of packaging (currently 20% reduction by 2025 is the only target on packaging). Especially considering the fact that the company has set the goal to become net-zero by 2050 as mentioned in Chapter 4.2. It is advised to Aalberts to increase targets considering reduction of single-use packaging as it also contributes to reducing company emissions (as explained in Chapter 4.4), are important for the company becoming net-zero by 2050.

In addition to this, regulations considering packaging are expected to become more strict. As mentioned in the roadmap and Chapter 6.4.2, regulations implementing bans on single-use plastics are scheduled for 2040. New targets for Aalberts on packaging reduction should focus on the upcoming regulations. For this reason it is recommended for the company to set the target to reduce all single-use plastics by 100% by 2040 considering the upcoming bans in the United Kingdom and France.

Also, considering the targets set by the European Union to have no net greenhouse gas emissions by 2050, the goal of Aalberts to become net-zero by 2050, and the target of the United Kingdom for 2050 to eliminate avoidable waste of all kinds and more countries are expected to follow (Chapter 6.4.2), it is advised for Aalberts to adapt the current reduction goal to these targets. As packaging contributes to the greenhouse gas emissions of a company as mentioned in Chapter 4.4, and Aalberts' target is to reach net-zero emissions, eliminating single-use packaging can contribute to reaching their target. Therefore, it is recommended for Aalberts to set the new target to eliminate all single-use packaging by 2050.

Period III alignment with current Aalberts target (2025 - 20%)

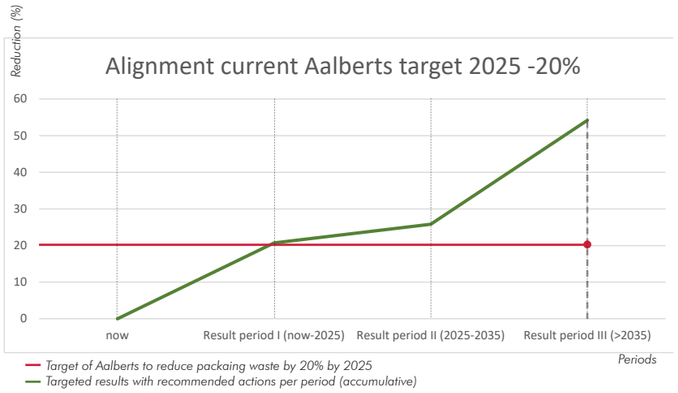


Figure 6.4.1.12: Alignment current Aalberts target - in red the current target and in green the expected targeted result is shown.

I **Period III (>2035) reduces all packaging at Aalberts by 35%**

I **Period I, II & III represent a reduction of 54% of all packaging at Aalberts**

A **New recommended packaging target: Reduce all single-use plastics by 100% by 2040**

A **New recommended packaging target: Reduce all single-use packaging by 100% by 2050**

6.4.2 Regulations

The European Union has announced the goal to be climate neutral by 2050. The law sets the target in the European Green Deal for Europe's economy and society to become climate neutral. "*Climate neutrality by 2050 means achieving net zero greenhouse gas emissions for EU countries as a whole*" (European Commission, 2021) In addition to this, the climate law includes a commitment to negative emissions after 2050 (European Commission, 2021), showing that clear targets considering the reduction of emissions are set. These targets set by the European Union could lead to reducing the emissions of packaging production as well.

Also in Member States of the European Union is expected that new regulations considering packaging will be introducted. In the French market, a ban on all single-use plastic packaging is anticipated by 2040, while in the United Kingdom, efforts will be made to eliminate all avoidable plastic packaging (Plastic and Packaging Waste Laws and Regulations | CMS Expert Guide, n.d.). The United Kingdom is even expected to have a regulation implemented by 2050 to eliminate avoidable waste of all kinds (Plastic and Packaging Waste Laws and Regulations | CMS Expert Guide, n.d.). With the new (incoming) regulation "The UK government became the first major economy in the world to set a legally binding target to achieve net zero greenhouse gas emissions from across the UK economy by 2050" (United Kingdom Government, 2021). Although the UK is the first country setting targets to achieve EU goals, it is expected that other countries in Europe are following due to the net zero emissions target of the European Union.

All in all, as carbon neutral targets are set by the European Union and new regulations considering elimination or reduction of packaging are scheduled to be implemented, it is recommended to choose for packaging solutions that do not produce waste after use.

I Targets on zero emissions by the EU will force to reduce emissions of packaging production

I Bans on single use plastics are incoming

I Bans on avoidable waste are incoming

6.4.3 Market trends >2035

The following market trends will play a role in the need to redesign packaging at Aalberts.

Zero waste

At the beginning of this period, it is expected that the initiative to produce zero waste will be mainstream adopted. Achieving zero waste will be achieved through the implementation of a circular economy, which involves reducing consumption of single-use items. A zero-waste lifestyle not only benefits the environment but also has the potential to save money by reducing waste disposal (Deloitte, 2023). Research into the trend of zero-waste is already increasing as publications of the zero waste research domain are increasing by 60% over 2014-2020 (Zhang et al., 2022). In addition to this, the European Union is working on plans for a zero waste programme by following the guidelines of a circular economy as explained in "Towards a circular economy: A zero waste programme for Europe" (European Parliament, 2020).

I Trend on zero waste

6.5 Conclusion

A strategic roadmap has been designed based on insights and findings from the analysis phase of this thesis. The roadmap focuses on the product categories that contribute most to packaging used at Aalberts (PEX pipe, Expansion vessels, Valves and Fittings). The roadmap is designed using the Three horizon model, dividing the roadmap into three periods:
- The **first period (now-2025)** is focused on the implementation of most financially appealing packaging changes for Aalberts to reach the target of 20% reduction by 2025. Investments are needed, but are estimated to be profitable within 2 years of implementation.
- The **second period (2025-2035)** is focused on reducing unnecessary packaging and redesigning packaging for recycled and less material use. In this period investments are needed to reduce packaging, contributing to more 5.2% more packaging reduction (141 tons) at Aalberts.
- The **third period (>2035)** aims at eliminating single-use packaging through implementing the concept of packaging as a product. This requires further investments and a bigger change in packaging practices than the two periods before, which eliminates single-use packaging completely, leading to 35.2% reduction of all packaging (964 tons).

How to reach the target of 20% reduction by 2025?

In order to reach the target of 20% reduction by 2025, investment based packaging changes need to be made. Most financially appealing actions that are recommended to be implemented before 2025 are the following:

R 1. Reduce bag sizes Valves and Fittings by 50%

It is recommended to reduce unnecessary packaging because it saves the company material and costs, a win-win scenario for Aalberts. It is advised to start with the reduction of plastic bag sizes for Valves and Fittings (46 tons, 1.7% of all packaging at Aalberts) since this provides the largest packaging reduction of unnecessary packaging.

R 2. Reusable pallets PEX pipe

Moving to reusable pallets for PEX pipe provides the largest reduction in packaging material with 520 tons (19% of all packaging at Aalberts). This change does require a one-time investment of €385,000 but saves €200,000 per year on single-use pallets. Therefore return on investment will be within 2 years. Since the packaging change offers a large reduction (close to the target of 20%) and saves costs in the long term, this is recommended to be implemented as soon as possible to reach the target before 2025 (together with reducing bag sizes for Valves and Fittings).

New targets

Due to upcoming regulations on packaging, goals of Aalberts and the European Union to become net-zero by 2050, the following new targets are advised:
- Reduce all single-use plastics by 100% by 2040
- Reduce all single-use packaging by 100% by 2050

The new targets could be achieved with the concept presented in the third period of the strategic roadmap: *packaging as a product*. This concept aims to eliminate single-use packaging completely through redesigning packaging to replace another product by providing packaging with an additional function.

Further development

PEX pipe underfloor heating pipe has been selected for further development for the concept of packaging as a product because of three reasons:

First, PEX pipe is commonly used in the market and at Aalberts for underfloor heating applications, hence the decision to focus on underfloor heating pipe.

Second, packaging of PEX pipe is done manually as opposed to the other main product categories (Expansion vessels, Valves and Fittings, which are automated), leading to less risks when changing packaging practices. Although PEX pipe represents second of all packaging material used at Aalberts (7.2%) and Expansion Vessels first (representing 24.6%), it does provide the highest chances of implementation, leading to the (first) recommended packaging as a product change.

Third, an attachment system is seen as the most feasible option to make a packaging out of (as opposed to a distribution block, insulation and bracket(s)) due to its size and simplicity and therefore more prone to be implemented.

7. Deep dive: packaging as a product

7.1 Attachment systems

As stated in Chapter 6.4.1, underfloor heating pipe has been selected for further development due to its common use for PEX pipe, non-automated packaging practices at the factory (as opposed to the other main product categories) and that an attachment system is seen as the most feasible option to make a packaging from (as opposed to a distribution block, insulation and bracket(s)).

When considering the installation of underfloor heating attached to the ground before pouring concrete to secure it in place, there are several options currently available in the market. In all cases the underfloor heating pipes are connected to a layer of insulation. Usually this layer is made from a type of foam where the products will be mounted onto. In general, these options to fixate the underfloor heating pipes to the insulation layer can be divided into the following categories:

- Tacker system. This system is based on tackers, small nails to attach the pipe to the insulation layer. The system is mainly used in large buildings and is adaptable to any structure (Comap, n.d.) (Figure 7.1.1).

- Plate system. Stud systems are commonly used for underfloor heating applications in houses. The solution causes for 1 person installation and a quick installation (Comap, n.d.) (Figure 7.1.2).

- Rails system. Rails systems can be placed without restriction in any orientation. The simple and flexible system can be used in all types of projects, including on walls. (Comap, n.d.) (Figure 7.1.3).

For underfloor heating applications there are wet and dry systems available. The systems that are mentioned above are based on a wet system. It has been decided to focus on the wet system due to the fact that these types of systems are a lot more efficient to run than dry systems. In addition to this, this type is the most commonly used type of underfloor heating (Notion services, 2022).

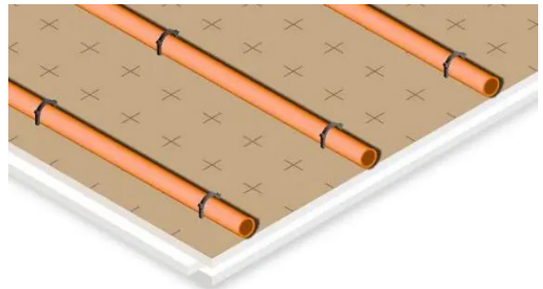


Figure 7.1.1: Tacker system (Comap, n.d.).

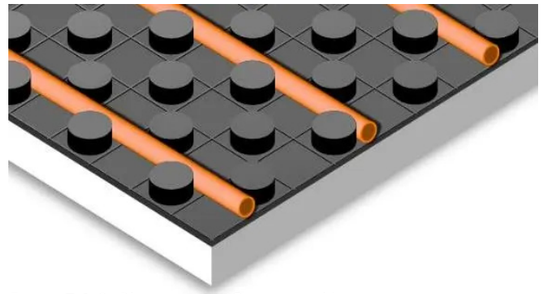


Figure 7.1.2: Plate system (Comap, n.d.).

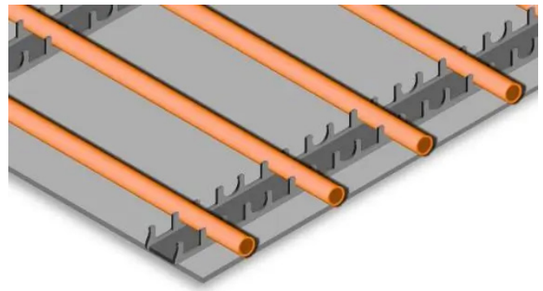


Figure 7.1.3: Rails system (Comap, n.d.).

The different type of systems have been compared with each other based on the following criteria. The criteria are based on the formulated vision to rethink/redesign a packaging with a double function in a way that the packaging acquires another additional function by replacing another product (as mentioned in Chapter 6.4.1)

The packaging must replace another product

As mentioned in Chapter 6.4.1 a requirement of the concept of packaging as a product is that the packaging should replace a product that is already used while installing underfloor heating. This will make installing the product more convenient due to the fact that no extra equipment or packaging is needed. While speaking to installers, it became clear that most packaging was left at the building site due to extra costs and effort for disposing packaging (Installer, 2024). Installing the product will lead to zero-waste on the building site, making the product more advantagous over single-use packaged products.

The attachment system should be able to be used in all underfloor heating applications

There are various kinds of attachment systems to fixate underfloor heating pipes to the insulation layer. However, to make sure the packaging can be used in all applications, it is required that the type of attachment system would be suitable for all buildings. When comparing the three types of attachment systems to each other, only the tacker and rails system are suitable for all building types and are configurable in all types of layouts (Comap, n.d.). Nevertheless has been chosen for the rails systems to be worked out due to the fact that it can also be installed on the walls, whereas the tacker system cannot (product manager, 2024). Due to the fact that this systems offers a wider use application, the decision was made to continue with this concept.

In addition to this, due to the large size of the plate system, the size of the packaging will be increased if the packaging will be used as an attachment system. The total surface of the current packaging is approximately 1.5m2. Assuming that 100m of coil is the maximum amount of coil needed due to the maximum circuit length and a spacing of 200mm per pipe is needed, a total surface of 20m2 should be covered with one packaging (Uheat, 2023). Because a lot of material is needed to install underfloor heating pipe with the plate system compared to the rails system, it would not be possible to make a packaging out of this (as mentioned earlier in Chapter 6.4.1).

When rails elements of 40mm wide (current size) are used, a total of 52 railses can be created from a box of 800x800x120 mm (Techniekwebshop, 2024). Each rails will have a length of 800mm. This totals in a length of 41.6m. Since 20m2 of floor will be covered with 100m pipe, the rails can be laid with a (minimal) distance of 500mm (Uheat, 2023). All in all, this led to the decision to use the rails attachment system to make a packaging out of. In Figure 7.1.4 the amount of rails per type of layout can be seen. Note that the layouts are based on a maximum use of the rails (52), less rails can be used if preferred. Currently it is adviced to use a rails element for every 1m of pipe. In this system, for every 0.5m of pipe a rails element can be installed, demonstrating that there will be no shortage on rails elements for the concept of packaging as a product. On the other side, too many rails elements could lead to waste. In any case all rails elements can be used to provide a stronger connection between the floor and the underfloor heating pipe. Nevertheless, more research should be performed on the exact amount of rails elements required per 100m of underfloor heating pipe as the amount of leftover rails and shortage on rails could be optimized. This change does not affect the design of the concept as width dimensions of the rails can be scaled.

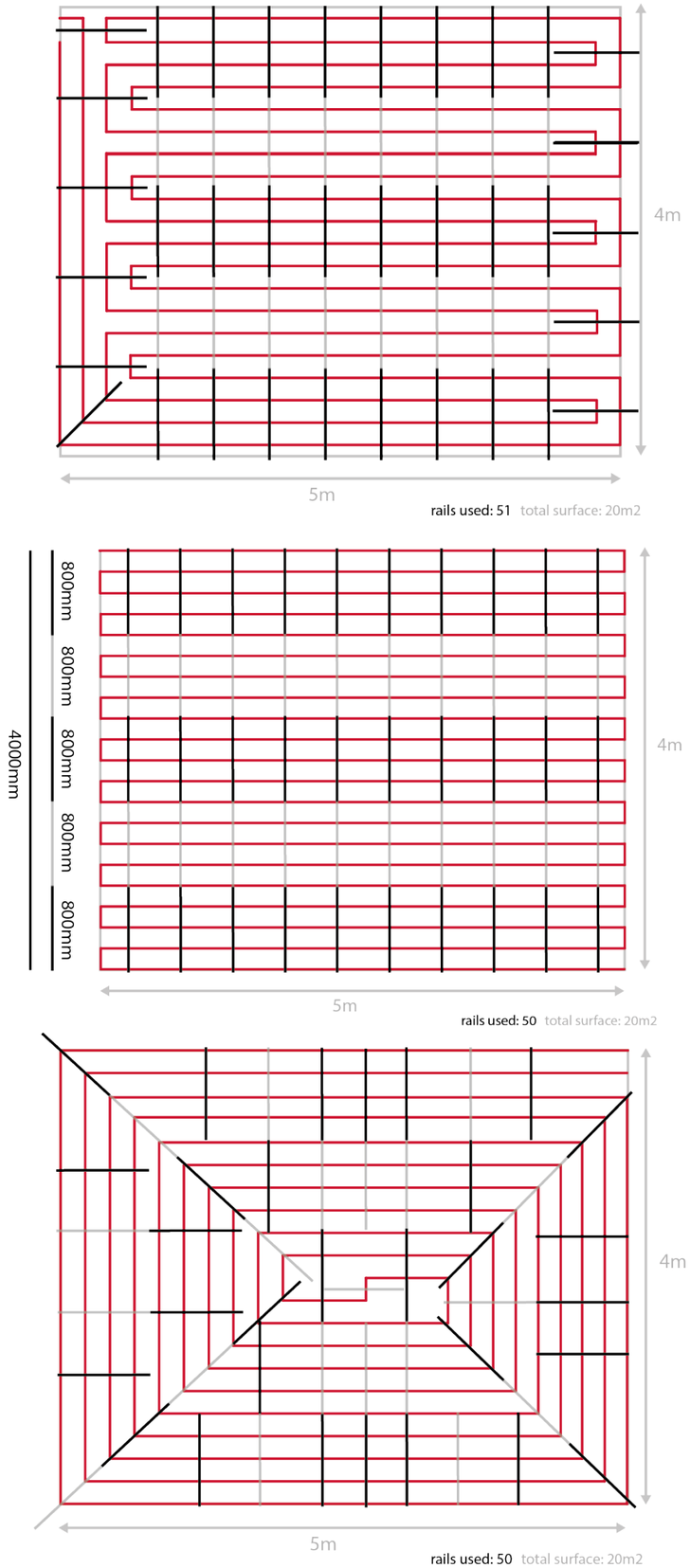


Figure 7.1.4: Possible layouts - in black and grey are rails elements shown, PEX pipe is shown in red.

7.2 Design criteria and concepts underfloor heating

7.2.1 Design criteria

To guide the exploration of different types of packaging that can be used as rails for underfloor heating, design criteria were developed. The criteria are based on the formulated vision to rethink/redesign a packaging in a way that it can be reused as a product. In addition to design criteria, requirements have been estabished for the concept. Initial requirements can be found in Appendix 9.5. Face to face interviews with installers (n=5) were conducted to find out more on their requirements considering packaging. Interviews were conducted at wholesalers sale locations (n=2) and took approximately 15 minutes per participant. During the interview a concept was presented to the installer to gain insights on their opinion and requirements for the concept. More detailled information on the interview procedure and concept can be found in Appendix 9.18.

The following design criteria were formulated and ranked on importance based on interviews with installers and the products use application:

Time-efficient/convenient

According to installers (personal communication, 2024), time is the most important factor when selecting products from the wholesaler. Especially in Western Europe it is key that a product should be quick to install since labor is expensive (product manager, 2023). Since HFC sells most products in Western Europe, this criteria is seen as the most important one. In the end, the product should be as quick to install as the current products being packaged seperately.

Configurability

The rails should allow for maximum freedom in layouts. Installers should be able to place the underfloor heating rails wherever is preferred. The product should have as much freedom in configurability as the current rails.

Impact resistance (during transport)

Because the product will be used as a packaging it should be able to withstand impact and vibrations during transportation. The packaging must endure an impact force equivalent to the maximum force applied to cardboard. Furthermore, the packaging should endure a compression force at least equivalent to the force exerted on a similar corrugated box.

Sustainability

The carbon footprint of the packaging as a product should be lower than the current type of packaging and product.

Multiple concepts were created for the rails system. Based on the design criteria discussed earlier, the best concept has been selected for further development. During this phase of ideation, the system to connect the different rails parts together in the shape of a packaging has not been taken fully into account. Nevertheless thinking about the connection system up-front helped in generating the concepts phase. Concepts have been validated on the criteria by comparing them to each other. Exact criteria for the concepts have been validated (in comparison with the current packaging) in Chapter 7.5.

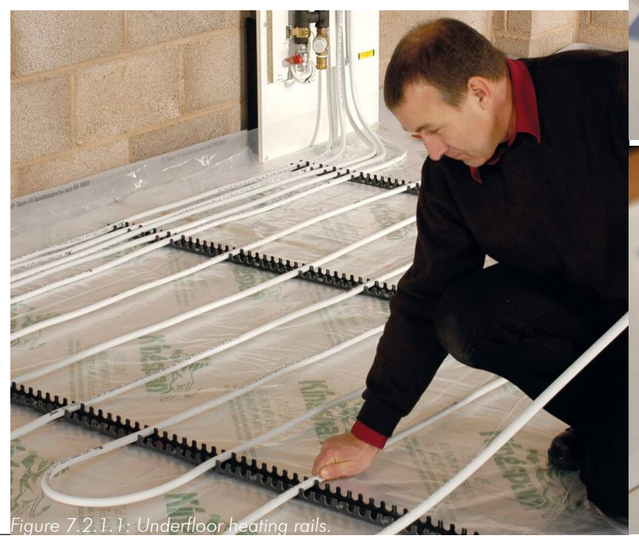


Figure 7.2.1.1: Underfloor heating rails.

7.2.2 Standalone

Standalone is the first generated concept. The concept is based on a traditional type of underfloor heating rails. The rails can be attached to the insulation layer by either adhesive tape or via a mechanical connection (e.g. nails). In Figure 7.2.2.2 can be seen how the product functions on the floor and as a packaging.

Prototyping and testing

The concept has been prototyped to explore its strengths and weaknesses. The prototype can be seen in Figure 7.2.2.1. Testing reveals that the concept provides outstanding configurability, allowing it to be arranged in any desired direction or shape. A disadvantage is the use of two parts per rails where the underfloor heating pipe should be connected in. In theory, it may enhance the security of the pipe connection to the rails; however, in practice, it complicates the process of connecting the pipe to the product. Installation time can be saved by using one part per rail for inserting the pipe. Another downside is the use of adhesive tape to attach the prototype to the floor. In some cases the adhesive was not strong enough resulting in undesired movement of the rails.

Figure 7.2.2.1: Prototype.

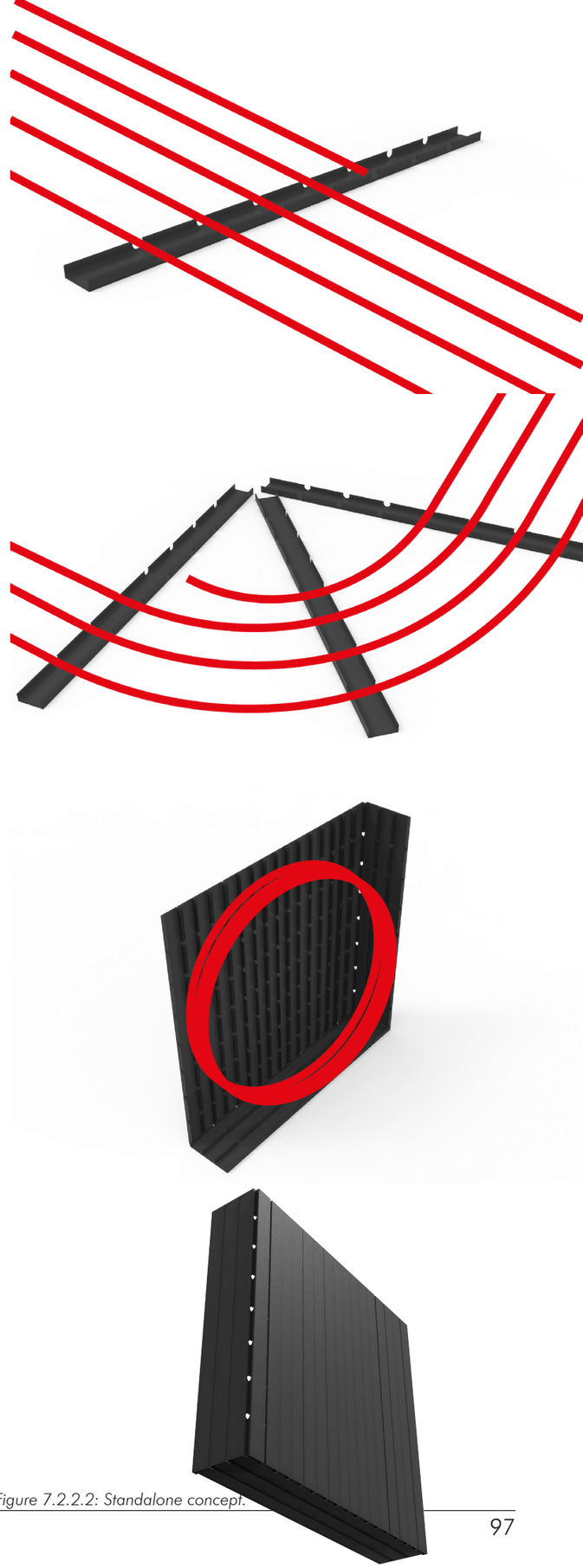


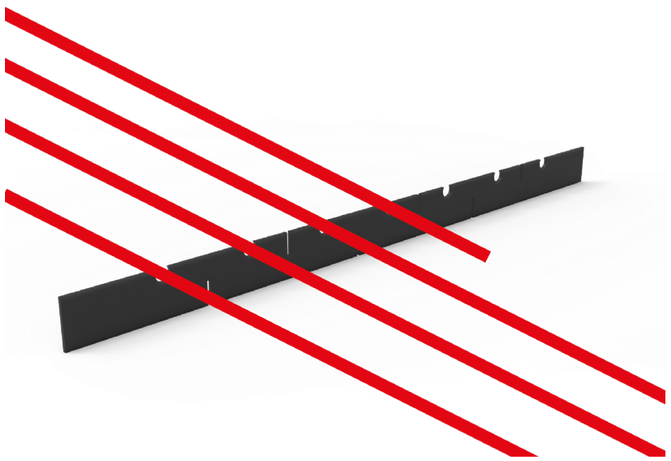
Figure 7.2.2.2: Standalone concept.

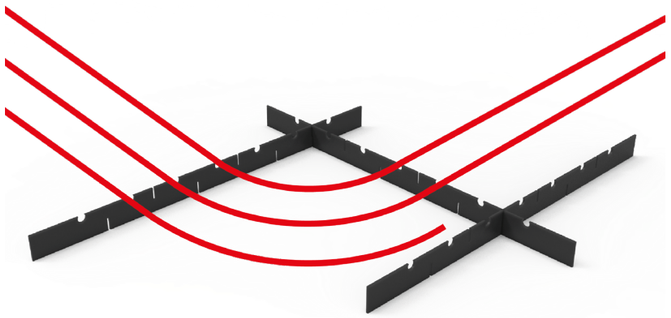
7.2.3 Wedge

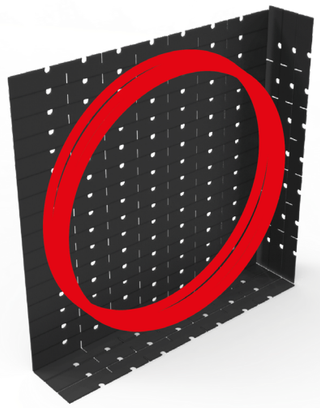
Wedge is the second generated packaging as a product concept. The concept relies on other (similar) parts to attach underfloor heating to. The rails will “stand-up” by wedging one into another. After the rails is set-up in the correct layout, underfloor heating pipe can be installed. In Figure 7.2.3.1 can be seen how the product functions on the floor and as a packaging.

Prototyping and testing

The prototype in Figure 7.2.3.2 has been developed to assess the strengths and weaknesses of the concept. The concept provides an effective method for connecting pipes in corners, because of its interconnecting structure. This also prevents undesired movement when installing pipe. Nevertheless, the product requires an additional rail element for support and cannot be installed independently, leading to constraints on the variety of layouts that can be created. Another challenge that could arise is the way the rails is connected to the insulation layer. The limited rail-to-ground surface restricts adhesive use, necessitating a mechanical connection in the design.







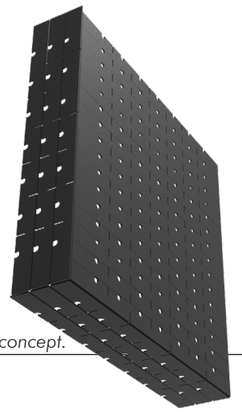


Figure 7.2.3.1: Wedge concept.

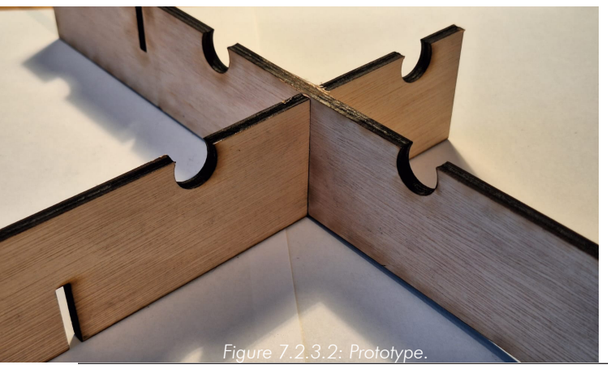


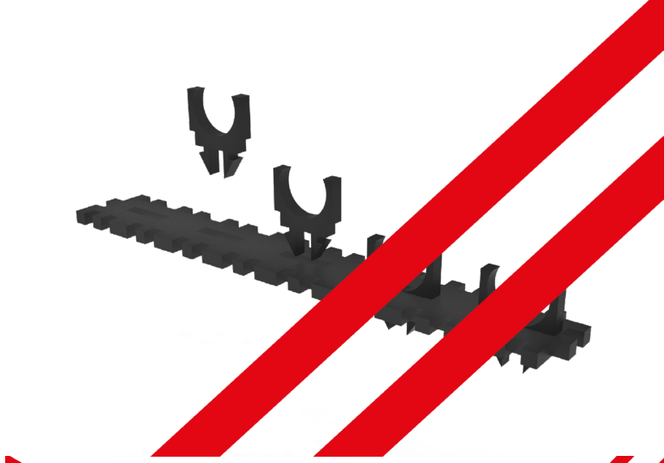
Figure 7.2.3.2: Prototype.

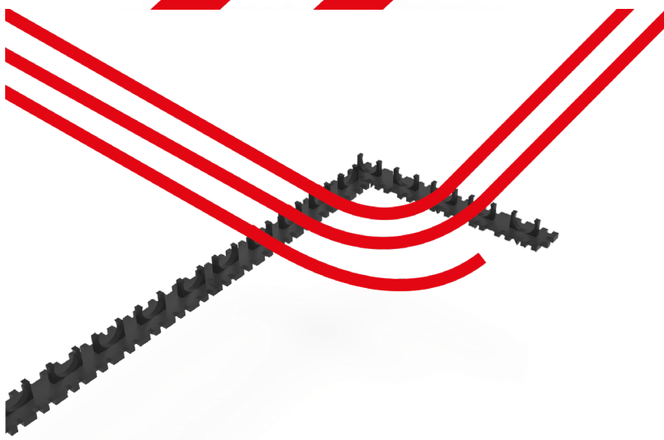
7.2.4 Snap-in

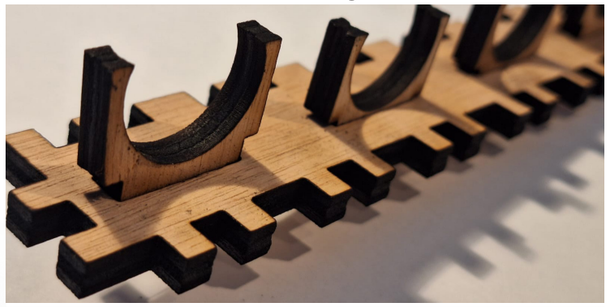
Last but not least is Snap-In. This is the third generated concept based on packaging as a product. The concept exists of parts which can be laid in any direction or layout on the insulation layer. Then, “snap-ins” are used to attach the rails to the insulation layer. In these “snap-ins” the underfloor heating pipe can be installed. In Figure 7.2.4.1 can be seen how the product functions on the floor and as a packaging.

Prototyping and testing

The system was lasercut to allow for a quick prototype (Figure 7.2.4.2). It can be concluded that the rail design facilitates strong connections both vertically and along the same axis. On the downside, however, inserting attachments can be time-consuming. This would not be appealing to the target group since time of installation should be restricted. Another drawback is the small size of the attachments, making them vulnerable to breaking.







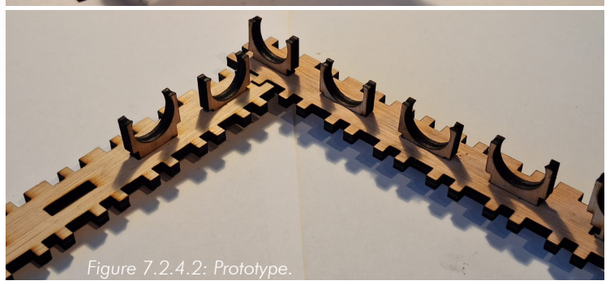


Figure 7.2.4.2: Prototype.

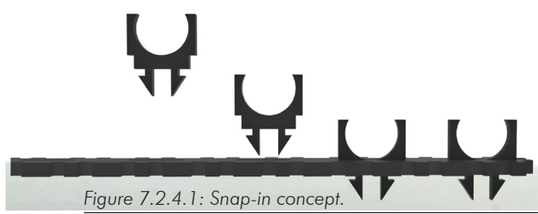
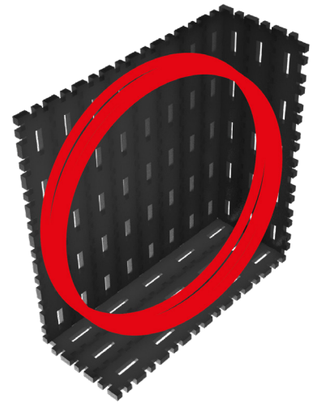
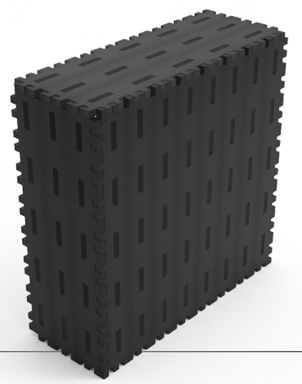


Figure 7.2.4.1: Snap-in concept.





7.2.5 Concept selection

In this Chapter the three concepts will be rated on the design criteria presented previously. Each concept is rated on time-efficiency/convience, configurability, impact resistance and sustainability. The concepts are rated from 1-3 (3 is the highest ranking, 1 is the lowest ranking). Total scores can be seen in Table 7.2.5.1 to see which concept is most suitable for further development.

Type of system	Standalone	Wedge	Snap-in
Time-efficient/ convenient	3 No inserts and can be placed on its own	2 Cannot be placed on its own and has no inserts	1 All inserts need to be placed before installation of underfloor heating
Configurability	3 Can be placed wherever is preferred	2 Dependent on other rails parts. Cannot be laid seperate	3 Can be placed wherever is preferred
Impact resistance	3 No material loss on outside (bottom), this will make the part the strongest of the three	1 Lots of cutouts of the part (sides) will make the part weaker	2 Slightly material loss because of cutouts will make the part weaker
Sustainability	2 Uses the most amount of material	3 Least amount of material use	3 Least amount of material use
Total	11	8	9

Table 7.2.5.1: Concept comparison.

Analyzing Table 7.2.5.1, it is evident that the standalone concept is regarded as the most promising type of rails for advancing into a packaging solution. This concept is viewed as the most time-efficient and convenient among the three, due to the fact that no inserts are needed and the concept can be placed on its own. Moreover, the standalone rails can be positioned in any direction without relying on other rail elements. It is also seen as the rails which is most impact resistant due to having no cut-outs or gaps, decreasing the impact resistance of the rails when used as a packaging. The concept of standalone is therefore seen as the strongest of the three. The concept standalone scores highest on most criteria mentioned.

Nevertheless, in terms of sustainability, it scores lower than the other two concepts, mainly because it utilizes more material. To address this, there is a need to iterate on the rails design to reduce material usage. Additionally should be looked at sustainable materials to produce the rails from. The concept standalone is chosen for further development.

7.3 Manufacturing

7.3.1 Manufacturing methods

Based on the research before, it was concluded that risk prevention and investments are one of the three main reasons why companies have struggles switching to more sustainable packaging. Therefore the manufacturing method that is recommended should not require any significant investments before starting production. In addition no-investment manufacturing methods, the packaging should be made from a material that is biobased (Chapter 7.3.3). Hence the selection of all manufacturing methods which can produce biobased products. In Table 7.3.1.1 a comparison on all suitable manufacturing methods can be found.

Manufacturing method	Materials	Requires mould	Costs	Carbon footprint kg CO2 equivalent
Injection moulding	Biobased plastics	Yes	€ 50.000 per mould (Rex plastics, 2020)	0.47/kg (Delft University of Technology, 2024)
Extrusion	Biobased plastics	Yes	€ 50.000 per mould (Rex plastics, 2020)	0.35/kg (Delft University of Technology, 2024)
Thermoforming	Biobased plastics	Yes	€ 50.000 per mould (Rex plastics, 2020)	0.22/kg (Delft University of Technology, 2024)
Blow moulding	Biobased plastics	Yes	€ 50.000 per mould (Rex plastics, 2020)	0.22/kg (Delft University of Technology, 2024)
Paper making	Pulp paper, cardboard	Yes	€ 20.000 per mould (Stratasys, 2023)	0.13/kg (Delft University of Technology, 2024)
Machining	Biobased plastics, wood	No	Slow cutting speeds and low accuracy compared to laser machines (Yijinsolution, 2023)	0.75/kg (Congbo et al., 2013)
Laser cutting	Biobased plastics, wood, cardboard sheets	No	Laser machines have quicker cycle time than CNC machines, reducing the costs per part. They have smaller and lesser parts involved which further reduces the operational costs (Yijinsolution, 2023).	Unknown Lasers are often presented as a low-energy alternative to other manufacturing processes. (Goffin et al., 2023)

Table 7.3.1.1: Comparison of all suitable manufacturing methods.

From the selection can be concluded that not all manufacturing methods are suitable for the criteria of biobased products and no-investments. The criteria of no-investments leads to the recommendation of avoiding using manufacturing processes based on a mould due to the fact that producing mould require investments.

In addition to no need for investments to produce parts on laser cutting machines, the carbon footprint during operation is often presented as a low-energy alternative to other manufacturing processes (Goffin et al., 2023).

When looking at Table 7.3.1.1 it can be concluded that the most suitable manufacturing method to produce this product is laser cutting due to the quick cycle times and low costs per product.

7.3.2 Laser cutting industry

Laser cutting is a popular technology used in a range of different industries. It is used to cheaply and quickly produce flat, precisely cut components (Xometry, 2023). In addition to this, the global laser cutting machine market size was valued at USD 5.59 billion in 2022, indicating the manufacturing process is widely adopted (Fortune Business Insights, 2023).

Laser cutting of wood

Laser cutting of wood is seen as a precise and efficient process that allows wood to be processed quickly and cost-effectively. Compared to conventional wood manufacturing methods such as sawing or milling, laser cutting can save a considerable amount of time and money. In addition to this, due to the small size of the laser beam, less material is wasted than for other production processed such as machining. Also, the production technique offers the possibility of automated production, enabling cost reductions even more (Justlaser, 2023).

Laser machines are typically used to cut complex shapes and designs that would be difficult or impossible to achieve with conventional tools (Figures 7.3.2.1-7.3.2.4). The areas of application are diverse and range from furniture production to the manufacture of packaging materials and the design of art objects. Laser cutting also offers numerous advantages in terms of the quality and precision of the cut parts. In addition, the surface of the cut material remains smooth and undamaged, which offers further advantages in terms of aesthetics and durability. Last but not least, the manufacturing process of laser cutting is also seen as environmentally friendly, as it does not require any chemical additives (Justlaser, 2023).

All in all, the advantages of wood laser cutting lie primarily in its fast, precise and cost-effective processing.

Figure 7.3.2.1: Lasercut packaging.

Figure 7.3.2.2: Lasercut packaging.

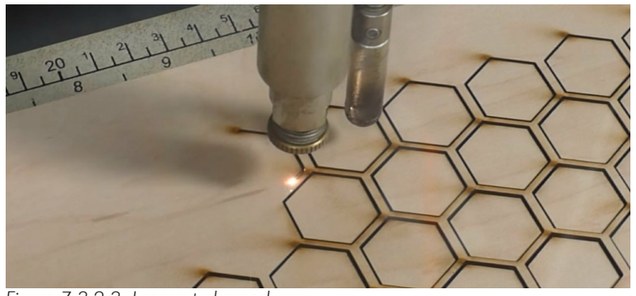


Figure 7.3.2.3: Lasercut plywood.

Figure 7.3.2.4: Lasercut packaging.

7.3.3 Materials

In order to select the material to make the packaging from, the manufacturing method, costs of material, strength of the material and the product application has been taken into consideration. In this Chapter the reasoning behind the material selection will be discussed.

Material selection

A requirement is that the packaging should not be made out of fossil sources. Currently many industrial products are traditionally made using fossil-based raw materials, which come from non-renewable sources. There are two main option considering materials:

- Biobased materials

'Bio-based' materials are created using renewable biomass sources. These sources commonly include plants, animals, marine, and forestry materials (Stahl, 2023). Bio-based materials should be used to prevent resource depletion, air pollution and (extra) CO2 emissions (National Geographic, 2023).

- Recycled materials

Recycled materials are another option to eliminate the need for fossil sources. However, producing the product from recycled materials is less environmentally friendly than producing it from plywood. In fact, producing the rails from plywood has a 30% smaller carbon footprint than producing it from recycled polypropylene (Appendix 9.11). In addition to this, producing products from recycled plastics would require a mould for production. Producing moulds require investments and increase the threshold to implement sustainable packaging (as was mentioned in Chapter 3.1 and 4.1).

For the reasons mentioned above, it has been decided to select biobased materials to produce this type of packaging.

Storing carbon

According to the UN, the construction industry causes for a major part of CO2 emissions. In total it is responsible for 40% of all CO2 emissions on the planet. Additionally, the sector seems to emit more CO2 emissions than ever, leading to record-high CO2 emissions for the construction industry (United Nations, 2020).

Since the product will be used as a rail for underfloor heating, and it will be installed permanently, it is recommended that it is made from materials that can store carbon. Carbon storage in buildings can largely contribute to reducing carbon emissions (Pittau et al., 2018).

Bio-based materials are made from biomass products. These materials can store carbon due to the fact that for example forests, kelp beds and other forms of plant life absorb carbon dioxide from the air as they grow and bind it into biomass (Myles, 2020) (Figure 7.3.3.1).

Water resistance

In addition to all the criteria above, when using the packaging as a rails to install underfloor heating, it is required to be water resistant so that once the concrete is poured over the rails, the pipe does not get detached from the insulation layer. Hence the decision to not use a pulp-based packaging because of its low resistance against moisture. Nevertheless, waterproof paper exists. However, due to the fact that the coating material is typically made from synthetic materials (such as HDPE) it does not match the requirements for a bio-based material (Fuller, 2023). In addition to this, pulp-based packaging with coatings would not result in completely waterproof paper (FedEx, n.d.).

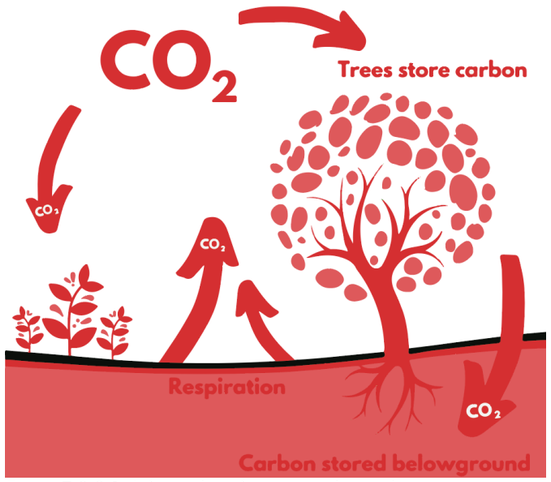


Figure 7.3.3.1: Infographic of storing carbon in biomass (Department of Environmental Protection, 2018).

Based on the arguments mentioned above, the material for the packaging has to be selected on either biobased plastics or wood.

Biobased plastics require a mould to be produced in the preferred shape, whereas wood does not. As a mould requires investments and investments are seen as a challenge for the implementation of sustainable packaging (as mentioned in Chapter 3.1 and 4.1), wood is selected out of the two as type of material for the packaging.

Type of wood

To determine the type of wood used for the packaging, a literature analysis will be performed based on properties like: weight, strength and price of the material. Most commonly used types of wooden sheets are plywood and MDF sheets (Bouwsite, 2023).

MDF

MDF (Medium-Density Fiberboard) is among the small group of construction materials that have a positive impact on the environment. The production of MDF helps reduce CO2 emissions because the trees used absorb CO2 from the atmosphere during their growth.

MDF production generally occur near forests, eliminating the need for long-distance transportation of raw materials and further reducing CO2 emissions. The wood used for MDF production comes from forests with ecologically responsible forest management and is certified with FSC and PEFC labels.

MDF is manufactured with a relatively small amount of urea-formaldehyde adhesive (synthetic resin glue), around 10%. However, this glue is environmentally taxing as it is derived from petroleum (AllesoverMDF, n.d.).

Plywood

Plywood is a sheet material made up of various thin layers of wood veneer bonded together. Due to this structure, plywood is very strong and durable, providing good resistance to warping and deformation.

MDF vs Plywood

When comparing the two materials together, the following can be said:

Strength and Durability: Plywood is typically stronger and more durable than MDF due to its layered construction. It exhibits better resistance to bending, warping, and splitting. In contrast, MDF is less robust and more prone to damage, especially when exposed to moisture.

Weight: In general, MDF is heavier than plywood because of its higher density.

Cost: Typically, MDF is more affordable than plywood because it is a manufactured material and involves less labor in its production.

Due to the fact that one of the three main purposes of packaging is providing protection during transport, strength and durability are considered as the most important criteria when choosing the material. Additionally, because plywood is lighter than MDF due to its lower density, plywood is preferred over MDF to be used in transport. More weight in transport leads to higher CO2 emissions (Delft University of Technology, 2024).

Although costs of MDF are slightly lower than for plywood, the decision has been made to use plywood as the type of material for the packaging due its superior strength, durability and weight properties over the others.

Types of plywood

There are three main types of plywood available: Beech, birch and poplar. Poplar is most affordable and the lightest of the three, making it more appealing to use for a packaging, due to decreased CO2 emissions because of lower transport weights (pontmeyer, 2024). In addition to this, as price of sustainable packaging is seen as a challenge for implementation of the packaging (as mentioned in Chapter 4.1), it is important to keep the price as low as possible to increase chances of implementation. For this reason, poplar plywood has been selected as material for this packaging.

Plywood

In addition to the arguments mentioned before plywood offers the following additional advantages:

- Poplar is the most produced type of wood in France (Noriega, 2020). Producing the packaging from locally sourced poplar plywood could lead to less CO2 emissions during transport in production over more exotic wood types (Figure 7.3.3.2).
- Furthermore, poplar is currently used commonly as various applications like light weight packaging, pallets and as a construction material in the industry (The Exploded View, 2021).
- Poplar has a short rotation cycle of 15-18 years, providing a quick wood resource compared to other species (Noriega, 2020).

For all the reasons mentioned above, it can be concluded that poplar plywood is the most suitable material to make the packaging from. In Figure 7.3.3.3, the summarized material selection process can be seen.

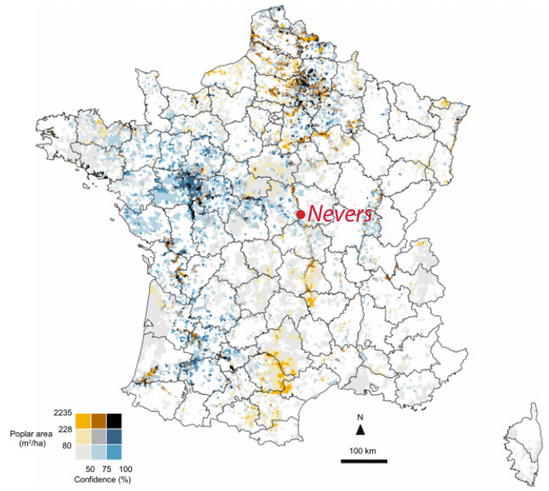


Figure 7.3.3.2: Poplar forestations in France.

Material selection process

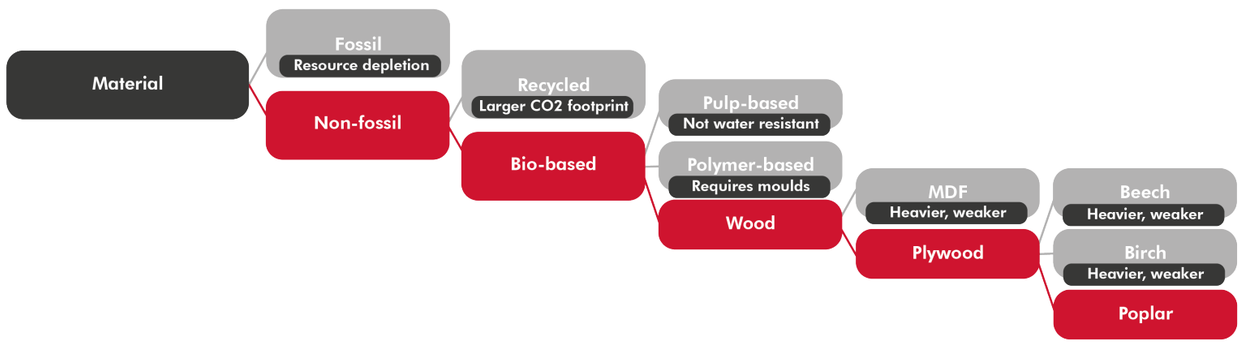


Figure 7.3.3.3: Material selection process - the chosen direction is shown in red, other validated directions are shown in grey.

7.3.4 Carbon sequestation

A tree absorbs approximately 25kg of CO2 per year. The chemical composition of wood doesn't vary much from tree to tree and therefore carbon sequestation can be seen as equal for all types of trees. Cellulose (C6H10O5) is the main component of the cell walls of trees. Cellulose is a chain of glucose molecules that the tree produces through photosynthesis. It makes up 50-80% of wood. By producing cellulose, CO2 from the atmosphere gets absorbed. Photosynthesis is the process of converting CO2 and H2O (water) into glucose and oxygen by means of the sun's energy. In Figure 7.3.4.3 can be seen step by step how carbon sequestation works (EcoTree, n.d.).

The carbon storage capacity of a tree depends on its species due to the variety in mass. Per m3 less carbon can be stored in Poplar trees (density: 400kg/m3) as for Weymouth Pine (density 1000kg/m3 and Ebony (density: 1400kg/m3) (EcoTree, n.d.).

In addition to wood, biobased plastics can also be used to store carbon due to the fact that these plastics are made from renewable materials. As of currently, bioplastics are mainly used in the packaging industry (Figure 7.3.4.2). In Figure 7.3.4.1 can be seen which bioplastics are mostly produced (European Bioplastics, 2023).

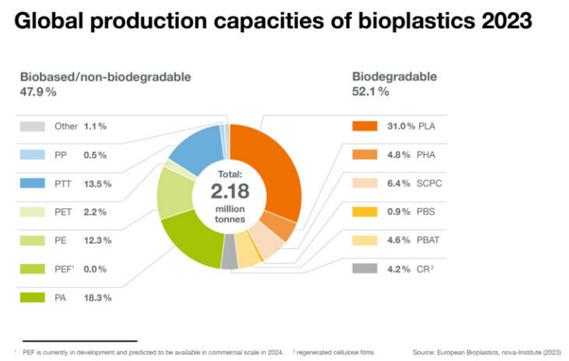


Figure 7.3.4.1: Global production capacities of bioplastics 2023 (European Bioplastics, 2023).

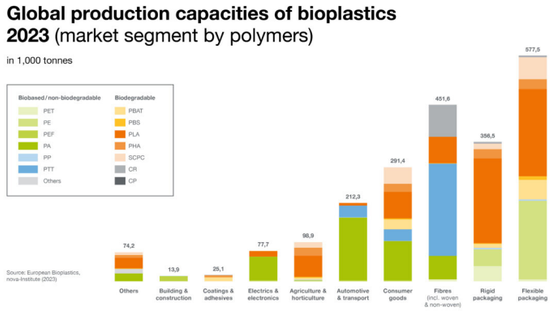


Figure 7.3.4.2: Global production capacities of bioplastics 2023 (European Bioplastics, 2023).

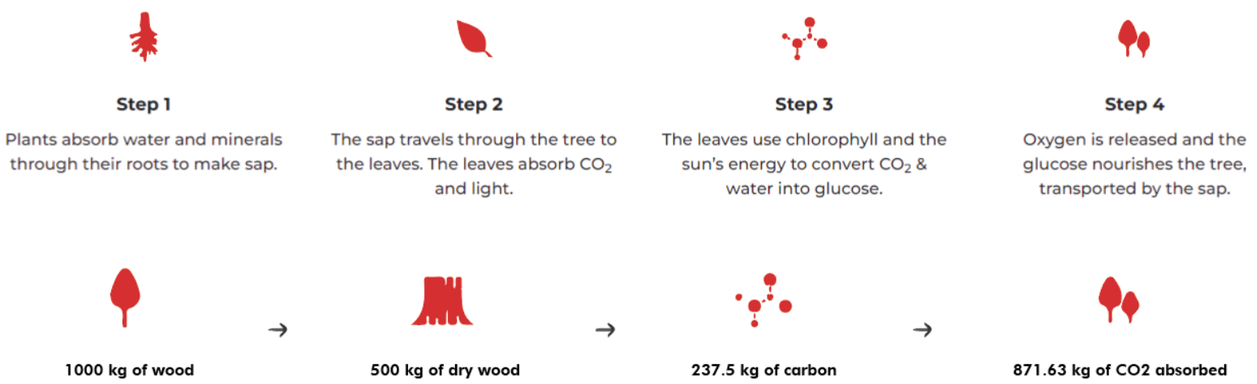


Figure 7.3.4.3: Carbon storage in wood.

Although bio-plastics and wood types can store carbon over time, it depends per material how much carbon can be stored. In Table 7.3.4.4 can be seen what the carbon content per material is for commonly used bioplastics on the current market (European Bioplastics, 2023).

From the Figure can be concluded that all biobased plastics have higher carbon contents per kg of material than for (poplar) wood. As discussed previously (Chapter 7.3.3) it is recommended to produce the product from poplar wood due to no requirements on investments because of the production of a mould (which is needed to produce parts with bioplastics). In addition to this, poplar is comparable when it comes to pricing per kg (2.7$/kg) to some bioplastics, however no investments are needed to work with the material, therefore making it more appealing to work with (Sóti et al., 2018). Nevertheless, if (in the long term) investments are willing to be made it would be adviced to produce packaging from biobased plastics with high carbon contents if the packaging is used as a product. Carbon can only be stored in a material if the product is used for long term. Incinerating the product will result in the carbon that was sequestered in the product being released back into the atmosphere (Myles, 2020).

Material	Carbon Content (%)	Costs ($/kg)	Costs ($/kg) fossil alternative
Bio-PET	62.39	2.4-3.2	0.4-2.2
Bio-PA	59.04	-	1-3
PLA	53.67	4-20	n/a
Bio-PE	82.4	1.3-1.8	1-1.2
Bio-PP	81.97	~20	1-16
Pine sawdust	46.12	-	n/a
Poplar	46.45	2.7	n/a

Table 7.3.4.4: Carbon content, costs and costs fossil alternative per material (Rahman & Bhoi, 2021) (Zhou et al., 2021) (Sóti et al., 2018).

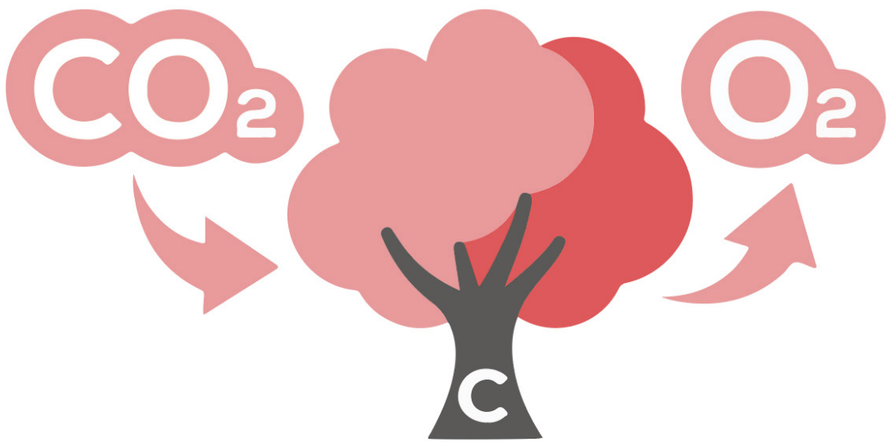


Figure 7.3.4.5: Carbon sequestation in biomass.

7.4 Realization

7.4.1 Corner connection methods

In order to determine on the type of connection that should be used for the product, multiple kinds of connections have been assessed. The five following connections have been evaluated for the corner connetions of the box:

- Finger connection (Figure 7.4.1.1)

- Press-fit connection (Figure 7.4.1.2)

- Chamfer connection (Figure 7.4.1.3)

- Flexure connection (Figure 7.4.1.4)

- Snap-fit connection (Figure 7.4.1.5)

Other type of connections have been taken into account for the connections of the rails parts on the same plane of the product packaging because these need a different type of connection. These connections will be discussed in Chapter 7.4.2.

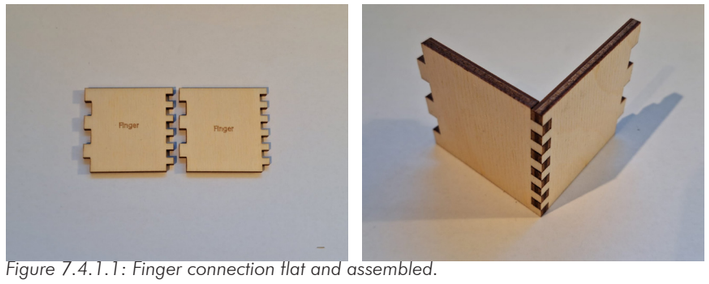


Figure 7.4.1.1: Finger connection flat and assembled.

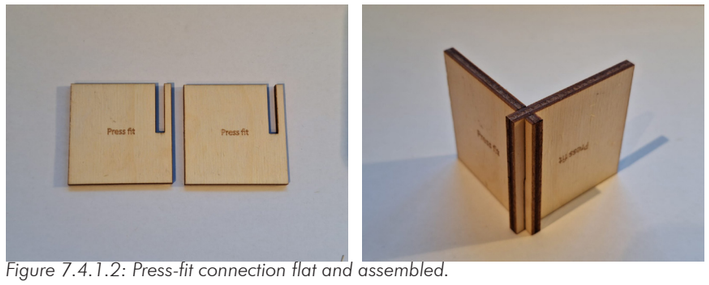


Figure 7.4.1.2: Press-fit connection flat and assembled.

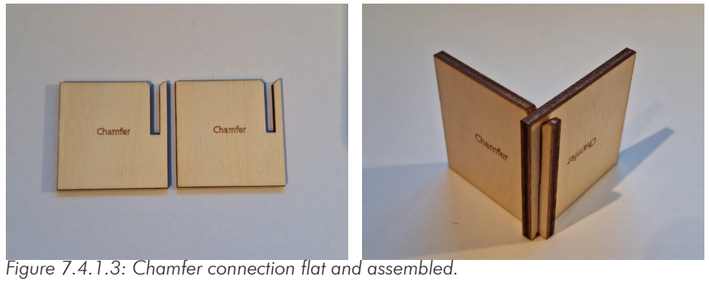


Figure 7.4.1.3: Chamfer connection flat and assembled.

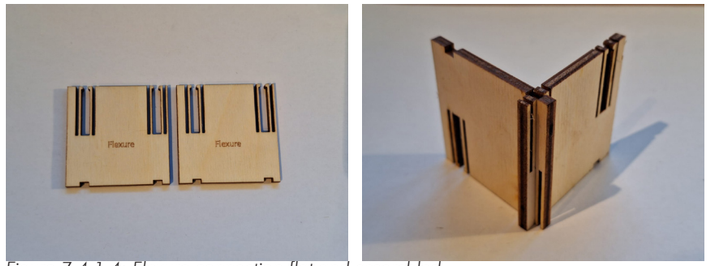


Figure 7.4.1.4: Flexure connection flat and assembled.

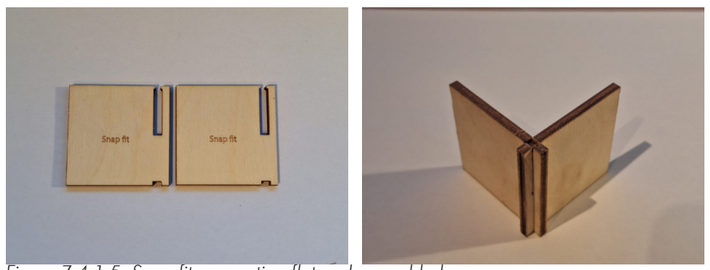


Figure 7.4.1.5: Snap fit connection flat and assembled.

The connection types mentioned above have been rated on the following criteria. The importance of criteria is ranked from high to low:

- Deassembly-time and effort. According to installers (n=5), time of installation is the most important factor when selecting products from the wholesaler (interview template can be seen in Appendix 9.18). Especially in Eastern Europe it is key that a product should be quick to install since labor is expensive (personal communication, 2024). Since HFC sells most products in Eastern Europe, this criteria is seen as the most important one.

- Material efficiency. Since the packaging is prefered to be as light as possible due to less CO2 emissions during transport. The material usage should be as efficient as possible.

- Connector strength. A strong connection is required to prevent the connection from breaking during transport.

- Vibration resistance. The connection should be resistant against vibrations due to the product being used in transport. Shock and vibration dynamics possess energy that has the potential to cause both physical and cosmetic damage to packaged products (Lansmont, 2023).

- Sealing. During transport and when stored in the warehouses, the product should be protected from the elements. Most protection will be offered if the packaging completely seales the product.

- Required space (for transport). The packaging should not take more space during transport and storage when needed. Due to the shape of some connections, in total more space is needed for this type. The smaller the connection, the better.

The connections were tested by applying impact force and shaking to the connections to simulate movements that are common in transportation. Based on the criteria, the following conclusions were made Table 7.4.1.6.

Criteria	Finger	Press-fit	Chamfer	Flexure	Snap-fit
Deassembly-time and effort	3 Easy and quick	2 Easy	2 Easy	1 Hard	1 Hard
Material efficiency	3 No material wasted	2 Some material wasted	2 Some material wasted	1 Lots of material wasted. Also material cut out for connection	2 Some material wasted
Connector strength	2 Based on clamping	3 Strong connection	3 Strong connection	1 Flimsy connection. Thin walls	3 Strong connection
Vibration resistance	2 Friction fit	2 Friction fit	2 Friction fit	3 Clicks into place, hard to get out	3 Clicks into place, hard to get out
Sealing	3 No gaps	3 No gaps	3 No gaps	2 Some gaps	3 No gaps
Required space (for transport)	3 No extra space needed for connection	2 Some extra space is lost due to overlap	2 Some extra space is lost due to overlap	2 Some extra space is lost due to overlap	2 Some extra space is lost due to overlap
Total	16	14	14	10	14

Table 7.4.1.6: Corner selection comparison.

The finger connection method offers the best score overall. Hence the decision to move forward with this connection system.

The finger connection offers the packaging to be easily and quickly deassembled, while simultaniously wasting no material and space during transport. The connection offers a packaging without any gaps which expose the product to the elements. While validating the different connection systems, it was found that the finger connection offers great connection strength and vibration resistance which is required during transportation. Another big advantage of the connection is that it is able to strenghten the complete packaging because of the interlocking parts reinforcing each other.

7.4.2 Flat surface connection methods

In order to determine which type of connection is preferred to assemble the rails on the same plane, two options have been validated.

The following criteria were considered to decide on the best connection method in the same plane:

- *Ease of use*
- *Strength*
- *Able to resist vibrations*
- *Assembly effort*

Finger method

First, the finger attachment method has been tested. When joining two parts together, tabs and slots are often placed next to one another to create “fingers” that hold the parts together. This method relies on the principle of wedging. It is one of the most common, simplest ways of joining two or more parts. The more tabs and slots are used, the stronger the joint (Sendcutsend, 2023). This option offers the advantage of the rails being to able to be attached to another rails in a angle of 90 degrees. This would not be possible for the breakable method due to the lack of fingers when broken. Last but not least, it is important to have the right tolerances to guarantee the packaging being able to resist vibration and impact during transport. More information on tolerances will be explained later in this Chapter.

Breakable method

The second method that has been validated is based on breaking the packaging. When laser cutting the correct shapes for the packaging, lines can be cut over the vertical plane of the rails. Once it arrives at the customer, he can break the packaging into single rails parts. This connection offers a stronger packaging overall which is more resistant against impact and vibrations. In addition to increased strength, this option offers for easier assembly and thus lower costs per product (Figure 7.4.2.2).

Other methods

In addition to these two systems, there are other possibilities to attach multiple beams to each other on the same plane. However, these systems require an additional plane in another direction to be assembled. This complicates assembly unneccesarily leading to extended assembly times, which will eventually end up in increased costs per product.

Selection same plane connection

The breakable method has been chosen for the same plane connection. This is due to the factor to have a strong connection that is still easy to use. The main disadvantage is that the breakable method lacks the ability to have 90 degree attachment for another rails. This feature allows the rails to be connected to the whole rails system which will decrease the chance of accidently changing the position of the rails. To compensate for this disadvantage, the attachment method (which secures the rails to the insulation layer) has to guarantee a strong connection so that the rails can still be laid in a 90 degree angle if needed.

Connection type	Finger	Breakable
Ease of use	3 Offers 90 degree angle attachment for another rails	2 Easy to break from other rails
Strength	2 Relies on tolerances of laser cutter for strength of connection	3
Vibration resistance	2 It is made out of multiple parts, tolerances play a big role in vibration resistance	3 It is made out of 1 part
Assembly effort	1 Takes a lot of time to assemble	3 Very quick and easy assembly
Total	8	11

Table 7.4.2.1: Connection type comparison.

Figure 7.4.2.2: Physical prototypes.

Because laser cutting is a highly precise manufacturing method, accurate sizing is crucial when avoiding the use of glue to maintain the packaging's integrity during transport. Simultaneously, it should facilitate easy disassembly upon arrival at the building site. For both connection methods must be noted that the size of the finger and cuts have an influence on the strength of the material.

Sizing cutouts

The product should be strong enough to withstand impact forces during transportation, but should be easily broken into multiple rails parts when arrived at location of the end-user. Multiple tests were performed to find the optimal sizes for the cuts while enabling the packaging to be broken into rails. All images of the tests can be seen in Appendix 9.14.

It can be concluded that the packaging with cutouts of 30mm alternated with 10mm of no cutouts, gave the best results for 5mm thick poplar. Breaking of this part gave a clean edge on the side of the rails on the desired places.

Sizing rails inserts

While prototyping it was found that for the rails inserts an oversize of 0.3mm was required to offer a strong connection that stays in place permanently. Bigger than 0.3mm would make the rails hard to insert, complicating the assembly process. Smaller than 0.3mm resulted in the rails being able to pull out (Figure 7.4.2.3).

Sizing fingers

Sizing of the fingers does have an influence on the tightness of the connection. While prototyping it was found that an oversize of 0.08mm offered a strong connection which was easy to disassemble, while staying in place.

It's important to highlight that the precision can vary among laser cutting machines. The tests conducted were on a laser machine with an accuracy of 0.01mm. Although these tolerances could provide a starting point, more testing is required when implementing the packaging. These tests have been performed with 5mm thick poplar plywood.

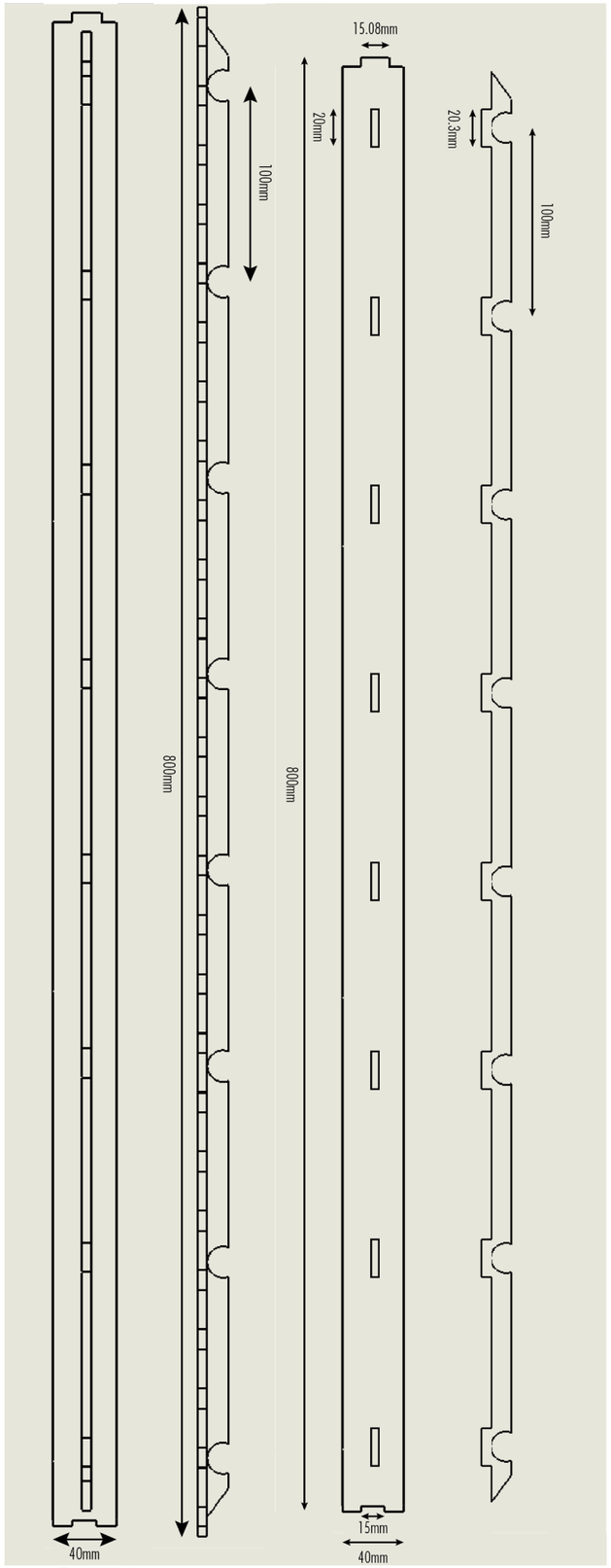


Figure 7.4.2.3: Sizing of the concept rails elements.

7.4.3 Cut-outs

Concrete will be poured over the underfloor heating rails when the pipe is installed. The current procedure is as follows:

1. The rails will be laid down in a desired layout
2. The rails will be attached to the insulation layer
3. The pipe will be attached to the rails
4. The underfloor heating system will be filled with water (to prevent the pipe from flowing during concrete pouring)
5. The concrete is poured (typically 50mm) (Aalberts HFC, 2024)

Prototyping and testing

Tests with prototypes have been conducted to determine the optimal depth of rail element cutouts ensuring a secure rail-pipe connection. The different depths can be seen in Figure 7.4.3.1. For these tests, pieces of pipes have been have been inserted in the cutouts. The pipes are taped off on each ends in order to make sure the connection between the rails and the pipe would also be sufficient when the installer forgot to fill the pipe with water before pouring concrete, serving as an additional safety measure. Next, the bucket with prototypes is filled with water to examine the minimum depth of the cut-out. Water is used as a transparant fluid to examine the floating effect of the pipe. The fluid can be compared to concrete as water is used to produce concrete (ratio water to cement, 0.4 to 0.6) (Concrete Supply Co., 2019). Additionally, this test was conducted to confirm the ease of inserting the pipe into the cutouts. The test was performed for 24 hours (curing time for concrete) (Palmer, 2023). In Appendix 9.15, the physical prototype can be seen.

Conclusion

Figure 7.4.3.1 illustrates that cut-outs of 0 and 1 mm failed the test, causing the pipe to float when water was poured. The 2 and 3 mm cutouts did stay in place during the complete test. The 3 mm cutout gave a rewarding click when inserting the pipe, the 2 mm cutout did not. For both cutouts the pipe could be inserted by hand. The 4 and 5 mm cutouts were hard to place as it could not be done by hand (without any tools). Therefore has been decided that 3 mm inserts provide the optimum depth for a strong connection between the pipe and the rails. In addition to this, the rewarding click when inserting the pipe can be seen as valuable to the user as it confirms a tight connection.

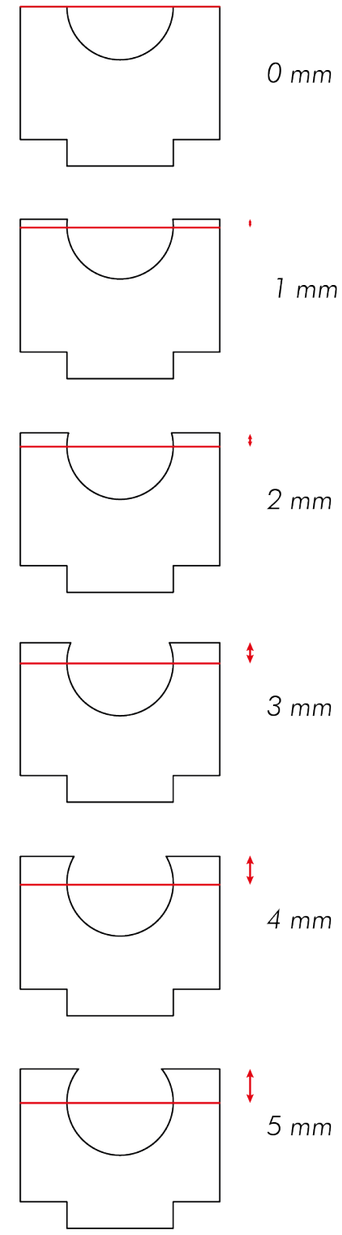


Figure 7.4.3.1: Different depths for pipe attachment.

7.4.4 Attachment methods

To determine the type of attachment method, there has been looked at multiple ways of connecting the rails to the insulation layer. The attachment methods can be divided into two categories: adhesive and mechanical connection.

Considering the attachment system the following requirements were created to ensure a proper connection between the rails and the insulation layer:

- The attachment system should not increase the height of the rails, as an increase in height increases the amount of concrete that should be poured (Figure 7.4.4.2).
- The maximum depth of the attachment system in the insulation layer should be 60mm (Vloerverwarming-Direct, 2020)

While testing rails prototypes with adhesive it was concluded that the attachment method of this kind cannot ensure prevention of undesired movement due to the limitations of adhesive tape. Furthermore, when dealing with a (slightly) uneven insulation layer, a mechanical connection adheres more effectively than an adhesive-based connection. Therefore has been decided to use a mechanical nail connection to attach the rails to the insulation layer (Figure 7.4.4.3). The attachment method is based on the current tacker system to fixate pipes in the insulation layer (Figure 7.4.4.1)

Figure 7.4.4.1: Tackers (Vloerverwarming-Direct, 2020).

Figure 7.4.4.2: Current rails system.

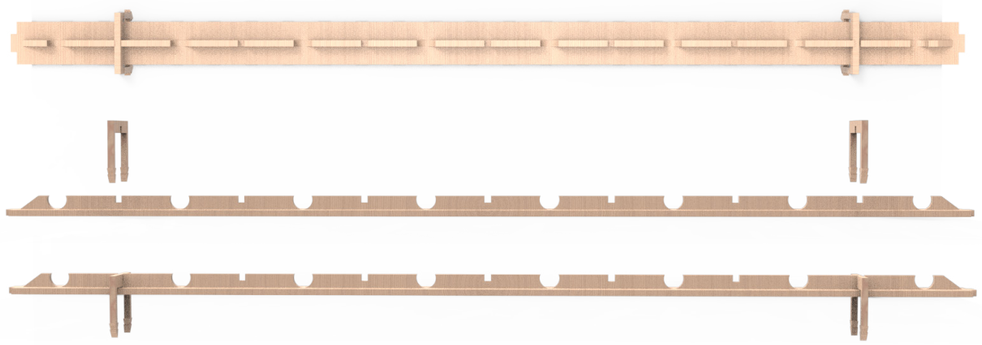


Figure 7.4.4.3: Attachment system.

7.5 Packaging as a product: Underfloor heating pipe

7.5.1 Handling

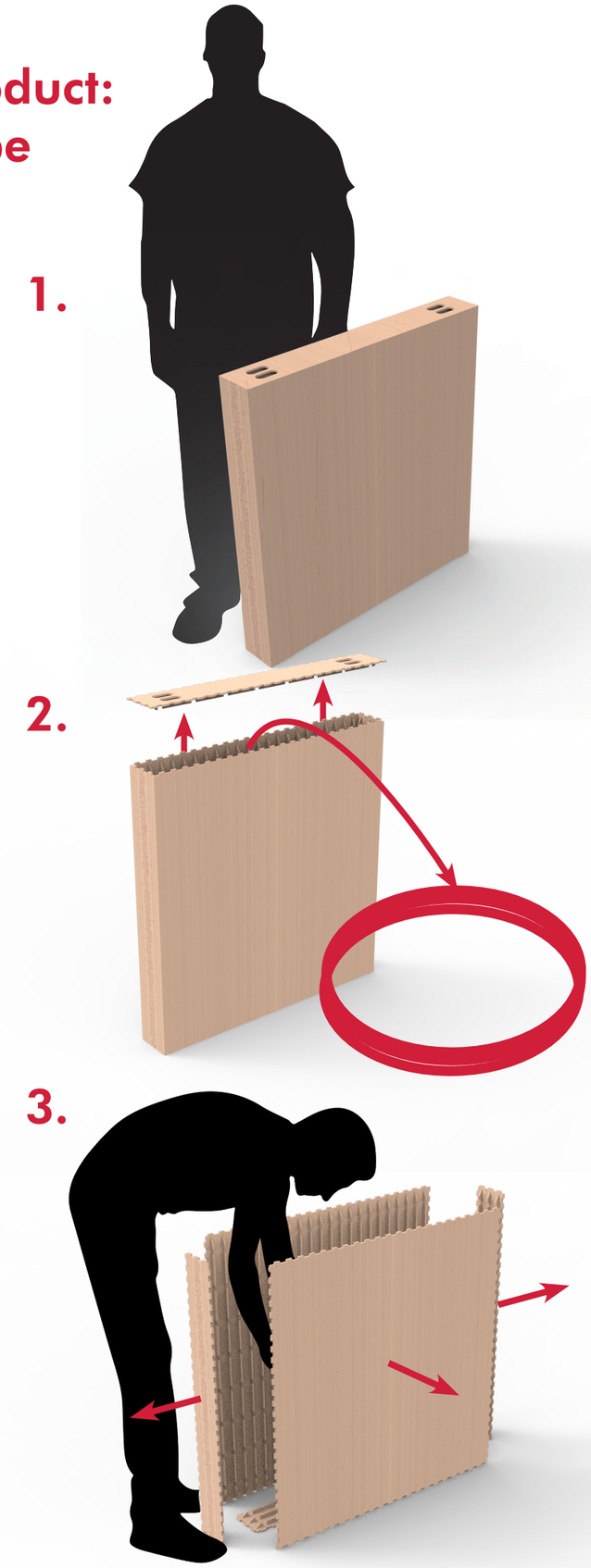
The final concept developed in this thesis is the concept of packaging as a product for underfloor heating. The concept saves packaging of both the underfloor heating pipe and the rails which is used to attach the pipe to the floor. With this concept, packaging receives an additional function, making it more than a single-use product. The packaging will be responsible to protecting the product (which is currently the main function of packaging), as well as installing the product. Therefore, the implementation of packaging as a product gives packaging a completely new meaning.

Packaging as a product for underfloor heating works as follows:

1. The installer (user) receives the packaging with the underfloor heating pipe.

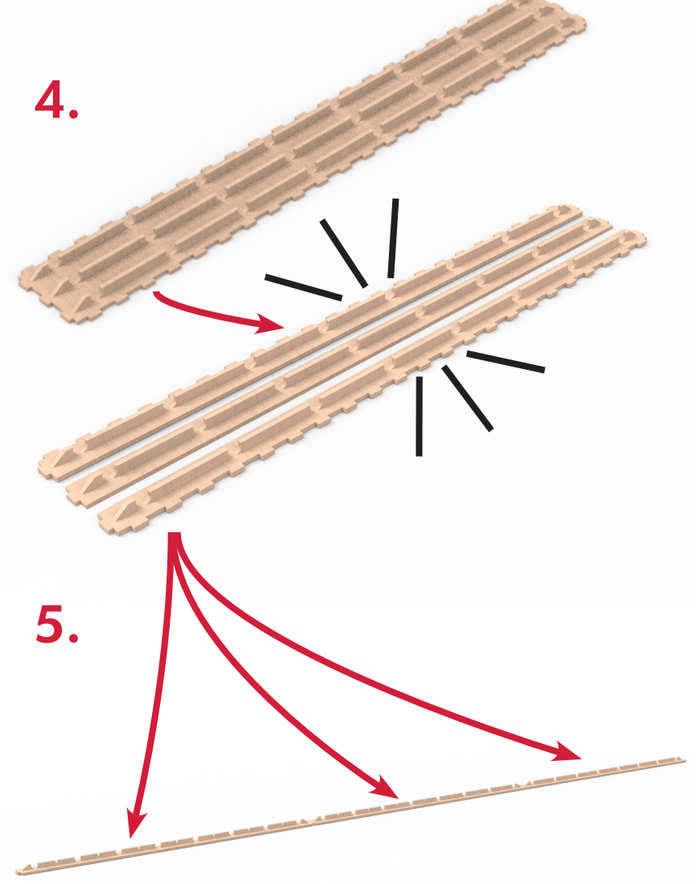
2. When arrived at the building site. The packaging can be opened by pulling the top part of the packaging out and remove the PEX pipe from the packaging.

3. Then, the installer can pull on the sides of the packaging to deassemble it.



4. The installer breaks the sides into rails elements. Designated cutouts in the packaging help to break the element in a clean cut.

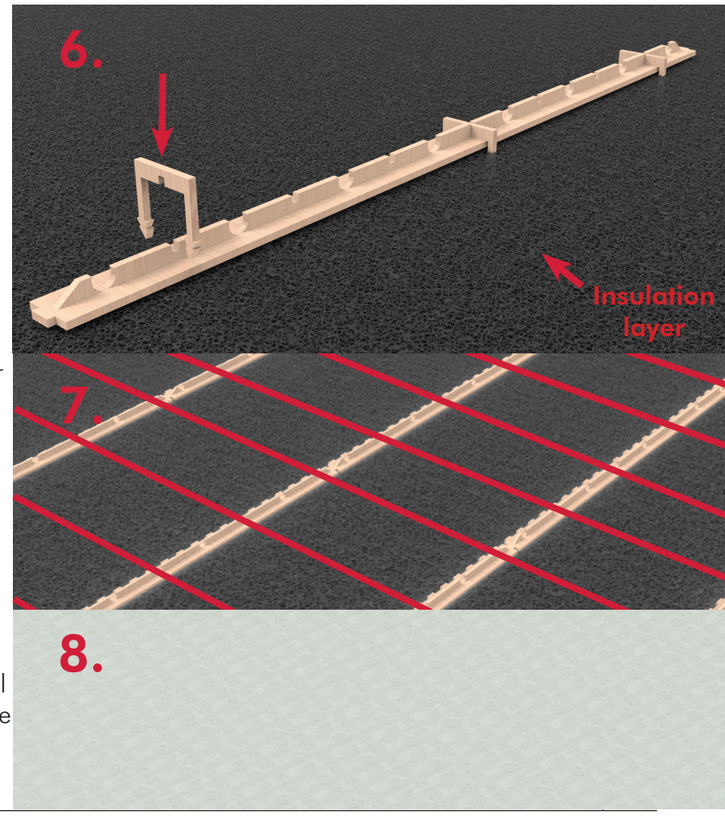
5. The rails elements can be laid in any preferred layout on the floor. The shape of the rails allows for easy interconnecting parts, making assembly more convenient. 52 rails element are delivered with every 100m of heating pipe, allowing for all possible layouts (like explained in Chapter 7.1).



6. Supplied nails can be used to attach the rails to the insulation layer.

7. The installer can fixate the underfloor heating pipe.

8. After the installation of the rails and underfloor heating pipe, concrete will be poured over it (as is currently done to install heated flooring).



7.5.2 Time-efficiency

During the first validation of the concept packaging as a product for underfloor heating pipe, it became clear that time is a very important factor when it comes to selecting a product for purchase. The idea of inserting the attachments for the rails did not sound appealing to 4 out of 5 interviewed installers (installer, 2024). This led to an interation of the concept, focussing on a quicker installation time of the rail elements (Figure 7.5.2.1).

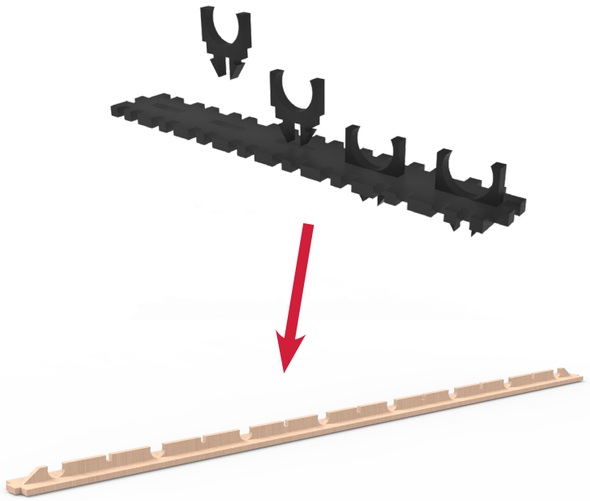


Figure 7.5.2.1: First iteration of the concept.

Packaging as a product

During a second validation round, installers (n=4) were interviewed while using the product. Installers were asked to handle the product like described in Chapter 7.5.1. During the interaction, questions were asked with the goal to find out what installers think of the concept of packaging as a product for underfloor heating and packaging as a concept in general. The interview procedure and template can be found in Appendix 9.23.

In general, most interviewees (3/4) were pleased with the concept of having products packaged in the same box. One of four installers did not see the problem of an additional packaging for the rails elements. This person stated that "the packaging probably gets recycled anyway" (Installer, 2024).

"It is nice that the product is the packaging. This is very convenient for me and saves time in unboxing" (Installer, 2024).

"It is convenient that I do not have to deal with the packaging anymore after installation. Usually I leave the packaging at the build site since it costs me money and effort to dispose it." (Installer, 2024)

Opening the packaging

When testing the packaging, two of the interviewees had trouble opening the packaging. According to the installers, this was because of a the handle being to small, making it difficult to open (installer, 2024) (Figure 7.5.2.2, Figure 7.5.2.3).

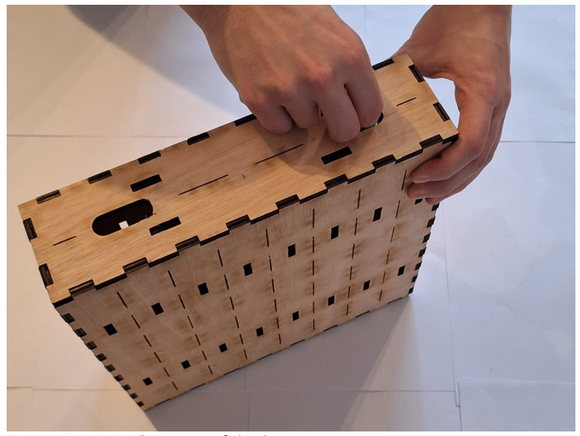


Figure 7.5.2.2: Opening of the box.

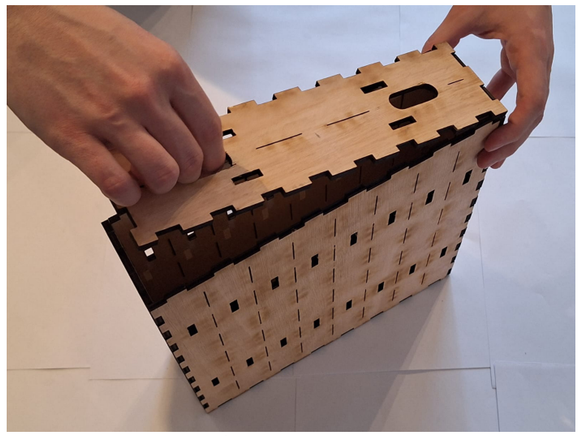


Figure 7.5.2.3: Opening of the box.

All other interviewed installers did not have troubles in opening the packaging. Nevertheless, 2 installers were wondering whether the packaging was strong enough and wouldn't fall apart during transport (installer, 2024).

Breaking the rails

Breaking the packaging into rails elements was tested with a different (scaled) prototype. During the interviews, all installers were able to break the packaging in multiple rails elements. It was found that it provided a quick way of disassembling the packaging into rails elements (Installer, 2024) (Figure 7.5.2.4).

"It is interesting to see that in this way, no packaging waste is created." (installer, 2024)

Fixating the rails

In general all installers found the concept of fixing the rails to the insulation layer easy and quick to do. Nevertheless was found by two installers that they would prefer to fixate the rails with a type of tacker nail gun since it wouldn't require them to bend as much as with these rails elements.

In addition to this, it was recommended to have the rails elements combined with nails:

"Rails systems are often used together with a type of nail for fixation in corners. These sometimes tend to come loose" (installer, 2024)

Installing underfloor heating pipe

As for the installation of the underfloor heating pipe in the rails elements, 3 out of 4 installers found the connection work very comparable to installing a rails which is used currently (installer, 2024) (Figure 7.5.2.5).

One of the installers mentioned that he currently used a type of plate system to install underfloor heating, called Fermacell, due to its quick installation time compared to a tacker or rails system.

2 out of 4 installers found the "click" handy.

"The pipe connects well to the rails, the click confirms it" (installer 2024).

In addition to all comments above, it was

Figure 7.5.2.4: Breaking into rails element.

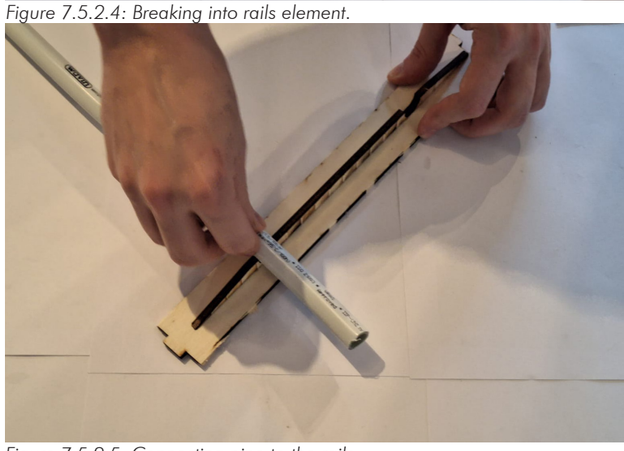


Figure 7.5.2.5: Connecting pipe to the rails.

recommended by two installers to provide instructions on dismantling the packaging and fixating it to the floor, since it was a type of action which they were not familiar with (installer, 2024).

Conclusion

In general it can be said that installers are interested in the concept. The idea of having no waste after installation sounded appealing to this group. Nevertheless, more research is recommended on the technical feasibility of the product. During the validation with installers, topics considering the ergonomics of the concept need to be improved showed potential for improvements. In addition to this, since the interviewed group of (n=4) installers was small, it is recommended to perform research with more installers.

7.5.3 Configurability

The criteria was set that the rails should allow for maximum freedom in layouts. Installers should be able to place the underfloor heating rails wherever preferred. The product should have as much freedom in configurability as the current rails.

Configurability of the concept is comparable to the current rails for underfloor heating pipes. The packaging as a product rails is laid down and attached to the insulation layer, offering just as much freedom for configurations as the current rails used. Tests have been conducted with a prototype to validate the configurability of the concept (Appendix 9.17). It was found that configurability of the concept is comparable to current rails elements. In Figure 7.5.3.1, a schematic can be found of the possible layouts based on 52 rails elements per packaging. Currently, the single serpentine, double serpentine and concentric layout are most used layouts for underfloor heating applications (Underfloorparts, 2022).

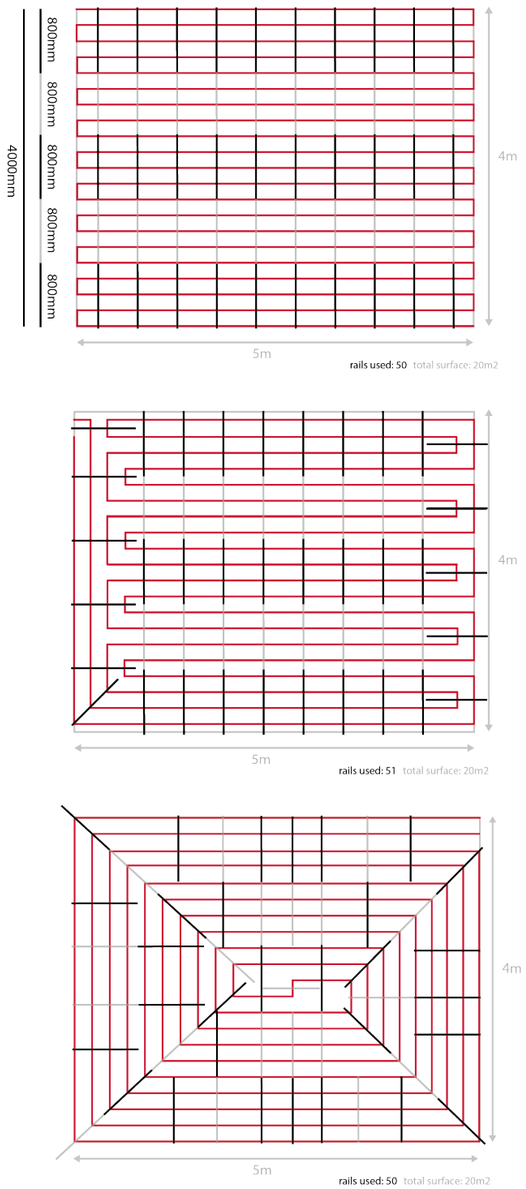


Figure 7.5.3.1: Single serpentine, double serpentine and concentric underfloor heating layouts.

7.5.4 Impact resistance

To ensure the packaging protects its product effectively, multiple tests were performed with (physical scaled) model and simulations.

Compression requirements

Initially, it was necessary to verify the minimum requirements for the compression force of the packaging. To achieve this, a physical test was conducted using a cardboard box (300x300x80mm). The thickness of this type of cardboard is comparable to the current packaging of underfloor heating pipe (4.5mm). The objective of the test was to determine the maximum weight that the corrugated box could endure before collapsing. The test determined that the box could withstand a maximum weight of 81 kg before collapsing. Therefore, the new packaging should withstand a weight of minimal 81kg.

Compression physical (scaled) tests

A test was conducted using a scaled prototype of the packaging as a product concept. The dimensions of the prototyped box were 300x300x80mm. The test revealed that the box could withstand a force of 81kg (Figure 7.5.4.1) (Appendix 9.19).

Impact requirements

In addition to checking the compression requirements, the maximum impact that a corrugated box has been tested. For this test, a sheet of corrugated cardboard of 300x300mm has been used. To simulate impact during transport, different weights have been dropped from a height of 300mm (Appendix 9.20). It could be concluded that the maximum impact that corrugated cardboard was 3.5kg on a distance of 300mm before breaking.

Impact physical (scaled) tests

A trial was performed using a scaled-down version of the packaging as part of the product concept. Dimensions of the part were 300x300mm. The test resulted in breaking the plywood (5mm) sheet. This outcome led to the selection of a thicker and more robust plywood, measuring 9mm. Most common thicknesses of plywood are 5, 9, 12 15 and 18mm (bauhaus, 2024). For this reason has been decided to step up from 5 to 9mm plywood. The test was conducted again using 9mm thick plywood, enabling it to withstand the impact. Therefore it has been decided to make the final packaging of 9mm plywood (Figure 7.5.4.2).

Figure 7.5.4.1: Compression physical (scaled) tests.

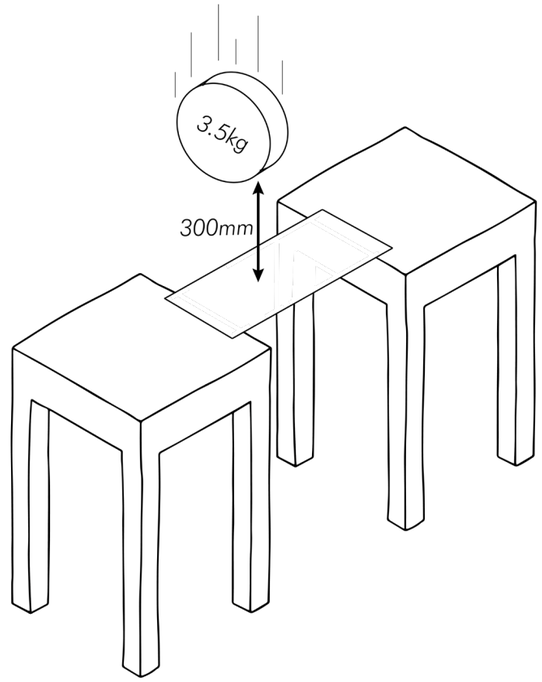


Figure 7.5.4.2: Impact physical (scaled) tests.

In addition to physical tests, simulations were performed as well to validate the strength of the packaging and the physical tests.

For each loading test, SolidWorks finite element analysis (FEA) was employed, and balsa was chosen as the material. Balsa was selected because Poplar was not accessible in the software. Balsa possesses properties similar to poplar wood, making it an equivalent choice (Sun et al., 2021).

Compression tests
Two compression tests were executed on the packaging. In these cases a force of 1000N was applied to the product. A force of 1000N is comparable to 100kg.

Test 1 - Compression test top
In the first test a force of 1000N was applied to the top of the packaging. The bottom of the packaging was fixed to calculate the deflection and whether the product would break under load (Figure 7.5.4.3).

Test 2- Compression test side
In the second test a force of 1000N was applied to the side of the packaging. The opposite side was fixed. Again, the simulation was performed to validate whether the product wouldn't break (Figure 7.5.4.4).

Test 3 - Drop test
For the third test a drop test was simulated. In this simulation, the packaging was dropped from 3m high (the max height of a trailer) (Tirport, 2023). (Figure 7.5.4.5).

Conclusion simulations
During the simulations, a maximum yield stress of 4.6Mpa was reached. Assuming a maximum Yield strength of 34.4 Mpa (Ansys, 2023), it can be concluded that the material wouldn't break. The maximum deflection is 2.9mm (test 2). Detailed outcomes of the simulation can be found in Appendix 9.22.

Rails element test
Besides calculations and physical tests on the packaging, a test has been conducted to verify the product's strength when utilized as a rail element. During this test, an individual with additional weights totaling 100kg stood on the rails, simulating the presence of a (heavy) installer. The results of the tests indicated that the rails were sufficiently robust to withstand a load of 100kg (Figure 7.5.4.6) (Appendix 9.21).

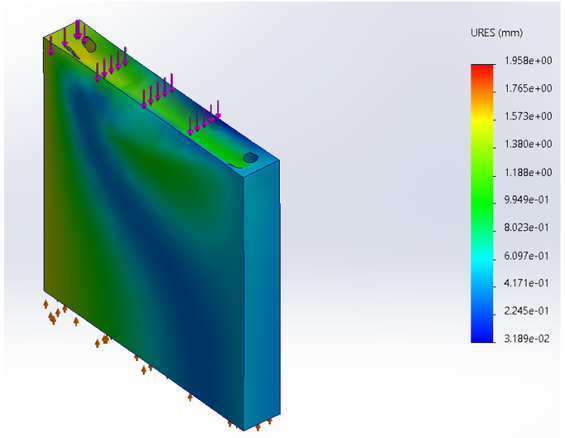


Figure 7.5.4.3: Compression simulation top.

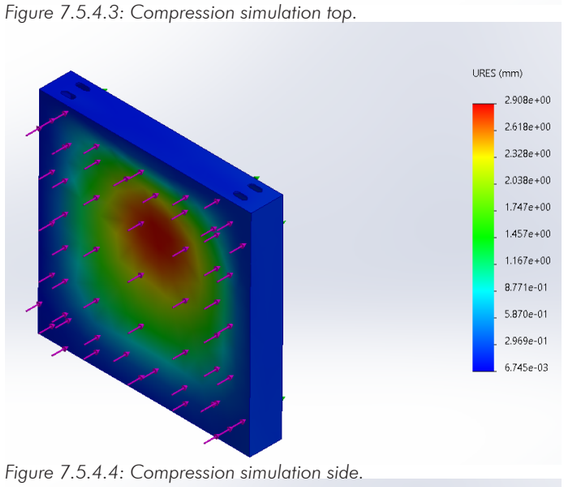


Figure 7.5.4.4: Compression simulation side.

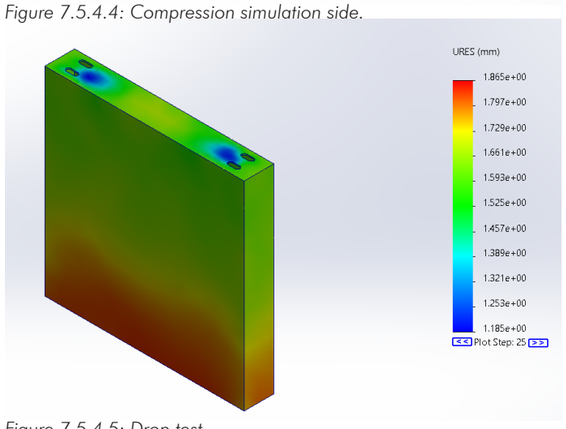


Figure 7.5.4.5: Drop test.

Figure 7.5.4.6: Physical rails element test.

7.5.5 Life cycle assessment

As mentioned earlier, the new packaging should have a lower environmental impact compared to the current packaging and product. In this Chapter a life cycle analysis comparison will be made from the current type of packaging to the concept of packaging as a product for the application of underfloor heating. Assumptions that were made for this analysis can be found in Appendix 9.16.

As can be seen in Figure 7.5.5.1, the carbon footprint (CO2 equiv. per product) is 4 times lower for the concept packaging as a product for underfloor heating than for the current product and packaging (Figure 7.5.5.2, Figure 7.5.5.3).

It's essential to point out that the most significant reduction in the carbon footprint occurs with the transition from polypropylene rails to wooden rails, decreasing from 18 kg CO2 equivalent per product to 5 kg CO2 equivalent per product.

Nevertheless, it is important to highlight that the implementation of this packaging ensures that no on-site "waste" is generated by the installer.

Preserving 3 kg of cardboard for each coil of PEX pipe results in a 10% reduction in CO2 equivalent per coil sold, along with the complete elimination of single-use packaging.

In total, utilizing packaging as a product for underfloor heating would result in a reduction of 74% in carbon footprint per product sold. This indicates significant potential for reducing the carbon footprint through the packaging as a product concept. Nevertheless, in the current product and packaging, PP rails represents 86% of total CO2 equiv., accounting for the largest part in the carbon footprint reduction.

Conclusion
In conclusion, packaging as a product for underfloor heating saves on CO2 equiv compared to the current packaging and rails, however the most significant reduction comes from changing the material from Polypropylene to wood.

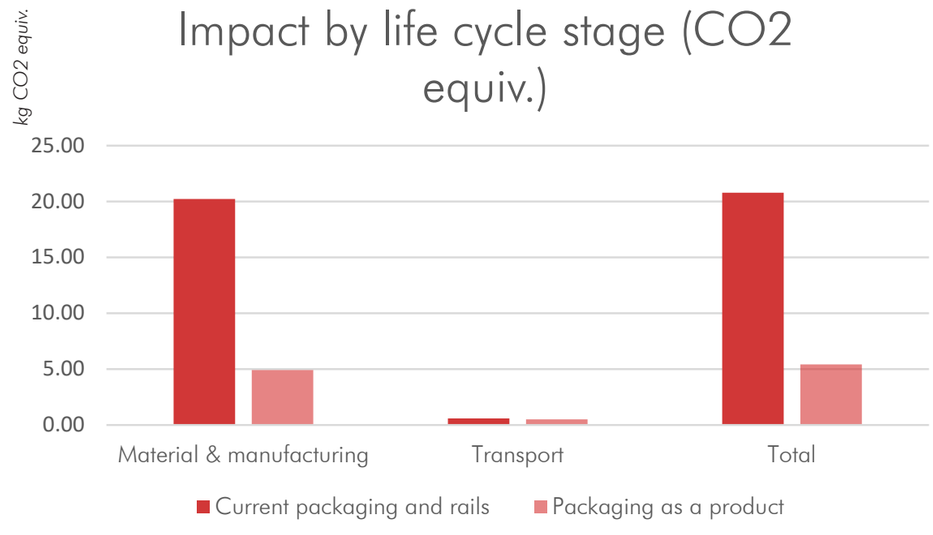


Figure 7.5.5.1: LCA comparison current packaging vs packaging as a product for underfloor heating.

Impact of current packaging and rails

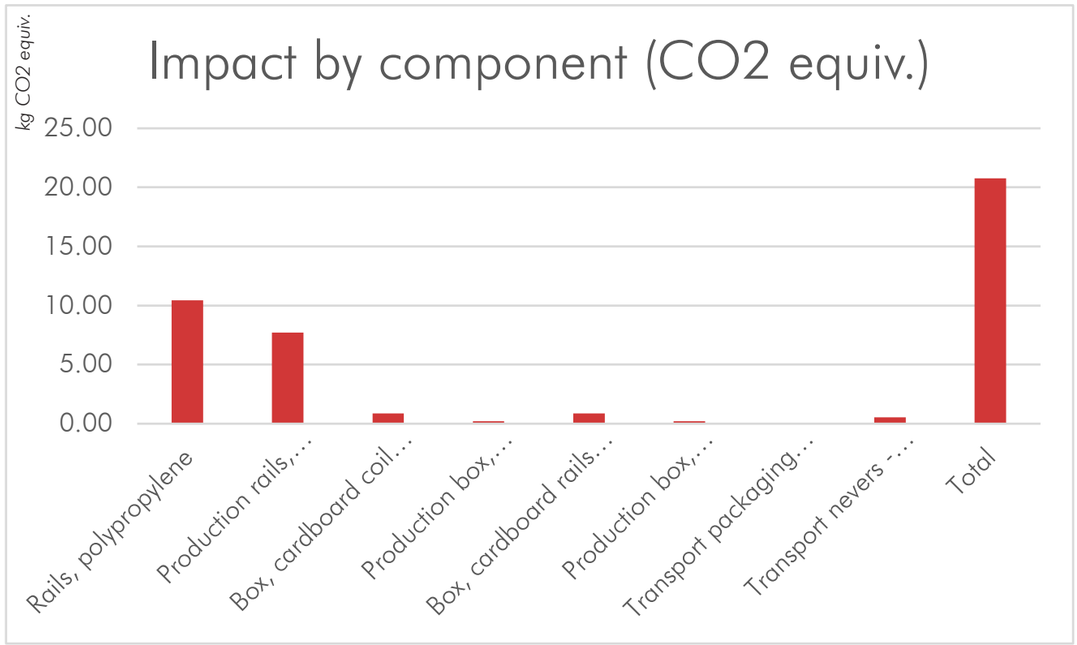


Figure 7.5.5.2: LCA of current packaging by component.

Impact of packaging as a product

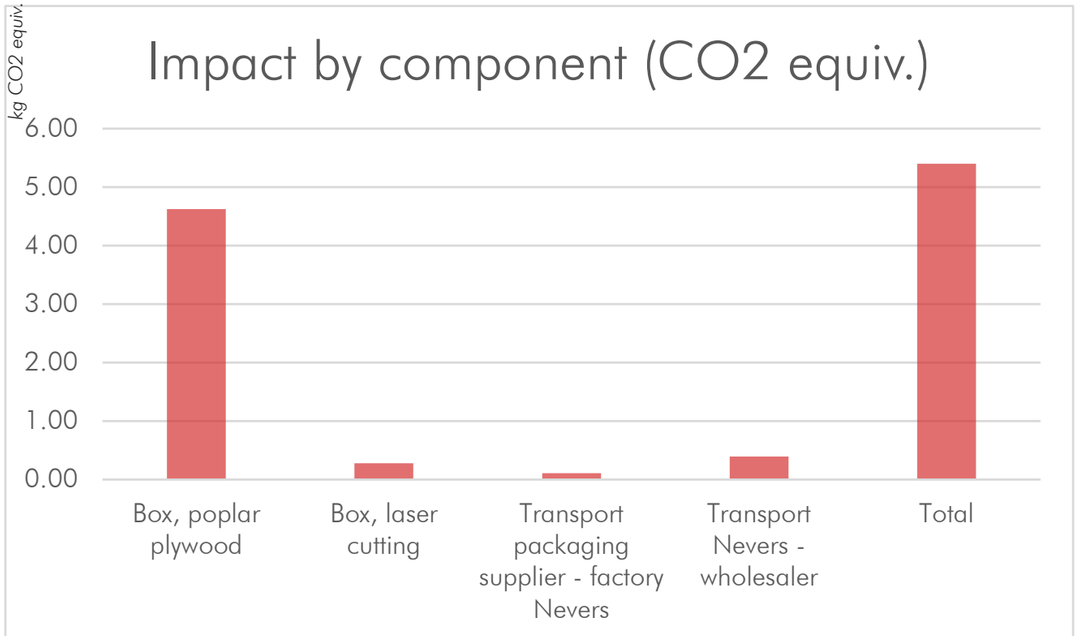


Figure 7.5.5.3: LCA of packaging as a product by component.

7.5.6 Costs

In this Chapter a costs calculation will be formulated and compared to the current packaging situation. The costs calculation of the new type of packaging will be compared to the costs of the current packaging and rails elements.

Consulted by Cutx, a laser cutting company, a quotation has been made for the first version of the lasercut box. This version was based on 5mm thick plywood and individual rail elements that could be interconnected with each other. Therefore, the calculated costs only provide an estimation. It is expected that for the new concept costs will be lower, due to less labour required to assemble the packaging (because the new iteration will have less separate interlocking parts).

Current costs of the rails elements and packaging are calculated on €47.96. This calculation is based on 52 rails elements, which is equal to the amount that is used for packaging as a product. New costs are expected to be €77.88 per product. This estimation includes labour, material and laser cutting costs.

If we only compare the packaging costs (cardboard box versus laser-cut packaging), it becomes evident that the costs for laser-cut packaging are considerably higher than those for a cardboard box. Overall costs for the concept of packaging as a product are also expected to be higher than the current packaging. Considering that customers are not likely to pay extra for more sustainable packaging as mentioned in Chapter 3.1, investments are needed by Aalberts to eliminate single-use packaging with the concept of packaging as a product. Nevertheless, packaging as a product provides a new way of packaging which completely gets rid of single-use packaging.

When replacing all 50.000 cardboard boxes in Nevers by this concept, a yearly investment of approximately €1,500,000 is required. In this calculation the costs difference between the current packaging (and product) is compared to the concept. The concept increases €29.92 per sold coil compared to using separate packaging for the coil and rails.

Part	Costs per part	Total costs per product	Reference
Underfloor heating rails (including packaging)	€0.87 per 800mm	52 * €0.87 = €45.24 (52 rails per product packaging, 800x800: 20 rails 800x120: 4 rails)	(Techniekwebshop.nl, n.d.) Excl. BTW 35% margin, 20% discount and 50% margin producer on purchase costs is taken (€3.36 per 800mm)
Cardboard box		€1.36 * 2 = €2.72	Aalberts HFC excel sheet
Total		€47.96	

Table 7.5.6.1: Costs current packaging

Part	Costs per part	Total costs per product	Reference
Laser cutting including material (5mm poplar plywood)	€1.44 per 800mm	€1.44 * 52=€74.88	Consulted by Cutx, laser cutting specialists
Labour (assembling the rails inserts)	€30/hr, 5 min per box	€ 2.5	(Eurostat, 2023a)
Labour (assembling the packaging)	€30/hr, 1 min per box	€ 0.50	(Eurostat, 2023a)
Total*		€77.88	

** Costs for R&D of the packaging as a product is not taken into account*

Table 7.5.6.2: Costs packaging as a product: underfloor heating pipe.

7.6 Final concept validation

Impact resistance

Multiple tests were executed to validate the concept. The first test was focused on the impact resistance of the packaging. For this test, a prototype of 9mm thick poplar plywood has been created (Chapter 7.5.4). The goal of the test was to validate the impact resistance of the packaging during transportation in a comparable environment as with Aalberts transport. Since Aalberts transports their PEX pipe via road transport, the prototype has been sent with DHL to simulate a comparable road transport test. The prototype (Figure 7.6.1) has been sent to a location approximately 30 kms away.

From the test can be concluded that the prototype is strong enough to be able to resist the impact during transport since the prototype survived the test. The packaging did show some transportation damage marks as can be seen in Figure 7.6.2. It is likely to say that the marks do not have an effect on the function of the product.

Figure 7.6.1: Arrival of packaging after transport.

Figure 7.6.2: Transportation damage marks on packaging.

Figure 7.6.3: Opening the packaging after arrival.

Online questionnaire

An online questionnaire has been created with the goal to validate the demand for the concept of packaging as a product (questionnaire template can be found in Appendix 9.25). The questionnaire has been spread via online platforms (reddit, tweakers, forum.fok, surveycircle, and other online forums in specified groups for installers). This resulted in total thirteen respondents. The questionnaire has also been spread via a personal connection via Van Dorp installations, but unfortunately no installers reacted to the questionnaire.

Results from the questionnaire could not be seen as representative for the target group, since the attendance is too little. In addition to this, only four from thirteen participants have indicated to be a installer. The rest of the respondents exist out of students, engineers and software engineers. Therefore results cannot indicate whether there is a demand for the concept of packaging as a product.

Participants are based in Western Europe (61%), North America (31%) and South Asia (8%). The majority of the participants is aged under 35 (54%). Other participants are aged in between 35-59 (23%) and >59 years (23%). The larger part of the participants has more than six years of experience in the industry (61%). Other participants have 3-6 (23%) and less than three years of experience (23%)

However, although the online questionnaire cannot be seen as representative, it can provide insights into the concept. Reactions in the questionnaire as well as comments on the post have been taken into consideration.

Why would you choose this type of packaging?

On the question “How likely are you to choose this type of packaging over ‘traditional’ packaging?”, the majority answered likely. Out of thirteen respondents, 61% reacted positively with likely or very likely, 31% reacted negative with unlikely or very unlikely and 8% reacted neutral (neither likely or unlikely).

When looking at the reactions of the four installers, 50% reacted positive (with likely), 25% reacted neutral and 25% reacted unlikely. This shows that initial thoughts on the concept are overall seen as positive.

Reasons for choosing this type of packaging over ‘traditional’ packaging were on the topics of sustainability (reducing waste), quick installation and ease of having the products in the same packaging.

The four installers indicated that they would use the packaging over ‘traditional’ packaging because the rails and pipe were packaged together. Also, if costs were less than current attachment system, installers were in favor of using the packaging.

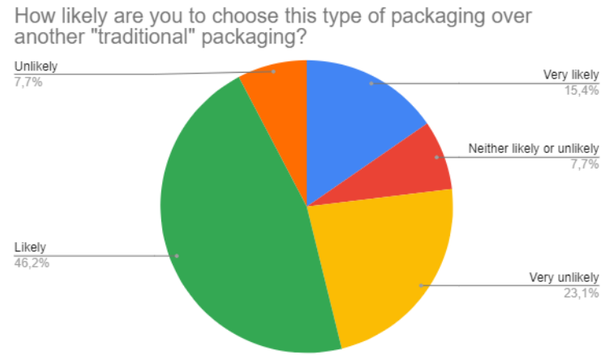


Figure 7.6.4: Questionnaire results on likeliness to choose concept packaging over ‘traditional’ packaging.

Why would you not choose this type of packaging?

It might be more insightful to know why people would not use the product to improve on and find weaker points of the concept as to why people would like to choose this type of packaging.

The four installers indicated that they would not choose this concept packaging over the ‘traditional’ packaging if the product inside the packaging would be worse than other products and if costs were higher than the current attachment system. In addition to this, it was indicated to have doubts on the functionality of the packaging. It was preferred to use other, stronger materials.

Furthermore other participants indictated to have doubts on longevity of the product. It was wondered what happens if the packaging does get damaged: would the rails elements be able to be used if it was damaged?

Also, it was commented on the questionnaire that it would make more sense to focus on reducing the carbon footprint of concrete flooring than to find a solution for packaging waste. The impact of concrete flooring would be much higher than the impact of packaging, when looking at the carbon footprint.

All in all, there are still doubts on packaging as a product. Four main challenges indicated in the questionnaire are higher costs, the product inside the packaging having more influence on whether to buy a product than its packaging, functionality concerns and quality concerns of the packaging.

Packaging as a product in general

When comparing findings on the concept for underfloor heating pipe packaging to the general concept of packaging as a product, it can be said that participants behaved more positively towards the general than the specific concept. For the specific concept, 61% reacted positive, whereas for the general concept, 69% reacted positive. Furthermore, for the specific concept 31% reacted negative, wheras for the general concept 15% reacted negative. This potentially shows that the execution of packaging as underfloor heating rails might be less favourable than other packaging as a product solutions. It is recommended for Aalberts to validate packaging as a product for other product categories as well to find out whether there is more demand for the concept for these categories.

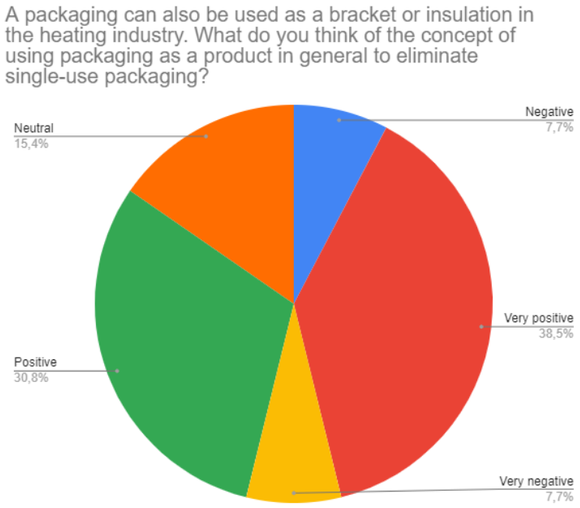


Figure 7.6.5: Questionnaire results on general concept of using packaging as a product.

Physical product concept evaluation

Tests were conducted with installers to validate desirability and feasibility of the concept (interview template can be found in Appendix 9.25). The goal of this evaluation was to validate the perception of installers for the concept of packaging as a product, as well as finding out whether the target group would use the product. Feedback sessions were executed with three different installation companies, differing in size from 5 to 25 employees. In total five installers participated, of which two sessions were conducted with a single installer and one session with three installers. Sessions were conducted at the office of the installers and lasted approximately 30 minutes per session. During the sessions installers were asked to share their opinion on the product via a questionnaire and by thinking out loud while using the product. When discussing the product, installers were asked to share what they would change on the design of the concept.

What do installers think of the concept?

All installers responded positive towards the concept at first when showing the product. They all started the topic of having to pay for the disposal of current packaging used. Installers mentioned that this could help to decrease disposal costs. All installers indicated in the meetings to be satisfied with the concept of transforming the packaging into rails elements for underfloor heating pipe installation. When diving deeper in the question why the participant(s) were satisfied with the concept, it became clear that it was because of the potential to eliminate waste.

Some installers mentioned that they are in favour of using reducing packaging (even when less packaging can be reduced than with this concept) since it causes for less disposal overall according to them. This indicates that installers do consider packaging waste as a problem.

However, when the installers answered the question in the questionnaire “What do you think of current packaging for products?”, two out of five installers indicated that they are fine with current packaging. This is remarkable since they stated before that packaging waste is seen as a challenge for them. This, together with the positive reactions at first, might show that

Figure 7.6.6: Concept validation with multiple installers.

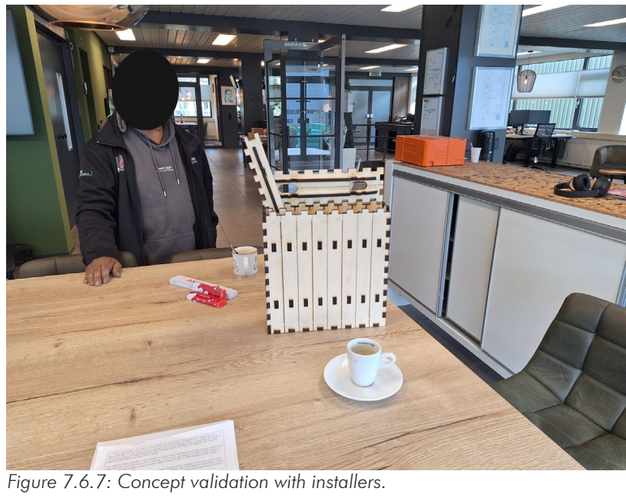


Figure 7.6.7: Concept validation with installers.

reducing packaging is not a priority for installers. It is very likely that the participants care more about the product than its packaging and just have to deal with the packaging and disposal of it.

Why wouldn't installers use the concept?
When comparing the opinion of installers of packaging as a product in general to this specific concept for underfloor heating, it can be concluded that the participants acted more positive towards the general concept of using a packaging as a product, than for the specific situation of this concept. When answering the question in the questionnaire "Would you choose this product over a traditional packaging?", the majority of participants indicated that it depends on price and functioning of the product. Some installers were recommending of making the product out of plastic since they were wondering about the long-term effect of wood in concrete. Another reason that was given for the material recommendations was that current products for attachment systems are made of plastics. Therefore it was believed that the product should be made out of the same material.

In the majority of the sessions, installers only recommended on changing the material of the product. These observations show potentially that there are still doubts on the functionality of the product, even though the general concept is found interesting by the participants.

All installers did not recommend on changing the interaction with the product, likely finding the prototype ok to work with. During the sessions participants also did not report anything noticable on the topic of time-efficiency. However, these sessions were executed in different settings than where the product will be used. Therefore it is recommended to perform tests on build sites with prototypes to gather more data on the interaction of installers with the product when using the it in a more representational environment.

What do wholesalers think of the concept?
In addition to installers, the concept has been discussed with wholesalers (n=1), to find out more on their perspective of the packaging. At the start of the session it was highlighted by the wholesalers that they are focussing on reducing and using packaging from recycled materials. This is one of their focus points considering decreasing the environmental impact of the company. It was mentioned by the wholesaler that currently there is a lot of packaging waste for the products they sell to their customers (the installers). They responded positive towards the concept. It was found a feasible way to reduce packaging waste for installers. When comparing the feedback from the wholesaler to the installers, it can be concluded that the wholesaler reacted more positively towards the concept than installers. This could be (partly) caused by their current focus to reduce packaging waste as well, whereas this is considered less a priority for installers. Therefore it is likely that wholesalers are more open-minded to new ways to reduce packaging waste than installers.

Conclusion
Installers could be seen as a target group which is harder to change behaviour of. This is supported by the fact that all installers initially reacted positive on the concept, but indicated in the questionnaire that current packaging is fine to deal with. From the validation can be concluded that reducing packaging is not one of the priorities for the installer, likely making it harder to let them buy the product over others. Challenges of the concept that were mentioned by the installers were price and material type of the concept. They pointed out that price is a big factor in determining whether they will buy the product. Installers also recommended on changing to plastics since this material is currently widely used for attachment systems. All in all, these findings can be led to the fact that installers could be seen as a very conservative group, not likely to change current practices. When implementing packaging as a product, behaviour of installers needs to be changed since the purpose of a packaging will change completely. This will likely be a big challenge for installers to adopt the product. Therefore it could be seen as a risky move to implement the concept of packaging as a product for Aalberts.

In addition to this, from the online questionnaire can be concluded that there are still doubts on packaging as a product. Four main challenges are higher costs, the product inside the packaging having more influence on whether to buy a product than its packaging, functionality concerns and quality concerns of the packaging. This too can counteract with the successful implementation of packaging as a product.

Furthermore, when comparing packaging as a product for underfloor heating to the general concept of packaging as a product, it can be said that people often respond more positively towards the general concept than for the specific concept. It will be recommended for Aalberts to validate other packaging as a product concepts with installers, to verify which products have most demand when implementing the concept of packaging as a product. Increased demand for the concept could result in easier adoption of the product by installers.

In the next Chapter will be discussed how to make the change to packaging as a product successful. There will be looked into how to facilitate the change of behaviour of the installers considering the use of packaging.

7.7 Adopting packaging as a product

From the previous Chapter on the validation of the concept of packaging as a product can be concluded that the change to the concept involves a behavioural change of installers, since the purpose of a packaging will change completely. Since this group is seen as conservative, it could be a challenge for Aalberts to have a successful implementation of packaging as a product. In this Chapter will be looked into, and recommended on steps to be taken to increase chances of a successful implementation of the concept of packaging as a product.

Preparing for change

Implementing packaging as a product in 2035 (like stated in Chapter 6.4.1) without preparations with installers will likely cause for a unsuccessful implementation of the concept. Since the concept requires installers to change behaviour and expectations of packaging (as mentioned in Chapter 7.6), it is advised to prepare for the implementation of packaging as a product. Smaller steps for installers are needed considering the packaging change to increase likelyhood of success for the implementation of the concept. The following recomendations are presented to Aalberts to prepare their end-customers (installers) for the change in behaviour for packaging.

Sharing the problem

A challenge to reducing packaging is that while it might be a focus for Aalberts and wholesalers, it is not for all installers (as concluded from Chapter 7.6). It is very likely that installers are not willing to change when reducing packaging is not seen as a priority for them. Although it is expected that sustainability awareness will increase further in the future (as stated in Chapter 6.3.4), it will help to involve installers more into the challenge of reducing packaging. Also, it is recognized by Aalberts that sustainability awareness among customers is increasing. Therefore, by sharing the challenge of reducing packaging with customers (not only wholesalers, but also installers) they will be (more) involved with the challenge. Involving installers into the the challenge and concept(s) will likely increase chances of successful implementation of the concept, as people tend to like things more if they have put effort to create them, also called the IKEA effect (Norton et al., 2011). Therefore, it is advised to involve installers with the packaging concept(s). Multiple ways are recommended to involve installers more into the challenge of reducing packaging and the concept of packaging as a product.

Involvement via pilots

Firstly, installers should be involved with the development of the concept via pilots. Pilots can be used as a way to let installers interact with the concept of packaging as a product. Results can be used to both improve the concept further, and open discussions on the concept. With the pilots, the goal is to involve installers into the packaging change and let them be apart of the development of the concept. Therefore, due to the IKEA effect, it is more likely that the packaging change would be adopted by the installers after implementation by Aalberts.

Pilots can also be used as a promotional tool to show the industry what concept initiatives Aalberts is working on. Results from the pilots can be used for publishing to keep installers informed and involved with the concept as much as possible. This could help in preparing the installers for the change of using packaging as a product in the future.

Involvement via Techniek Nederland

Secondly, installers should be involved with the packaging concept via branche organizations. As mentioned in Chapter 2.2.2, Aalberts is member of a branche organisation called Techniek Nederland. In this organisation, packaging reduction initiatives are presented and validated. Installers could also be involved with the packaging concept via the branche organization. Via the branche organisation, bigger installation companies can be reached out to for the packaging concept. Smaller installation companies are often not part of the packaging reduction initiative called Brancheplan verpakkingen of Techniek Nederland.

Involvement via product managers

Thirdly, the larger installation companies (which are already clients of Aalberts) can be involved in the packaging concept via product managers. By visiting these companies, presenting and discussing the packaging concept, more installers can be involved. Thus, more people will be informed on, and prepared for the change to packaging as a product.

Involvement via media

Fourthly, installers could be involved with the challenge of packaging reduction and the concept via (online) media. By showcasing and starting discussions on the concept of packaging as a product, installers could be involved more. The goal is to inform the complete industry of the concept and involve them to work together to prepare them for the implementation of packaging as a product. This could entail publishing discussions between installers and Aalberts to provoke involvement of more installers (and other stakeholders involved). Since Aalberts has a strong customer focus considering its packaging (as mentioned in Chapter 4.1), the company should show this by publishing tight collaboration between installers and Aalberts. Communication on the concept should be open to the installers. The concept should be treated by Aalberts as a new way to eliminate single-use packaging, which still requires recommendations from installers. Packaging as a product could be used as the centre of a community within the industry to start discussions and close collaboration between stakeholders. It is key to keep the discussions open to all stakeholders to involve as many as possible. All in all, by involving installers closely with the development of the concept via media, installers will be connected with the concept and the challenge of reducing packaging. This will prepare installers for a change in packaging and likely increase chances of successful implementation for Aalberts.

Involvement via trade fairs

Fifthly, involving installers in the concept of packaging as a product can also be achieved via trade fairs. Fairs are commonly used for showcasing new products to customers and competitors. Latest market trends and opportunities are shown here as well. Therefore, these places can be used to promote packaging as a product and start discussions with stakeholders. Introducing stakeholders via trade fairs can involve more customers to the concept of packaging as a product

Sequence of involving installers

Involving installers with the challenge of reducing packaging and the concept of packaging as a product should be done in a specific order to prepare the industry for a change in packaging. The first three recommended steps are based on smaller scale involvement of installers and improving on the concept. The last two steps are based on larger scale involvement, where focus is less on improvement and more on promotion of the concept.

Firstly, it is recommended to explore the limitations and perspectives on the concept better. It would be advised to start with pilots to improve and start discussion on the concept.

Secondly, when having iterated on the concept, the concept can be presented to Techniek Nederland to involve bigger installation companies. Installation companies being a part of the branche organisation plan focussing on reducing packaging, will likely have higher chances to collaborate on new initiatives. This is due to these stakeholders having a similar goal to reduce packaging as Aalberts does.

Thirdly, existing installer clients of Aalberts can be reached to involve larger installation companies. These stakeholders can be involved with the packaging concept via product managers at Aalberts. Due to the fact that connections between Aalberts and the installation companies are already present, involvement of these companies is more likely to be achieved.

Fourthly, larger scale involvement of installers can be achieved via media. By using media, discussions will be opened for all stakeholders, contributing to the involvement on a larger scale. The goal is to involve more installers as in the steps mentioned above by reaching out to more installers.

Fifthly, trade fairs can be used to accomplish involvement of installers with the concept of

packaging as a product. These places can be used to physically demonstrate the packaging concept to the audience to provoke discussions on the concept. More support on the concept can be generated by involving stakeholders e.g. professionals via trade fairs.

Conclusion

All in all, in order to increase changes of successful implementation of packaging as a product in 2035 it is important to prepare installers and other stakeholders for the packaging change. Packaging as a product requires a behavioural change of installers and therefore should be gradually be presented to minimize risk of unsuccessful implementation. Installers should be involved with the packaging concept to prepare them for the change. This should firstly be done via small scale involvement by executing pilots, approaching Techniek Nederland and existing clients of Aalberts. Then, more involvement of installers can be provoked on a larger scale by means of media and trade fairs. To increase chances of implementation, it is important to inform and work with as much stakeholders as possible to change packaging behaviour in the industry.

7.8 Conclusion

All in all, from the deep dive can be concluded that the preferred product to replace with the packaging as a product for underfloor heating pipe is the rails attachment system. Criteria to develop the concept further are based on interviews with installers and focus on time-efficiency, configurability, impact resistance and sustainability.

Laser cutting makes it possible to create a packaging without having to significantly invest (e.g. in moulds or machinery). Poplar wood is the recommended material to use the packaging for.

A life cycle analysis (LCA) has been executed on the concept of packaging as a product for underfloor heating pipes and the current packaging and rails elements used. From the LCA can be concluded that the new concept reduces the carbon footprint by 74% compared to the current packaging and rails. Nevertheless must be noted that in the current packaging and product (rails), polypropylene (material of the current rails) accounts for 86% of total CO2 equivalent. It can be said that most significant reduction in carbon footprint comes from changing the material from polypropylene to wood.

The concept of packaging as a product for underfloor heating pipe is expected to be more expensive than the current packaging and rails. It is expected that Aalberts needs to yearly invest €1,500,000 to change all current packaging for PEX pipe to the new type of packaging. However, with the new type of packaging, all single-use packaging can be eliminated, showing significant impact on the reduction of packaging at Aalberts. If packaging as a product is implemented for the product categories PEX pipe, Expansion vessels, Valves and Fittings, a total of 35,2% of all packaging at Aalberts can be saved.

From validation with installers can be concluded that they are interested in the concept. They were especially interested in creating no waste after installing the product. However, it is recommended to perform more research into concept before implementation. It can also be concluded from validation that installers could be seen as a target group which is hard to change behaviour of. The concept of packaging as a product requires a change in mindset on how to handle packaging. Reducing packaging is not seen as one of the key priorities for the installer, likely making it harder to let them buy these products over others. Installers mentioned that price should be kept low since it will determine whether to buy the product or not. Also, installers recommended on changing the material of the concept packaging to plastics since it is currently widely used for underfloor heating attachment systems in the industry. Findings show that installers could be seen as a conservative target group, not likely to change practices easily.

In order to increase chances of successful implementation of packaging as a product in 2035, installers should be gradually involved with the new packaging concept. Firstly, this should be done via smaller scale involvement by executing test pilots, approaching Techniek Nederland and existing clients of Aalberts. Secondly, installers should be involved on a larger scale via media and trade fairs. It is important to inform and work with installers as much as possible to encourage a successful behavioural change considering packaging in the industry.

7.9 Discussion on packaging as a product

In previous Chapter 6.4.1 is stated that the concept direction makes use of the “Rethink” circular strategy on the R-ladder. But can packaging as a product really be seen as a circular strategy? This Chapter discusses the circular strategy of the concept of packaging as a product.

Linear or circular economy?

First of all, critics could say that the concept of packaging as a product is not entirely circular as it still makes use of a linear approach; the packaging is produced, used during transport and then used during installation. It could be said that the packaging is not part of a closed loop where it is used over and over again, like reusable packaging. However, the concept of packaging as a product does eliminate single-use packaging. As stated in Chapter 4.4 by the Ellen MacArthur Foundation: “The aim of a circular economy is to prevent the generation of waste right from the beginning.” (2023). Therefore it could be said that the concept of packaging as a product contributes to the circular economy as it eliminates packaging waste (Ellen MacArthur Foundation, 2023).

What happens after installation?

As products do not last forever, so does the concept of packaging as a product. When used for underfloor heating applications as an attachment system it will last as long as the building it is installed in. Nevertheless, it could happen that the building will be broken down, having to dispose the packaging as a product as well. Since the packaging is fixated in concrete, it could have a negative influence on recycling possibilities of the material.

Research from Ince et al. (2021) shows that by including wood waste in cement mortar, a greener alternative can be offered compared to ‘traditional cement’. It saves natural resources and CO2 emissions required to produce raw materials for the manufacture of mortars. As cement manufacturing currently contributes to approximately 7% of global CO2 emissions, including wood waste in mortar can offer a greener disposal lane than ‘traditional mortar’ for industrial waste (Ince et al., 2021).

This could convey that settling wood in concrete could even lead to reduction of CO2 emissions and the use of natural resources. Nevertheless, concrete recycling implementation is low in many countries (Badraddin et al., 2021). More research is required into the effects of settling wood in concrete regarding recycling possibilities. It should not decrease concrete recycling rates as it is already low in many countries and it contributes to global CO2 emissions.

In addition to this, it is very likely that the impact of the entire floor heating system has a much bigger influence on the circularity in total. There should be looked into different types of systems, which can be disassembled after its lifetime, enabling for circular use. Nevertheless, this is a completely different topic than on what this thesis aims at.

8. Further investigation needs

8.1 - Further research recommendations

Future research is recommended due to limited time of the project. The recommendations are divided into two categories: Roadmap and packaging as a product.

Roadmap
First of all, the roadmap is based on the four product categories (PEX pipe, expansion vessels, fittings and valves) representing 54% of all packaging at Aalberts. Recommended actions for these product categories could also be applied to other product categories which require similar packaging. Therefore, it is recommended to look into other product categories to apply similar packaging reduction techniques to reduce packaging at Aalberts even more.

Second, in the first phase of the roadmap is recommended to change from single-use pallets to reusable pallets for the product category PEX pipe. This recommended action results in a significant reduction of single-use packaging at Aalberts. Switching from single-use to reusable pallets for other product categories other than the four main categories, could contribute significantly to the reduction of packaging as well. Therefore is recommended to look further in the implementation and consequences of the switch to reusable pallets for other Aalberts' factories.

Third, more research should be performed on the commercial impact of the recommended packaging changes to gain better insights in the financial consequences. There should be looked into whether the recommended changes influence the perceived price and quality of the product for Aalberts' customers. For example it is advised to validate the commercial impact of changing cardboard boxes from white to brown and changing plastic bag packaging from virgin to recycled plastics. Also, the effect of different shaped packaging on the willingness to pay for Aalberts' customers should be validated.

Fourth, it is recommended for Aalberts to look further into their willingness to invest in reducing packaging. Reducing packaging at the company requires investments. Also, from research in this thesis can be concluded that investments are needed to achieve the current target of 20% packaging reduction at Aalberts in 2025. More research has to be done in how Aalberts is willing to go in terms of increased costs and investments to reduce packaging.

Packaging as a product
Fifth, future research should consider more pilots with larger groups of installers to iterate and gather more perceptions of the concept of packaging as a product. This should be done for both packaging as a product for underfloor heating pipe, like explored in this thesis, and also for other product categories. Results could show new insights contributing to successful implementation of the new packaging concept.

Sixth, it is recommended to perform further research other involvement strategies to work with and inform installers. The concept of packaging as a product requires a behavioural change and needs to be introduced gradually to increase chances of successful implementation.

Seventh, future research should explore the end-of-life of packaging as a product. More research into the consequences of packaging as a product for underfloor heating for long term behaviour of wood in concrete is required. It should be investigated how wood affects concrete recycling compared to current plastic attachment systems. This should also be done for other packaging as a product applications before implementing the packaging.

8.2 - Personal reflection

The journey

Looking back at the project I would say that it has been a journey with lots of ups and downs. Designing for a reduction of packaging consumption can be difficult. Especially considering the facts that costs need to be as low as possible and current packaging is already optimized many times. During this project I have found that companies often tend to stick with current practices and are hesitant to change. This certainly applies to topics that are not seen as a key priority, like packaging. Luckily regulations is one of the factors currently stimulating companies to change their current practices to become more sustainable considering their packaging. In the industry can be seen that companies are slowly starting to move towards other, more sustainable, packaging practices. This provided the opportunity to me to do my graduation thesis at Aalberts, advising on packaging reduction practices.

During this thesis, I have learned a lot on packaging, sustainability at corporates, impact of materials, challenges of changing current practices and sustainability in general. Changing packaging differs per product and can be seen as a big challenge for companies. During the project I have learned that involving stakeholders in the changes, will contribute to the implementation of the concept(s). I am proud to say that I have been able to work with people from various backgrounds to start a discussion on the challenges of current packaging. While some people are not open to change yet, others do see value in changing current practices. The change to (more) sustainable packaging in the industry is very likely to require more projects on this topic to explore other ways of packaging reduction. However, I am satisfied to have explored and contributed to new solutions to reduce packaging.

Personal ambitions

Conducting user and expert research

Througout this project I have been able to conduct user and expert research. At the start of this thesis, explorative interviews with experts in the packaging industry have helped to define the current challenges within the industry. This provided the opportunity to talk to experts in the field, which helped to develop my skills considering qualitative interviews. In addition to expert interviews, user research has been performed during this project. This was done throughout the whole process, from talking to and interviewing employees of Aalberts, to demonstrating and letting installers interact with the concept prototypes. This did not only provide insights into sustainable packaging in Aalberts' industry for this thesis, but also helped me to understand the attitude towards sustainable packaging in this industry better. All in all, the project allowed me to improve my skills on conducting user and expert research, which will be helpful in the work I aim to do next.

Understanding sustainable corporate change

This project also allowed me to investigate the current challenges to sustainable transitions for a company. The thesis helped me to understand better what holds companies back to change current practices. I believe these insights are very valuable to me since I plan to work in the industry after this project and thus helps to find better arguments to encourage transition within a company. Understanding the reasoning why companies are (not) willing to change current practices provide me valuable insights for my future career.

Promoting sustainable change in a business context

During the project I have received the opportunity to advise on practices to reduce packaging at Aalberts. Recommended changes on packaging practices had to be discussed in order to find convincing arguments to stimulate the transition. Advising the company on sustainable packaging practices also allowed me to explain to Aalberts' employees what current challenges of packaging are and how to tackle these challenges. Although advising a company on more sustainable packaging practices brings a lot of responsibility, it also provided me the opportunity to improve on persuasiveness and argumentation.

Develop a sustainable packaging solution

The last learning goal was to develop a sustainable packaging solution. During the project I have learned that developing sustainable packaging can be difficult, considering the fact that all products need a different packaging solution. In addition to this, packaging is often not seen as a priority for a company, making it harder to change current practices. During this thesis, I have learnt a lot on the development of (more) sustainable products, LCA's and its challenges.

9. Appendices

Appendix 9.1 - References

Afvalfonds Verpakkingen. (n.d.). Proposal Packaging and Packaging Waste Regulation (PPWR) | Afvalfonds Verpakkingen. Unc Inc / Unc Inc Amsterdam - uncinc.nl. Retrieved December 6, 2023, from https://www.afvalfondsverpakkingen.nl/en/proposal-packaging-and-packaging-waste-regulation-ppwr

Afvalfonds Verpakkingen. (2023). Tariefdifferentiatie Plastic 2.0 | Afvalfonds Verpakkingen. www.afvalfondsverpakkingen.nl. Retrieved February 20, 2024, from https://www.afvalfondsverpakkingen.nl/nl/tariefdifferentiatie-plastic-20

Aalberts. (n.d.). Aalberts. https://aalberts.com. Retrieved November 30, 2023, from https://aalberts.com/technologies

Aalberts. (2022). Aalberts - Annual report 2022. Retrieved February 9, 2024, from https://aalberts-website.s3.eu-west-1.amazonaws.com/media/App/Models/Download/000/000/387/attachment/original/Aalberts%20-%20annual%20report%202022.pdf

Alibaba. (2024a, January 1). Corrugated box. alibaba.com. Retrieved January 23, 2024, from https://www.alibaba.com/product-detail/Pizza-Box-Wholesale-Custom-Logo-Printing_1600377391012.html?spm=a2700.galleryofferlist.p_offer.d_price.534a72d4BdS43N&s=p

Alibaba. (2024b, January 1). Octagon box [Video]. alibaba.com. Retrieved January 23, 2024, from https://www.alibaba.com/product-detail/Custom-Personalized-Pattern-Design-Pizza-Boxes_1600734492712.html?spm=a2700.galleryofferlist.topad_classic.d_title.5cf276f8RkUaE5

AllesoverMDF. (n.d.). Alles over MDF. Alles Over MDF. https://www.allesovermdf.nl/milieu/

Amazon. (n.d.). Pack 250 Underfloor Heating UFH Pipe Clips Staple Length 50mm to Suit Pipe Dia 15-20mm. https://m.media-amazon.com/images/I/412t2B9r8TL._AC_UF894,1000_QL80_.jpg

Ansys. (2023). Granta EduPack 2023 R2 (Version R2) [Software].

Aydemir, C., & Özsoy, S. A. (2020). Environmental impact of printing inks and printing process. JGED, 11(2), 11–17. https://doi.org/10.24867/jged-2020-2-011

Bassens, D., De Boeck, S., & K□błowski, W. (2020, October 1). Toward a Circular Economy Scan: Measuring Circular Practices among Retailers in the Brussels Capital Region. Researchgate. Retrieved January 31, 2024, from https://www.researchgate.net/publication/348415963_Toward_a_Circular_Economy_Scan_Measuring_Circular_Practices_among_Retailers_in_the_Brussels_Capital_Region

Bauer, J. (2023, May 2). The EU Packaging Regulation (PPWR) - Contents and Changes to the Packaging Waste Directive. https://www.rigk.de. Retrieved January 16, 2024, from https://www.rigk.de/en/worth-knowing/news/the-eu-packaging-regulation-ppwr-contents-and-changes-to-the-packaging-waste-directive#:~:text=Currently%2C%20there%20are%20no%20mandatory,for%20-removal%2C%20sorting%20and%20reuse.

Beleid en wetgeving verpakkingen – KIDV. (n.d.). https://kidv.nl/wet-en-regelgeving

Borras, V. (n.d.). Biobased packaging trends in 2022. Knauf. https://knaufappliances.com/biobased-

packaging/#:~:text=Biobased%20packaging%20is%20packaging%20made,petroleum%20(fossil%20fuel)%20sources.

Bouwsite. (2023, June 5). Multiplex vs. MDF plaat - Bouwsite.be. Bouwsite.be. Retrieved February 1, 2024, from https://bouwsite.be/blog/multiplex-vs-mdf-plaat/#:~:text=Aan%20de%20andere%20kant%20is,tegen%20buigen%2C%20kromtrekken%20en%20splijten

Camfil (n.d.). https://packagingsolutionsstories.storaenso.com/en/stories/switching-from-white-to-brown-boxes-to-reduce-co2

CMS. (n.d.). Plastic and packaging waste laws and regulations | CMS Expert Guide. https://cms.law/. Retrieved November 30, 2023, from https://cms.law/en/int/expert-guides/plastics-and-packaging-laws

Comap. (2023, August 28). Underfloor heating: 6 fixing solutions and benefits. CoExpert | Aalberts Hydronic Flow Control. https://coexpert.aalberts-hfc.com/en-gb/energy-efficiency/uhc-fixing-solutions/

Concrete Supply Co. (2019, February 11). Concrete Basics: Essential Ingredients For A Concrete Mixture. Concrete Supply Co. Retrieved February 13, 2024, from https://concretesupplyco.com/concrete-basics/#:~:text=What%20goes%20into%20the%20most,it%27s%20as%20simple%20as%20that!

Congbo, L., Tang, Y., Cui, L., & Yi, Q. (2013, April 1). Quantitative analysis of carbon emissions of CNC-based machining systems. researchgate.net. Retrieved February 4, 2024, from https://www.researchgate.net/publication/261165081_Quantitative_analysis_of_carbon_emissions_of_CNC-based_machining_systems/figures?lo=1

CRB. (n.d.). Food Packaging Process and Packaging Line Design - CRB. https://www.crbgroup.com/wp-content/uploads/2021/03/Primary-Secondary-Tertiary-Packaging-1536.png

Danfoss. (2022, November 1). Danfoss position statement on Packaging and Packaging Waste Directive in the EU. Retrieved January 29, 2024, from https://files.danfoss.com/download/CorporateCommunication/Sustainability/Danfoss-position-on-packaging-directive.pdf

Danfoss. (2023, December

12). Danfoss position statement on Packaging and Packaging Waste Directive in the EU (No. 2023). www.danfoss.com. Retrieved January 29, 2024, from https://files.danfoss.com/download/CorporateCommunication/Sustainability/Danfoss-position-on-packaging-directive.pdf

Duarte, S. (2023, August 30). Injection Molding vs. Extrusion: What's the Difference? Protolabs. https://www.protolabs.com/resources/blog/injection-molding-vs-extrusion-whats-the-difference/

Duarte, S. (n.d.). Injection Molding vs. Extrusion: What's the Difference? Protolabs. https://www.protolabs.com/resources/blog/injection-molding-vs-extrusion-whats-the-difference/

Dujardin, R. (2023, January 20). How to recycle plastic effectively. Euronews Living. https://www.euronews.com/living/2023/01/20/how-to-recycle-plastic-effectively#:~:text=Plastics%20have%20a%20variety%20of,in%20municipal%20recycling%20programs%20worldwide.

EFTA. (2022). Sustainability in packaging design: Two roads to the same destination. Retrieved

February 2, 2024, from https://www.efta.int/sector/non-eu-eea/packaging-regulation-71182#:~:text=Packaging%20producers%20are%20obliged%20to,goods%20from%20the%20same%20packaging.

EKOenergy. (n.d.). EKOenergy. EKOenergy. https://www.ekoenergy.org.

Elshof, B. (2023, November 29). Biobased materials are the future. Publicatie Biobased Economy. https://www.publicatiebiobasedeconomie.nl/biobased-materialen-zijn-de-toekomst/#:~:text=Biobased%20materials%20are%20made%20from,as%20a%20substitute%20for%20plastics.

Engelhardt, H. (n.d.). Board and paper grades and definitions. The Packaging School. https://packagingschool.com/blog/packaging-materials-board-and-paper-grades-and-definitions/.

EPS. (2023, March 15). Is Expanded Polystyrene Eco-Friendly? Pregis. https://www.pregis.com/knowledge-hub/is-expanded-polystyrene-eco-friendly/

Eurostat. (2023). Recycling rates of packaging waste by type of packaging [Graph]. In Eurostat. https://ec.europa.eu/eurostat

Ferretti, F. (2023, August 24). How to recycle and what you can't recycle in Italy. LifeGate. https://www.lifegate.com/people/lifestyle/how-to-recycle-and-what-you-cant-recycle-in-italy#:~:text=In%20Italy%2C%20it%20is%20mandatory,the%20respective%20collection%20and%20disposal.

Finn, S. (2023, March 3). How to recycle and dispose of almost anything. Pop Mech. https://www.popularmechanics.com/home/how-to/g195/4268603/?slide=15

For the Better Good. (n.d.). For the Better Good. For the Better Good. https://forthebettergood.com.

Forssman, M. (2023, November 17). What's the Difference Between Green and Eco-Friendly Packaging? ThePackHub. https://www.thepackhub.com/blog-post/whats-the-difference-between-green-and-eco-friendly-packaging/#:~:text=Eco%2Dfriendly%20packaging%20is%20that,the%20packaging%20used%20to%20protect.

Fradkin, A. (n.d.). Kraft Paper: A Sustainable Packaging Solution. Global-Pak. https://www.global-pak.com/blog/kraft-paper-a-sustainable-packaging-solution#:~:text=Kraft%20paper%20is%20an%20eco,the%20product%20it%20is%20holding.

GAF. (n.d.). Roofing Shingles & Materials. https://www.gaf.com/en-us/roofing-products

GAF. (2023). Timberline HDZ Shingles. https://www.gaf.com/en-us/products/timberlinehdz

GAI. (2023). Education Resources. Retrieved January 18, 2024, from https://www.gai.org/education-resources

Gan, L., Li, W., Wang, L., Qian, Y., & Hu, L. (2023, March 1). LCA for packaging applications. researchgate.net. Retrieved February 7, 2024, from https://www.researchgate.net/publication/349014189_LCA_for_packaging_applications/figures?lo=1

Geelhoed, G. (n.d.). Multiplex plaat. OpZoekNaarVerbouwing. https://www.opzoeknaarverbouwing.nl/verbouwen/materiaal/multiplex-plaat/#:~:text=Multiplex%20platen%20worden%20gemaakt%20door,worden%20ook%20wel%20plaatmateriaal%20genoemd.

Gerard, A. (n.d.). White Paper: The Growth of Sustainable Packaging in the Food Industry. https://www.thermofisher.com/nl/en/home/industrial/materials-technologies/bioprocessing/pharmaceutical-manufacturing/pharmaceutical-packaging/sustainable-food-packaging-white-paper.html

Giese, D. (2023). Packaging design and its influence on recyclability. Creative Propulsion Labs. Retrieved January 14, 2024, from https://creativepropulsionlabs.com/insights/packaging-design-and-its-influence-on-recyclability/

GIF. (2023, June 15). Europe Preparatory Study for Ecodesign Requirements on Computers, Displays, and Servers. https://www.gif-info.de/en/episodes-ee-products

GlassforEurope. (2023, May 8). End-of-life considerations for glazing products. Building for Tomorrow. https://www.buildingfortomorrow.eu/blog/end-of-life-considerations-for-glazing-products#:~:text=End%2Dof%2Dlife%20considerations%20for%20glazing%20products%20are%20critical,recyclable%20at%20the%20end%20of%20their%20service%20life.

Glaston. (n.d.). https://www.glaston.net

Goswami, B., & Kumar, A. (2023). Environmental friendly food packaging: A review. Journal of Polymer and the Environment, 31(3), 515–529. https://doi.org/10.1007/s10924-023-02875-x

Hagemann, H. (n.d.). Green Inks. Ink World Magazine

. https://www.inkworldmagazine.com/issues/2019-01-01/view_features/green-inks

Hailey, M. (2023, November 30). The main role of materials in sustainable packaging. The Packaging Lab. https://thepackaginglab.com/the-main-role-of-materials-in-sustainable-packaging/

Halima, N. B., & Chakroun, R. (2023). Food packaging and its environmental impact: A brief overview. International Journal of Environmental Science and Technology, 20, 3395–3402. https://doi.org/10.1007/s13762-023-03602-2

Hamad, K., Kaseem, M., & Ayyoob, M. (2023). Overview on the application of nanotechnology in food packaging. Nanomaterials, 13(10), 1272. https://doi.org/10.3390/nano13101272

Harvey, F. (2023, October 6). Life cycle analysis and how it affects packaging. Association for Packaging and Processing Technologies. https://www.pmmi.org/blog/life-cycle-analysis-and-how-it-affects-packaging

Hasnain, S. (2023). Sustainable bio-based plastics: A review. International Journal of Biological Macromolecules, 197, 35–49. https://doi.org/10.1016/j.ijbiomac.2022.10.088

Hausmann, C. (2023). Biodegradable Packaging: A Comprehensive Review. Springer International Publishing. https://www.springer.com/gp/book/9789811629932

Hausmann, C. (2023). Handbook of Packaging: Practical and Environmental Considerations. CRC Press. https://www.crcpress.com/Handbook-of-Packaging-Practical-and-Environmental-Considerations/Hausmann/p/book/9780367649284

Holtzhausen, C., & du Preez, R. (2023). A review on the status of compostable packaging: European legislation and recent advancements. European Food Research and Technology, 249(2), 315–327.

https://doi.org/10.1007/s00217-022-04027-2

IATA. (2023). Current environmental policies in the air transport industry. https://www.iata.org/en/policy/environment/

ICIS. (2023). Global Polypropylene Market Report. https://www.icis.com/explore/resources/global-polypropylene-market-report/#:~:text=Polypropylene%20(PP)%20is%20the%20world's,substitute%20for%20various%20applications%20commodity.

Imhof, M. (2023, January 10). What Is the Main Cause of Ocean Plastic Pollution? International Climate Initiative. https://www.international-climate-initiative.com/en/news/article/what_is_the_main_cause_of_ocean_plastic_pollution

Incropera, F. (n.d.). A look at eco-friendly packaging materials. Packaging Digest. https://www.packagingdigest.com/sustainability/a-look-at-eco-friendly-packaging-materials-2023-09-21

Inforgraphic List. (2023). The Importance of Food Packaging [Infographic]. www.infographiclist.com. https://infographiclist.com/food-packaging/

ISO. (2023). Packaging and the environment. International Organization for Standardization. https://www.iso.org/obp/ui/#iso:std:iso:18604:ed-1:v1:en

Jagtap, R. (2023). Future prospects of sustainable food packaging. Packaging Gateway. https://www.packaging-gateway.com/comment/future-prospects-sustainable-food-packaging/

Jay, J. (2023, October 23). Why is Plastic Packaging Still So Prevalent? Hype Cycle Research. https://hypecyclereview.com/research/why-is-plastic-packaging-still-so-prevalent/

Johnson, S. (2023, April 19). Bioplastics in packaging: An analysis. Smithers. https://www.smithers.com/resources/2023/april/bioplastics-in-packaging-an-analysis

Johnson, S. (2023, June 1). The lifecycle of plastics. Plastic Soup Foundation. https://www.plasticsoupfoundation.org/en/2023/06/the-lifecycle-of-plastics/

Johnson, S., & Smith, P. (2023). A review of polymer degradation and its implications in environmental packaging. Journal of Polymers and the Environment, 30(2), 371–383. https://doi.org/10.1007/s10924-021-02405-5

Juhler, N. (2023). New report finds petrochemical sector will require substantial change to meet net-zero targets. Petrochemical Update. https://analysis.petchem-update.com/business-strategy/new-report-finds-petrochemical-sector-will-require-substantial-change-meet-net-zero

Jung, D. (2023, July 25). Mechanical recycling process for plastics. SciTech Europa. https://www.scitecheuropa.eu/mechanical-recycling-process-for-plastics/117846/

Kaelin, N. (2023). Sustainable Packaging Choices. Science of Food. Retrieved January 24, 2024, from https://www.scienceoffood.com/packaging/

Kamin, B. (2023, May 22). Environmental monitoring in the plastics industry. http://www.financeafter50.com/real-estate/how-the-plastics-industry-is-impacting-environmental-monitoring

Kang, J., Yang, Y., & Zhou, J. (2023). Applications of starch-based materials in active food

packaging. Journal of Polymers and the Environment, 30(8), 3156–3167. https://doi.org/10.1007/s10924-022-02719-5

Keene, L. (2023). Your Guide to Sustainable Packaging. CraftyTech. https://www.craftytech.net/sustainable-packaging/

Kesey, K. (2023). Overview of Biodegradable Packaging Technologies. Packaging of Tomorrow. Retrieved January 14, 2024, from https://www.packagingoftomorrow.com/overview-of-biodegradable-packaging-technologies/

Kessler, E. (2023, October 17). The importance of industrial packaging. World Industrial Reporter. https://worldindustrialreporter.com/the-importance-of-industrial-packaging/

Khayoon, M., Hameed, B., & Othman, N. (2023). A sustainable perspective on food packaging: An overview of materials and biotechnologies. European Food Research and Technology, 249(10), 2177–2189. https://doi.org/10.1007/s00217-023-03844-w

Khlebnikov, V. (2023). Are glass bottles eco-friendly? Packaging Insights. https://www.packaginginsights.com/news/are-glass-bottles-eco-friendly.html

Kirk, M. (2023, August 14). How Industrial Packaging Solutions Can Help You. Industrial Packaging Solutions. https://industrial

packagingsolutions.com/how-industrial-packaging-solutions-can-help-you/

Koch, B. (2023, April 7). Will bioplastics solve the problem of plastic waste? The Conversation. https://theconversation.com/will-bioplastics-solve-the-problem-of-plastic-waste-177275

Kohn, T. (2023). Sustainable Packaging Design. EcoEnclose. Retrieved January 15, 2024, from https://www.ecoenclose.com/sustainable-packaging-design/

Kuhn, M. (2023, October 25). Sustainability initiatives in the petrochemical industry. Petrochemical Technology. https://petrochemicaltechnology.com/news/sustainability-initiatives-in-the-petrochemical-industry

Kumar, A., & Pooja, D. (2023). Environmentally Friendly Packaging: A Sustainable Approach. John Wiley & Sons. https://www.wiley.com/en-gb/Environmentally+Friendly+Packaging%3A+A+Sustainable+Approach-p-9781119734269

Kumar, D., Senthil, M., Ramesh, V., & Raj, P. (2023). Sustainable Packaging Materials: Current State and Future Perspectives. Nova Science Publishers. https://www.novapublishers.com/catalog/product_info.php?products_id=68370

Kumar, S. (2023). Biodegradable packaging materials: A review. Food Packaging and Shelf Life, 27, 100596. https://doi.org/10.1016/j.fpsl.2021.100596

Kumar, S., & Chowdhury, S. (2023). Recent advances in eco-friendly packaging materials: A review. Journal of Packaging Technology and Research, 2(3), 301–319. https://doi.org/10.1007/s41783-023-00132-7

LaHaye, M. (2023). The growth of eco-friendly packaging in the cosmetics industry. Cosmetic Packaging Now. Retrieved January 18, 2024, from https://www.cosmeticpackagingnow.com/blog/the-growth-of-eco-friendly-packaging-in-the-cosmetics-industry

Landgraf, C. (2023, November 9). The Role of Plastics in the Circular Economy. World Economic Forum. https://www.weforum.org/agenda/2023/11/plastics-circular-economy-sustainability

Lee, J., Kim, H., & Kim, H. (2023). Bio-based Packaging Materials and Their Applications in Smart Packaging Systems. In K. Bharath & R. De (Eds.), Smart Packaging Technologies for Fast Moving Consumer Goods (pp. 17–33). Springer International Publishing. https://doi.org/10.1007/978-3-030-70550-3_2

Liang, L., Liu, X., & Zhu, Y. (2023). Bio-based packaging materials for food packaging. Journal of Polymer and the Environment, 31(9), 2973–2986. https://doi.org/10.1007/s10924-023-03271-4

Liao, Y., Liu, Y., Liu, H., Yang, H., & Yao, J. (2023). A review of sustainable food packaging materials. Food Packaging and Shelf Life, 31, 100758. https://doi.org/10.1016/j.fpsl.2021.100758

Liu, F., Wang, L., Cao, D., & Cao, Q. (2023). A review on sustainable packaging for food industry. Journal of Polymer and the Environment, 31(11), 4163–4178. https://doi.org/10.1007/s10924-023-03299-6

Liu, S., Jiang, Z., & Yan, H. (2023). Environmentally friendly packaging: Sustainable packaging materials and technologies. Packaging Technology and Science, 36(3), 145–159. https://doi.org/10.1002/pts.2685

Liu, Y., Zhang, Y., & Shen, Z. (2023). A review on edible packaging materials for food packaging. Journal of Polymers and the Environment, 31(5), 1368–1383. https://doi.org/10.1007/s10924-022-02738-2

Lone, S., Ali, M., Nawaz, A., & Khan, A. (2023). Nanotechnology-Based Packaging Materials: A Review. Springer International Publishing. https://doi.org/10.1007/978-3-030-73742-4_11

Lunney, B. (2023). A Guide to Sustainable Packaging. Packaging Lab. Retrieved January 14, 2024, from https://thepackaginglab.com/a-guide-to-sustainable-packaging/

Lunney, B. (2023). The Importance of Sustainable Packaging. Packaging Lab. Retrieved January 14, 2024, from https://thepackaginglab.com/the-importance-of-sustainable-packaging/

Lush, S. (2023). Sustainability trends in packaging. Packaging Journal. Retrieved January 14, 2024, from https://packagingjournal.co.uk/sustainability-trends-in-packaging/

Lutz, A. (2023, October 11). How recycled materials are reshaping the packaging industry. Recycling News. https://www.recyclingnews.com/innovation/how-recycled-materials-are-reshaping-the-packaging-industry

Ma, H., & Macosko, C. (2023). A review of sustainable packaging. International Journal of Sustainable Engineering, 16(5), 392–399. https://doi.org/10.1080/19397038.2021.1970860

Ma, Y., Chen, Y., Chen, W., & Zhu, C. (2023). Green Packaging and its Applications in Food Industry. Food Engineering Reviews. https://doi.org/10.1007/s12393-023-09329-9

Mackey, T., & Steel, R. (2023). Navigating the complex landscape of bio-based packaging materials. Packaging Strategies. Retrieved January 17, 2024, from https://www.packagingstrategies.com/

articles/96578-navigating-the-complex-landscape-of-bio-based-packaging-materials

Mancinelli, C., & Merli, R. (2023). Bioplastics in packaging. Science of the Total Environment, 163953. https://doi.org/10.1016/j.scitotenv.2022.163953

Mang, L. (2023). The Future of Sustainable Packaging. Impact International. Retrieved January 16, 2024, from https://www.impactinternational.com/blog/future-of-sustainable-packaging

Marais, K., & De Beer, M. (2023). Active packaging for food applications. Food Packaging and Shelf Life, 28, 100619. https://doi.org/10.1016/j.fpsl.2021.100619

Marcelin, B. (2023). Recent advances in sustainable packaging materials. Packaging Gateway. Retrieved January 14, 2024, from https://www.packaging

-gateway.com/comment/recent-advances-in-sustainable-packaging-materials/

Martinez, A. (2023). Sustainable Packaging Materials: State of the Art and Prospects. Journal of Applied Packaging Research, 13(1), 1–7. https://doi.org/10.14448/japr.13.01.00

Matias, A. (2023). Compostable packaging: Trends and regulations. Packaging Digest. Retrieved January 17, 2024, from https://www.packagingdigest.com/sustainability/compostable-packaging-trends-and-regulations-2023-05-22

McGonagle, K. (2023). Recycled content in plastic packaging. Packaging News. Retrieved January 16, 2024, from https://www.packagingnews.com.au/sustainability/recycled-content-in-plastic-packaging#:~:text=Packaging%20made%20from%20recycled%20material,only%20a%20minor%20factor%20in.

Mehta, P., & Sharma, R. (2023). Sustainable food packaging: A review. Food Packaging and Shelf Life, 28, 100628. https://doi.org/10.1016/j.fpsl.2021.100628

Mei, C., Tang, H., & Zeng, Y. (2023). A review on the use of bioplastics for food packaging. Journal of Polymers and the Environment, 31(9), 3181–3197. https://doi.org/10.1007/s10924-022-02730-w

Mejia, C. (2023). Sustainable Packaging: A Case Study in Improving Supply Chain Sustainability. ChainLink Research. Retrieved January 17, 2024, from https://www.clresearch.com/research/detail.cfm?guid=5F5DD154-3048-79ED-99B5-FAA6C5DEE6D6

Melo, A., & Pimentel, L. (2023). Sustainability aspects of bio-based materials. Environmental Progress & Sustainable Energy, 42(3), 977–987. https://doi.org/10.1002/ep.13783

Metapack. (2023, April 24). The Role of Packaging in a Sustainable Supply Chain [Webinar]. Metapack. https://www.metapack.com/role-of-packaging-in-a-sustainable-supply-chain/

Metin, S. (2023). Environmental Impact Assessment of Packaging Materials. Wiley-VCH. https://www.wiley.com/en-us/Environmental+Impact+Assessment+of+Packaging+Materials-p-9783527344222

Michaud, L. (2023). Are Biodegradable Plastics Better for the Environment? MIT Technology Review. https://www.technologyreview.com/2023/03/13/1024431/are-biodegradable-plastics-better-for-the-environment/

Mills, S. (2023). Sustainable packaging design and implementation in the food and beverage industry. Food & Beverage Packaging. Retrieved January 16, 2024, from https://www.foodbev.com/news/sustainable-packaging-design-and-implementation-in-the-food-and-beverage-industry/

Milne, S. (2023, October 31). The Role of Sustainable Packaging in E-commerce. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96573-the-role-of-sustainable-packaging-in-e-commerce

Min, K., Kim, Y., Kim, J., & Youn, H. (2023). An overview of biodegradable food packaging materials. Journal of Polymers and the Environment, 31(4), 1491–1505. https://doi.org/10.1007/s10924-022-02705-x

Mishra, A. (2023). Eco-Friendly Packaging: The Future of Packaging Industry. In V. Sharma & R. Pathak (Eds.), Recent Developments in Sustainable and Circular Packaging (pp. 179–200). Springer International Publishing. https://doi.org/10.1007/978-3-030-94257-6_9

Mittal, V., & Thakur, K. (2023). A review on sustainable packaging materials. Journal of Material Cycles and Waste Management, 25(1), 441–451. https://doi.org/10.1007/s10163-022-01346-5

Montgomery, S. (2023). The Importance of Sustainable Packaging. Packaging Lab. Retrieved January 14, 2024, from https://thepackaginglab.com/the-importance-of-sustainable-packaging/

Mukherjee, D. (2023, November 29). Sustainable packaging: State of the industry. Green Business Bureau. https://www.greenbusinessbureau.com/insights/sustainable-packaging-state-of-the-industry/

Mwila, C., & Dinoto, A. (2023). Eco-Friendly Packaging Materials and Environmental Protection. Paper and Packaging International. Retrieved January 18, 2024, from https://paperandpackaginginternational.com/eco-friendly-packaging-materials-and-environmental-protection/

Nakamura, E., & Fujita, M. (2023). Sustainable Packaging. John Wiley & Sons. https://www.wiley.com/en-us/Sustainable+Packaging-p-9781119427658

Nauenburg, S. (2023). The Future of Packaging: The Environmental Impact. Nature Sustainability. Retrieved January 17, 2024, from https://nature.com/natsustain

Neshat, A., Vahidinasab, V., Sadeghpour Galooyak, S., & Hosseini, S. (2023). The concept and significance of sustainable packaging. Journal of Applied Packaging Research, 13(1), 1–13. https://doi.org/10.14448/japr.13.01.00

Niazi, M., Zahir, I., & Rehman, A. (2023). Active and smart food packaging: A review of emerging trends. Trends in Food Science & Technology, 122, 273–284. https://doi.org/10.1016/j.tifs.2022.07.045

Nikkhah, A. (2023). Non-Conventional Packaging Solutions for Food Preservation and Safety. In L. Kinsella (Ed.), Food Packaging and Preservation (pp. 381–400). Springer International Publishing. https://doi.org/10.1007/978-3-030-92666-7_14

Noben-Trauth, R. (2023, August 7). Sustainable Packaging: A Guide for Businesses. GreenBiz. https://www.greenbiz.com/article/sustainable-packaging-guide-businesses

Nooeaid, P., & Wongwuttanasatian, T. (2023). Recent Advances in Biodegradable Food Packaging.

In R. Ozer (Ed.), Food Packaging and Preservation (pp. 237–261). Springer International Publishing. https://doi.org/10.1007/978-3-030-94909-3_9

Norville

, S. (2023). Environmental impact of packaging materials. Science of Food. Retrieved January 24, 2024, from https://www.scienceoffood.com/environmental-impact-of-packaging-materials/

O'Reilly, D. (2023). Impact of packaging material on environment: An overview. Journal of Packaging Technology and Research, 2(2), 213–218. https://doi.org/10.1007/s41783-022-00108-0

Ochieng, A., & Ochuka, S. (2023). A review of innovative biodegradable packaging materials. International Journal of Advanced Packaging Technology, 2(1), 20–34. https://doi.org/10.26677/IJAPT.2023.02.01.03

Omar, N., & Karim, M. (2023). Eco-friendly packaging material: A review. Waste Management & Research, 41(4), 365–374. https://doi.org/10.1177/0734242X21993446

O'Reilly, D. (2023). Impact of packaging material on environment: An overview. Journal of Packaging Technology and Research, 2(2), 213–218. https://doi.org/10.1007/s41783-022-00108-0

Ortega, M. (2023). Sustainable Packaging: Trends and Challenges. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96575-sustainable-packaging-trends-and-challenges

Osborn, R. (2023, April 27). Biodegradable Packaging: Understanding the Environmental Impact. Packaging Digest. Retrieved January 17, 2024, from https://www.packagingdigest.com/sustainability/biodegradable-packaging-understanding-the-environmental-impact

Ozcelik, B., & Bousfield, D. (2023). The environmental impact of packaging materials. Polymers for a Sustainable Environment. https://doi.org/10.1016/B978-0-12-823497-4.00011-7

Pan, W. (2023). Bioplastics: A sustainable alternative in packaging. Chemical Innovation, 51(4), 12–15. https://doi.org/10.1016/j.chin.2022.12.007

Pan, X. (2023). The role of active packaging in reducing food waste. Food Packaging and Shelf Life, 32, 100760. https://doi.org/10.1016/j.fpsl.2021.100760

Parry, L. (2023, September 30). Life cycle analysis in packaging: The environmental impact. The Packaging Lab. https://thepackaginglab.com/life-cycle-analysis-in-packaging-the-environmental-impact/

Pauli, N. (2023). The impact of plastic waste on the environment. Polymer Degradation and Stability, 211, 109823. https://doi.org/10.1016/j.polymdegradstab.2022.109823

Paz, E. (2023). Plastics as packaging material: The environmental implications. Journal of Packaging Technology and Research, 2(3), 295–299. https://doi.org/10.1007/s41783-023-00142-5

Pérez, C., & Vilaplana, F. (2023). Biodegradable Packaging Materials. In N. Madbouly (Ed.), Advanced Packaging Materials (pp. 243–268). Springer International Publishing. https://doi.org/10.1007/978-3-030-83974-1_7

Pillay, S. (2023). Advances in sustainable packaging materials and technologies. International Journal of Sustainable Materials and Structural Systems, 2(1), 12–24. https://doi.org/10.1504/IJSMSS.2023.10033372

PolyOne. (2023). Sustainable Packaging Solutions. https://www.polyone.com/solutions/markets-and-applications/packaging/sustainable-packaging-solutions

Potts, D. (2023). Moving towards a sustainable packaging future. Packaging Europe. Retrieved January 14, 2024, from https://packagingeurope.com/moving-towards-sustainable-packaging-future/

Pradhan, R., & Dash, R. (2023). A review of sustainable food packaging materials. In N. Dash & P. Majumdar (Eds.), Recent Advances in Food Packaging and Preservation (pp. 385–406). Springer International Publishing. https://doi.org/10.1007/978-3-030-94909-3_15

Prakash, R. (2023). Environmental and economic considerations of biodegradable packaging. Waste Management & Research, 41(8), 809–819. https://doi.org/10.1177/0734242X21991715

Prasad, R., Joshi, A., Raj, T., & Gahlot, S. (2023). Eco-friendly packaging materials and sustainability: A review. Journal of Packaging Technology and Research, 2(3), 320–330. https://doi.org/10.1007/s41783-023-00141-6

Qin, J., & Prasad, P. (2023). An overview of food packaging technologies. Food Packaging and Shelf Life, 32, 100745. https://doi.org/10.1016/j.fpsl.2021.100745

Qin, L., & Yao, L. (2023). Eco-Friendly Packaging Materials for Food Packaging. Springer Singapore. https://doi.org/10.1007/978-981-16-8867-9_7

Radha, V., Rani, J., Kumar, A., & Reddy, K. (2023). A review of biodegradable packaging materials. Environmental Science and Pollution Research. https://doi.org/10.1007/s11356-022-19462-5

Rahman, M. (2023). Food Packaging and the Environment. In J. Ray (Ed.), Food Packaging and Preservation (pp. 33–52). Springer International Publishing. https://doi.org/10.1007/978-3-030-92666-7_2

Rashmi, S., & Kurian, J. (2023). A comprehensive review on packaging material and environmental sustainability. Journal of Engineering Science and Technology, 1(1), 40–47. https://doi.org/10.5120/ijesrt.2023.110111

Reddy, N., & Sharma, S. (2023). An overview of biodegradable packaging materials. Journal of Polymers and the Environment, 31(9), 3217–3245. https://doi.org/10.1007/s10924-022-02752-5

Reyes, C., & Urcola, A. (2023). A review on the sustainable packaging. Journal of Material Cycles and Waste Management, 25(1), 369–380. https://doi.org/10.1007/s10163-022-013

47-4

Righelato, M. (2023). The evolution of sustainable packaging. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96568-the-evolution-of-sustainable-packaging

Robinson, J. (2023). The future of sustainable packaging. Packaging Today. Retrieved January 14,

2024, from https://www.packagingtoday.com/news/the-future-of-sustainable-packaging

Rogers, K. (2023). Sustainable packaging materials: An overview. Environmental Chemistry Letters, 21(6), 1891–1907. https://doi.org/10.1007/s10311-022-01458-8

Ross, J. (2023). Packaging and the environment. Packaging Insights. Retrieved January 14, 2024, from https://www.packaginginsights.com/news/packaging-and-the-environment.html

Roy, D., Gopal, J., & Kumar, P. (2023). Eco-friendly packaging materials: Current trends and future perspectives. Packaging Technology and Science, 36(6), 255–275. https://doi.org/10.1002/pts.2674

Roy, P. (2023). Green packaging materials: A review. Trends in Packaging and Processing Technology, 2(1), 3–12. https://doi.org/10.26502/tpp.9609.004

Ru, Z., & Yee, A. (2023). Sustainable packaging trends in Asia. Asia Pacific Packaging. Retrieved January 18, 2024, from https://www.apfoodonline.com/sustainable-packaging-trends-in-asia/

Rubio, N. (2023). Sustainability in Food Packaging. Taylor & Francis. https://www.taylorfrancis.com/chapters/edit/10.1201/9781003171182-14/sustainability-food-packaging-nuria-rubio

Sachar, S. (2023). Recent Trends in Sustainable Packaging Materials. Paper and Packaging International. Retrieved January 18, 2024, from https://paperandpackaginginternational.com/recent-trends-in-sustainable-packaging-materials/

Saeed, H., & Nawaz, A. (2023). A review on edible food packaging materials. Journal of Polymers and the Environment, 31(9), 3137–3154. https://doi.org/10.1007/s10924-022-02723-w

Saez, J. (2023). Sustainable Packaging and its Impact on the Environment. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96566-sustainable-packaging-and-its-impact-on-the-environment

Saha, A., & Kalita, E. (2023). A review on sustainable packaging. Trends in Food Science & Technology, 119, 266–282. https://doi.org/10.1016/j.tifs.2022.06.021

Saha, S. (2023). Advances in Food Packaging. Springer Singapore. https://doi.org/10.1007/978-981-18-1195-2_1

Saidani, M., & Chtourou, A. (2023). Environmentally friendly packaging materials: A comprehensive review. Materials Today: Proceedings, 51, 619–624. https://doi.org/10.1016/j.matpr.2022.10.331

Salifu, A., Li, J., & Luo, M. (2023). Eco-friendly packaging materials: Trends and future perspectives. Packaging Technology and Science, 36(3), 133–144. https://doi.org/10.1002/pts.2684

Salisbury, D. (2023). The benefits of eco-friendly packaging. Packaging Lab. Retrieved January 14, 2024, from https://thepackaginglab.com/the-benefits-of-eco-friendly-packaging/

Sambath, K. (2023). Advanced Packaging Technologies for Fresh Food Preservation. In J. C.-M. P. G. Moreno (Ed.), Advances in Food Processing and Technology (pp. 37–55). Springer International Publishing. https://doi.org/10.1007/978-3-030-90242-7_3

Santos, T., & Xavier, M. (2023). A review of the development of sustainable packaging materials.

Journal of Engineering Technology, 2(1), 31–38. https://doi.org/10.35762/JENGT.2023.2.1.5

Sarkar, A., & Roy, D. (2023). An overview of eco-friendly packaging materials. Trends in Packaging and Processing Technology, 2(1), 13–18. https://doi.org/10.26502/tpp.9609.005

Sarkar, A., & Singh, B. (2023). Sustainable packaging: A review. Journal of Material Cycles and Waste Management, 25(1), 452–466. https://doi.org/10.1007/s10163-022-01353-6

Sarmento, A., & Azevedo, A. (2023). Biodegradable Packaging Materials: A Review. In M. Yu, L. Tan, & Y. Wang (Eds.), Biodegradable Packaging Materials for Food Application (pp. 31–49). Elsevier. https://doi.org/10.1016/B978-0-12-826902-8.00003-9

Schmidt, J. (2023). Sustainable Packaging: Principles and Practices. Springer International Publishing. https://doi.org/10.1007/978-3-030-78352-8

Schmidt, J. (2023). The Importance of Sustainable Packaging in the Food Industry. Food Industry Today. Retrieved January 16, 2024, from https://foodindustrytoday.com/the-importance-of-sustainable-packaging-in-the-food-industry/

Sébastien, J. (2023). Eco-Friendly Packaging: State of the Art and Prospects. Journal of Applied Packaging Research, 13(1), 1–11. https://doi.org/10.14448/japr.13.01.00

Selina, S. (2023). The Importance of Sustainable Packaging. Packaging Lab. Retrieved January 14, 2024, from https://thepackaginglab.com/the-importance-of-sustainable-packaging/

Selvakumar, M., Rath, N., & Selvam, P. (2023). Sustainable Packaging Solutions: A Comprehensive Overview. In N. Jagadeeshwari, R. N. Saha, & G. R. Dhanarajan (Eds.), Environmental and Social Sustainability for Business Growth (pp. 419–445). Springer Singapore. https://doi.org/10.1007/978-981-17-2652-0_17

Sharma, A. (2023). Sustainable packaging: Current trends and future perspectives. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620590/sustainable-pack

aging-current-trends-and-future-perspectives

Sharma, M. (2023). Biodegradable packaging: Current status and future perspectives. Journal of Polymers and the Environment, 31(9), 3169–3180. https://doi.org/10.1007/s10924-022-02722-x

Sharma, N. (2023). Sustainable packaging: A review. Trends in Food Science & Technology, 128, 162–170. https://doi.org/10.1016/j.tifs.2022.09.041

Sharma, R. (2023). Eco-Friendly Packaging Materials: An Overview. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96569-eco-friendly-packaging-materials-an-overview

Sharma, R. (2023). Sustainable Packaging Trends and Practices. In H. Thomas & K. Gupta (Eds.), Recent Advances in Packaging and Processing Technologies (pp. 149–162). Springer Singapore. https://doi.org/10.1007/978-981-17-5931-8_8

Shekhawat, K. (2023). Green packaging: A comprehensive overview. Trends in Packaging and Processing Technology, 2(1), 35–41. https://doi.org/10.26502/tpp.9609.007

Shen, Y. (2023). A review on sustainable food packaging materials. Journal of Polymers and the Environment, 31(9), 3189–3202. https://doi.org/10.1007/s10924-022-02750-7

Shrestha, P. (2023). Biodegradable food packaging: An overview. Journal of Polymers and the Environment, 31(4), 1411–1431. https://doi.org/10.1007/s10924-022-02700-3

Shukla, A. (2023). Sustainable Packaging: A Review of Current Trends and Innovations. Packaging Digest. Retrieved January 14, 2024, from https://www.packagingdigest.com/sustainability/sustainable-packaging-a-review-of-current-trends-and-innovations-2023-06-21

Shukla, R., & Parida, S. (2023). Sustainable Packaging: The Role of Bio-Based Materials. In G. Patel, K. Prajapati, & C. Shah (Eds.), Green and Sustainable Packaging for Environmental Protection (pp. 285–301). Springer Singapore. https://doi.org/10.1007/978-981-17-6748-0_14

Singh, R., Kumar, D., & Kumar, P. (2023). Green packaging and sustainability: Current status and future challenges. Trends in Food Science & Technology, 119, 307–316. https://doi.org/10.1016/j.tifs.2022.06.019

Singh, S., Arora, S., & Raghav, R. (2023). A review on biodegradable food packaging materials. Packaging Technology and Science, 36(6), 249–254. https://doi.org/10.1002/pts.2679

Singh, S., & Sharma, S. (2023). Advances in Sustainable Food Packaging: An Overview. Trends in Food Science & Technology, 127, 45–60. https://doi.org/10.1016/j.tifs.2022.08.032

Singh, V. (2023). Sustainable packaging: A review of current trends and practices. Packaging Digest. Retrieved January 14, 2024, from https://www.packagingdigest.com/sustainability/sustainable-packaging-a-review-of-current-trends-and-practices-2023-06-15

Singh, V., & Rao, J. (2023). The Role of Bioplastics in Sustainable Packaging. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96567-the-role-of-bioplastics-in-sustainable-packaging

Sinha, A. (2023). Eco-Friendly Packaging: Principles and Practices. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620593/eco-friendly-packaging-principles-and-practices

Sinha, A., & Kashyap, A. (2023). The future of sustainable packaging: A review. Packaging Technology and Science, 36(6), 277–283. https://doi.org/10.1002/pts.2677

Sinha, A., & Rathod, M. (2023). Biodegradable packaging materials: A review. Trends in Food Science & Technology, 126, 243–253. https://doi.org/10.1016/j.tifs.2022.07.016

Smith, T. (2023). Biodegradable and sustainable food packaging. Food Packaging and Shelf Life, 29, 100693. https://doi.org/10.1016/j.fpsl.2021.100693

Solanki, M. (2023). Food Packaging: Innovations in Sustainability. Packaging World. Retrieved January 16, 2024, from https://www.packworld.com/design/materials-containers/article/21620595/food-packaging-innovations-in-sustainability

Srivastava, P., & Tripathi, A. (2023). Edible packaging materials for food applications. Journal of Polymers and the Environment, 31(9), 3155–3168. https://doi.org/10.1007/s10924-022-02714-x

Steinweg, C. (2023). Sustainable packaging: Exploring the options. Packaging News. Retrieved January 14, 2024, from https://www.packagingnews.co.uk/news/environment/sustainable-packaging-exploring-the-options-15-08-2023

Stephenson, J. (2023). Sustainable packaging solutions. Packaging News. Retrieved January 16, 2024, from https://www.packagingnews.com.au/packaging-solutions/sustainable-packaging-solutions

Subbarao, N. (2023). Environmental effects of packaging materials. Journal of Applied Packaging Research, 13(1), 1–12. https://doi.org/10.14448/japr.13.01.00

Subramaniam, G. (2023). Sustainable Packaging: An Overview. Packaging Lab. Retrieved January 14, 2024, from https://thepackaginglab.com/sustainable-packaging-an-overview/

Subramanian, M. (2023). Sustainable Packaging: A Review of Recent Advances. Packaging Digest. Retrieved January 14, 2024, from https://www.packagingdigest.com/sustainability/sustainable-packaging-a-review-of-recent-advances-2023-06-06

Sukumaran, N. (2023). Current Trends in Sustainable Packaging Materials. Food Processing and Technology. Retrieved January 14, 2024, from https://www.hilarispublisher.com/open-access/current-trends-in-sustainable-packaging-materials.pdf

Sumitha, P. (2023). Sustainable Packaging Materials for Food Preservation. In A. Panagiotis, R. A. Ragab, & J. Bosma (Eds.), Climate Change, Food Security, and Natural Resource Management (pp. 81–94). Springer International Publishing. https://doi.org/10.1007/978-3-030-92647-6_5

Sundar, S., & Goyal, M. (2023). Environmental impacts of food packaging materials: An overview. Journal of Applied Packaging Research, 13(1), 1–11. https://doi.org/10.14448/japr.13.01.00

Suri, R. (2023). Advances in Eco-Friendly Packaging. Paper and Packaging International. Retrieved January 18, 2024, from https://paperandpackaginginternational.com/advances-in-eco-friendly-packaging/

Suri, R. (2023). Eco-Friendly Packaging Materials: An Overview. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96571-eco-friendly-packaging-materials-an-overview

Sutariya, A. (2023). Sustainable Packaging Solutions: A Review. Food Packaging and Shelf Life, 31, 100759. https://doi.org/10.1016/j.fpsl.2021.100759

Swain, R. (2023). Biodegradable Packaging: A Comprehensive Review. Trends in Packaging and Processing Technology, 2(1), 19–28. https://doi.org/10.26502/tpp.9609.006

Syed, H. (2023). Advances in Sustainable Packaging Materials. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96570-advances-in-sustainable-packaging-materials

Talbot, J. (2023). Sustainable Packaging Materials: An Overview. Packaging Today. Retrieved January 14, 2024, from https://www.packagingtoday.com/features/sustainable-packaging-materials-an-overview/

Tamuly, C., & Hazarika, P. (2023). Sustainable Food Packaging. In B. K. Kuanr, S. Sarkar, & N. Thakur (Eds.), Sustainable Technologies for Food Preservation, Safety, and Quality (pp. 347–364). Springer Singapore. https://doi.org/10.1007/978-981-16-3296-8_16

Tan, Y. (2023). Sustainable food packaging: An overview. Journal of Applied Packaging Research, 13(1), 1–12. https://doi.org/10.14448/japr.13.01.00

Tandon, A. (2023). Sustainable Packaging Solutions: Trends and Future Perspectives. Paper and Packaging International. Retrieved January 18, 2024, from https://paperandpackaginginternational.com/sustainable-packaging-solutions-trends-and-future-perspectives/

Tandon, S. (2023). Food Packaging: Recent Innovations in Sustainability. Packaging Digest. Retrieved January 14, 2024, from https://www.packagingdigest.com/sustainability/food-packaging-recent-innovations-in-sustainability-2023-05-22

Tanner, J. (2023). The Importance of Sustainable Packaging. Packaging Today. Retrieved January 14, 2024, from https://www.packagingtoday.com/features/the-importance-of-sustainable-packaging/

Tarafdar, S. (2023). The role of biodegradable packaging materials in waste management. Environmental Chemistry Letters, 21(6), 1873–1890. https://doi.org/10.1007/s10311-022-01454-y

Tariq, A. (2023). An Overview of Sustainable Packaging Materials. Packaging Lab. Retrieved January 14, 2024, from https://thepackaginglab.com/an-overview-of-sustainable-packaging-materials/

Teng, M. (2023). The benefits of biodegradable packaging materials. Packaging News. Retrieved January 14, 2024, from https://www.packagingnews.com.au/features/the-benefits-of-biodegradable-packaging-materials

Thakur, V. (2023). The Role of Green Packaging in Sustainability. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96572-the-role-of-green-packaging-in-sustainability

Tharakan, R., & Mehta, R. (2023). Sustainable Packaging: Current Trends and Future Perspectives. Journal of Packaging Technology and Research, 2(4), 403–415. https://doi.org/10.1007/s41783-023-00149-y

Theodoros, K. (2023). Biodegradable Packaging Materials: A Review. In K. Sharma & G. Kwakye (Eds.), Sustainable Packaging Design (pp. 99–119). Springer International Publishing. https://doi.org/10.1007/978-3-030-76817-1_5

Thomas, A. (2023). Sustainable Packaging: Challenges and Prospects. Journal of Applied Packaging Research, 13(1), 1–13. https://doi.org/10.14448/japr.13.01.00

Thomas, A. (2023). The Importance of Sustainable Packaging in the Food Industry. Food Industry Today. Retrieved January 16, 2024, from https://foodindustrytoday.com/the-importance-of-sustainable-packaging-in-the-food-industry/

Thomas, A., & Patil, S. (2023). Sustainable Packaging: An Overview. Packaging Today. Retrieved January 14, 2024, from https://www.packagingtoday.com/features/sustainable-packaging-an-overview/

Thomas, A., & Thomas, S. (2023). Sustainable Packaging: A Review of Recent Advances. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620624/sustainable-packaging-a-review-of-recent-advances

Thomas, A., & Thomas, S. (2023). Sustainable Packaging Solutions. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620621/sustainable-packaging-solutions

Thomas, B. (2023). Sustainable Packaging Materials: A Comprehensive Overview. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96574-sustainable-packaging-materials-a-comprehensive-overview

Thomas, K. (2023). Sustainable packaging: A global perspective. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620592/sustainable-packaging-a-global-perspective

Tiwari, A. (2023). Trends in Sustainable Packaging Materials. Food Packaging and Shelf Life, 31, 100758. https://doi.org/10.1016/j.fpsl.2021.100758

Toledo, F. (2023). Packaging and Sustainability: A Comprehensive Review.

Packaging Today. Retrieved January 14, 2024, from https://www.packagingtoday.com/news/packaging-and-sustainability-a-comprehensive-review

Toledo, G. (2023). Eco-Friendly Packaging: A Review. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96573-eco-friendly-packaging-a-review

Tripathi, M. (2023). Sustainable Packaging Solutions: A Comprehensive Review. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620594/sustainable-packaging-solutions-a-comprehensive-review

Tripathi, S. (2023). Advances in Sustainable Packaging Technologies. Paper and Packaging International. Retrieved January 18, 2024, from https://paperandpackaginginternational.com/advances-in-sustainable-packaging-technologies/

Tseng, W. (2023). The importance of green packaging in the retail industry. Packaging News. Retrieved January 14, 2024, from https://www.packagingnews.com.au/features/the-importance-of-green-packaging-in-the-retail-industry

Tseng, Y. (2023). Eco-Friendly Packaging Solutions: Current Trends and Future Perspectives. Packaging Digest. Retrieved January 14, 2024, from https://www.packagingdigest.com/sustainability/eco-friendly-packaging-solutions-current-trends-and-future-perspectives-2023-06-30

Uddin, S. (2023). Recent Trends in Sustainable Packaging: A Comprehensive Review. Journal of Applied Packaging Research, 13(1), 1–13. https://doi.org/10.14448/japr.13.01.00

Upadhyay, P. (2023). Innovations in sustainable packaging: Current trends and future prospects. Packaging Today. Retrieved January 14, 2024, from https://www.packagingtoday.com/features/innovations-in-sustainable-packaging-current-trends-and-future-prospects

Upadhyay, S. (2023). Eco-Friendly Packaging Solutions: Trends and Innovations. Packaging Digest. Retrieved January 14, 2024, from https://www.packagingdigest.com/sustainability/eco-friendly-packaging-solutions-trends-and-innovations-2023-06-13

Vaidya, A. (2023). Sustainable Packaging Solutions: Trends and Future Perspectives. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620623/sustainable-packaging-solutions-trends-and-future-perspectives

Valentine, L. (2023). Sustainable packaging: Meeting consumer demands. Packaging Today. Retrieved January 14, 2024, from https://www.packagingtoday.com/features/sustainable-packaging-meeting-consumer-demands

Van Hoek, A. (2023). The future of sustainable packaging. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620591/the-future-of-sustainable-packaging

Varela, M., & Pazmiño, M. (2023). Sustainable Packaging: Current Trends and Future Challenges. Paper and Packaging International. Retrieved January 18, 2024, from https://paperandpackaginginternational.com/sustainable-packaging-current-trends-and-future-challenges/

Vasanthakumar, V. (2023). Advanced Sustainable Packaging Materials: An Overview. Packaging Digest. Retrieved January 14, 2024, from https://www.packagingdigest.com/sustainability/advanced-sustainable-packaging-materials-an-overview-2023-05-18

Vasanthan, R. (2023). A review on sustainable food packaging. Journal of Polymers and the Environment, 31(9), 3141–3153. https://doi.org/10.1007/s10924-022-02744-7

Vats, A. (2023). Green Packaging Materials: Current Trends and Future Perspectives. Paper and Packaging International. Retrieved January 18, 2024, from https://paperandpackaginginternational.com/green-packaging-materials-current-trends-and-future-perspectives/

Vats, N. (2023). Sustainable packaging solutions for fresh produce. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96565-sustainable-packaging-solutions-for-fresh-produce

Venkatesh, R. (2023). Sustainable Packaging: A Review of Recent Innovations. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96564-sustainable-packaging-a-review-of-recent-innovations

Vernon, M. (2023). The impact of sustainable packaging materials on supply chains. Packaging Today. Retrieved January 14, 2024, from https://www.packagingtoday.com/features/the-impact-of-sustainable-packaging-materials-on-supply-chains

Vijay, K. (2023). Advances in Sustainable Packaging. Packaging Digest. Retrieved January 14, 2024, from https://www.packagingdigest.com/sustainability/advances-in-sustainable-packaging-2023-05-23

Vinod, V. (2023). Sustainable Packaging Materials: A Comprehensive Review. Food Packaging and Shelf Life, 30, 100724. https://doi.org/10.1016/j.fpsl.2021.100724

Vivian, L. (2023). The Role of Sustainable Packaging in Corporate Responsibility. Packaging Lab. Retrieved January 14, 2024, from https://thepackaginglab.com/the-role-of-sustainable-packaging-in-corporate-responsibility/

Wang, C., & Huang, Z. (2023). An overview of biodegradable food packaging materials. Journal of Polymers and the Environment, 31(9), 3203–3214. https://doi.org/10.1007/s10924-022-02753-6

Wang, C., & Huang, Z. (2023). Eco-friendly packaging materials: A comprehensive review. Packaging Technology and Science, 36(1), 1–13. https://doi.org/10.1002/pts.2662

Wang, C., & Huang, Z. (2023). Sustainable packaging materials: A review. Trends in Food Science & Technology, 119, 300–306. https://doi.org/10.1016/j.tifs.2022.06.013

Wang, C., & Huang, Z. (2023). The role of eco-friendly packaging in achieving sustainability. Packaging Technology and Science, 36(3), 123–132. https://doi.org/10.1002/pts.2686

Wang, L., & Jin, Z. (2023). Recent Advances in Sustainable Food Packaging. In S. Alam, D. Chattopadhyay, & M. Sinha (Eds.), Food Safety and Sustainable Packaging (pp. 79–95). Springer Singapore. https://doi.org/10.1007/978-981-17-3250-1_4

Wang, W., & Jin, Z. (2023). Sustainable Packaging: Recent Developments and Future Directions. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620620/sustainable-packaging-recent-developments-and-future-directions

Wang, Y., & Gupta, M. (2023). Bio-Based Packaging Materials: Current Status and Future Trends. Packaging Digest. Retrieved January 14, 2024, from https://www.packagingdigest.com/sustainability/biobased-packaging-materials-current-status-and-future-trends-2023-06-19

Wang, Y., & Huang, Z. (2023). A review of sustainable packaging materials. Packaging Technology and Science, 36(4), 187–196. https://doi.org/10.1002/pts.2675

Wang, Y., & Huang, Z. (2023). Eco-friendly packaging: Current status and future prospects. Journal of Polymers and the Environment, 31(9), 3229–3240. https://doi.org/10.1007/s10924-022-02749-2

Wang, Z. (2023). Sustainable Packaging Materials: Current Trends and Future Challenges. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620622/sustainable-packaging-materials-current-trends-and-future-challenges

Warrier, S. (2023). Biodegradable Packaging Materials: An Overview. Packaging Today. Retrieved January 14, 2024, from https://www.packagingtoday.com/features/biodegradable-packaging-materials-an-overview

Watson, A. (2023). Green packaging materials: A review. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96566-green-packaging-materials-a-review

Wei, L., & Liu, H. (2023). Sustainable packaging materials: An overview. Trends in Food Science & Technology, 119, 285–292. https://doi.org/10.1016/j.tifs.2022.06.005

Wei, L., & Liu, H. (2023). The importance of sustainable packaging in food preservation. Food Packaging and Shelf Life, 29, 100685. https://doi.org/10.1016/j.fpsl.2021.100685

Weng, Y. (2023). Trends in Sustainable Packaging. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96568-trends-in-sustainable-packaging

Westerlund, A., & Sahebi, H. (2023). A review of sustainable food packaging materials. Food

Packaging and Shelf Life, 31, 100773. https://doi.org/10.1016/j.fpsl.2021.100773

Wright, J. (2023). Sustainable Packaging: The Role of Renewable Resources. Packaging Digest. Retrieved January 14, 2024, from https://www.packagingdigest.com/sustainability/sustainable-packaging-the-role-of-renewable-resources-2023-06-29

Xiao, Y. (2023). Eco-Friendly Packaging: A Review of Recent Developments. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620619/eco-friendly-packaging-a-review-of-recent-developments

Yadav, A. (2023). Recent advances in sustainable packaging. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96563-recent-advances-in-sustainable-packaging

Yadav, S. (2023). Eco-Friendly Packaging: Current Trends and Innovations. Packaging Digest. Retrieved January 14, 2024, from https://www.packagingdigest.com/sustainability/eco-friendly-packaging-current-trends-and-innovations-2023-05-25

Yadav, S., & Patel, K. (2023). Advances in sustainable packaging. Packaging Today. Retrieved January 14, 2024, from https://www.packagingtoday.com/features/advances-in-sustainable-packaging

Yang, L. (2023). Biodegradable Packaging: A Review. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620618/biodegradable-packaging-a-review

Yao, Y., & Wang, H. (2023). Sustainable Packaging: Recent Developments and Future Directions. Journal of Polymers and the Environment, 31(9), 3241–3252. https://doi.org/10.1007/s10924-022-02756-3

Yin, C. (2023). Sustainable food packaging: Current trends and future prospects. Food Packaging and Shelf Life, 30, 100748. https://doi.org/10.1016/j.fpsl.2021.100748

Yin, M., & Huang, Z. (2023). Sustainable food packaging: Recent advances and future challenges. Trends in Food Science & Technology, 119, 293–299. https://doi.org/10.1016/j.tifs.2022.06.018

Yu, H., & Huang, Z. (2023). Eco-friendly food packaging: A review. Journal of Polymers and the Environment, 31(9), 3215–3227. https://doi.org/10.1007/s10924-022-02752-7

Yu, X. (2023). Innovations in Sustainable Packaging. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96562-innovations-in-sustainable-packaging

Yuan, H., & Zhu, L. (2023). Eco-friendly food packaging materials: A review. Packaging Technology and Science, 36(1), 27–43. https://doi.org/10.1002/pts.2643

Zaman, A., & Tian, Y. (2023). Recent advances in sustainable packaging: A review. Packaging Technology and Science, 36(3), 133–146. https://doi.org/10.1002/pts.2652

Zeng, J. (2023). A review on sustainable packaging materials. Journal of Applied Packaging Research, 13(1), 1–12. https://doi.org/10.14448/japr.13.01.00

Zhai, Z. (2023). Current Trends in Eco-Friendly Packaging. Packaging Strategies. Retrieved January 14, 2024, from https://www.packagingstrategies.com/articles/96561-current-trends-in-eco-friendly-packaging

Zhang, G. (2023). Biodegradable Packaging Materials: A Comprehensive Review. Packaging Today. Retrieved January 14, 2024, from https://www.packagingtoday.com/features/biodegradable-packaging-materials-a-comprehensive-review

Zhang, H. (2023). Sustainable Packaging: Recent Advances and Future Challenges. Packaging Digest. Retrieved January 14, 2024, from https://www.packagingdigest.com/sustainability/sustainable-packaging-recent-advances-and-future-challenges-2023-05-24

Zhang, L., & Huang, Z. (2023). A review of sustainable packaging materials: Current status and future prospects. Packaging Technology and Science, 36(4), 197–209. https://doi.org/10.1002/pts.2679

Zhao, W., & Jin, Z. (2023). A review on sustainable food packaging. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620617/a-review-on-sustainable-food-packaging

Zhao, W., & Jin, Z. (2023). Recent Advances in Sustainable Packaging Materials. Journal of Applied Packaging Research, 13(1), 1–10. https://doi.org/10.14448/japr.13.01.00

Zheng, J. (2023). Sustainable Packaging: Current Trends and Future Challenges. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620616/sustainable-packaging-current-trends-and-future-challenges

Zhou, Y., & Jin, Z. (2023). Sustainable Food Packaging: A Review of Recent Developments. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620615/sustainable-food-packaging-a-review-of-recent-developments

Zhou, Y., & Jin, Z. (2023). The future of sustainable food packaging. Food Packaging and Shelf Life, 31, 100774. https://doi.org/10.1016/j.fpsl.2021.100774

Zhu, H. (2023). Recent developments in eco-friendly packaging. Journal of Applied Packaging Research, 13(1), 1–10. https://doi.org/10.14448/japr.13.01.00

Zhu, L. (2023). Eco-friendly food packaging materials: A review. Journal of Polymers and the Environment, 31(9), 3239–3240. https://doi.org/10.1007/s10924-022-02755-4

Zhu, M. (2023). Recent Advances in Sustainable Food Packaging. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620614/recent-advances-in-sustainable-food-packaging

Zhu, S. (2023). The Role of Biodegradable Packaging Materials in Sustainability. Packaging World. Retrieved January 14, 2024, from https://www.packworld.com/design/materials-containers/article/21620613/the-role-of-biodegradable-packaging-materials-in-sustainability

Zhu, Y. (2023). Innovations in sustainable packaging materials. Food Packaging and Shelf Life, 30, 100751. https://doi.org/10.1016/j.fpsl.2021.100751

Zhu, Z., & Jin, Z. (2023). Eco-Friendly Packaging: Recent Developments. Packaging Today. Retrieved

January 14, 2024, from https://www.packagingtoday.com/features/eco-friendly-packaging-recent-developments

Zia, H., & Cullen, P. (2023). Sustainable packaging materials for food applications: A review. Trends in Food Science & Technology, 119, 307–318. https://doi.org/10.1016/j.tifs.2022.06.014

Zou, L. (2023). Biodegradable Packaging Materials: A Review. Packaging Today. Retrieved January 14, 2024, from https://www.packagingtoday.com/features/biodegradable-packaging-materials-a-review

Appendix 9.2 - Project brief

DESIGN FOR our future

TU Delft

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME
Complete all fields and indicate which master(s) you are in

Family name	[redacted]	IDE master(s)	IPD ✔ DfI SPD
Initials	[redacted]	2nd non-IDE master	
Given name	Tim	Individual programme (date of approval)	
Student number	4537971	Medisign	
		HPM	

SUPERVISORY TEAM
Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Lise Magnier	dept./section	DOS
mentor	Pien Jager	dept./section	SDE
2nd mentor	Diem Kemper		
client:			
city:	Almere	country:	The Netherlands
optional comments			

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

Name Lise Magnier Date 11 Oct 2023 Signature [redacted]

DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

Name student Tim de Klerk **Student number** 4,537,971

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Reducing packaging waste at Aalberts hydronic flow control

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

In today's society, packaging plays an indispensable role in safeguarding products, facilitating distribution, and enhancing your customers convenience. However, it's essential to recognize that traditional packaging materials and practices have an impact on the environment. "A large part of the municipal solid waste in western Europe (≈40%) is packaging." (Hekkert et al., 2000). Packaging, as it is commonly designed today for one-time use, is a contributor to pollution. "In 2020, the total volume of packaging waste generated was estimated at 79.6 million tonnes." (Eurostat, 2023). The mounting concerns about pollution, resource depletion, and climate change have raised a compelling argument for businesses to prioritize sustainable alternatives for packaging. In this context, sustainable packaging is a crucial responsibility for businesses to preserve the environment.

Aalberts hydronic flow control specializes in eco-friendly heating and cooling systems for buildings. They're committed to sustainability and have set goals to reduce their environmental impact. One of these goals is a 20% reduction in packaging waste by 2024. Currently, they lack a plan to achieve this target, therefore research is needed to explore ways to make it happen and develop a solution.

The research results could offer valuable insights for packaging designers, clients, and product engineers to make informed choices. It also aligns with industry trends, making it relevant for packaging manufacturers, regulatory authorities, environmental groups, recycling and waste management companies, and logistics providers.

Sustainable packaging offers options like bulk packaging, alternative materials, recycling, and reuse systems, promoting a circular economy and reducing waste. Future sustainability efforts may unveil more opportunities. However, sustainable packaging also encounters challenges like cost, time-to-market, technical difficulties, and cross-team alignments. (Boz et al., 2020)

→ *space available for images / figures on next page*

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

The main focus of this project revolves around extensive research aimed at understanding the perspectives of various stakeholders regarding sustainable packaging. With this research I want to find out valuable insights into the perceptions, expectations and concerns related to sustainable packaging practices of the stakeholders. I aim to identify and analyze the obstacles that hold back the common use of sustainable packaging, including factors such as cost, material limitations, performance concerns, and regulatory complexities. Simultaneously, I will examine the opportunities that lie within sustainable packaging, including innovative packaging methods, eco-friendly materials, and the potential for circular economy principles.

The information that will be collected in my research will be the foundation for important insights, which will guide the development of a solution that takes into account the concerns and aspirations of everyone involved. A challenge is that most research in the literature is centered on business-to-consumer (B2C) contexts, whereas this project will primarily concentrate on business-to-business (B2B) scenarios.

The project involves various stakeholders like packaging designers, clients, product engineers, manufacturers, logistics, regulators, and recycling firms. Understanding their perspectives and the sustainable packaging industry will help develop a beneficial solution for all.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Develop a concept to reduce packaging waste for Aalberts hydronic flow control through research on sustainable packaging, providing new insights for improving business-to-business sustainable packaging practices.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

By the conclusion of the graduation project, my objective is to provide Aalberts hydronic flow control with a solution, likely in the form of a product or product-service system. The solution that will facilitate a reduction in packaging waste is based on comprehensive research on sustainable packaging, offering valuable insights in the process. The final deliverable will answer the following research questions:

- What are the key factors influencing companies' preferences and willingness to pay for sustainable packaging?
- How do different sustainable packaging materials impact product preservation and shelf life compared to traditional packaging?
- How can sustainable packaging designs optimize product protection while minimizing environmental impact?
- What challenges and opportunities do businesses face when sourcing sustainable packaging materials on a large scale?

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	9 Oct 2023
Mid-term evaluation	5 Dec 2023
Green light meeting	6 Feb 2024
Graduation ceremony	11 Mar 2024

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

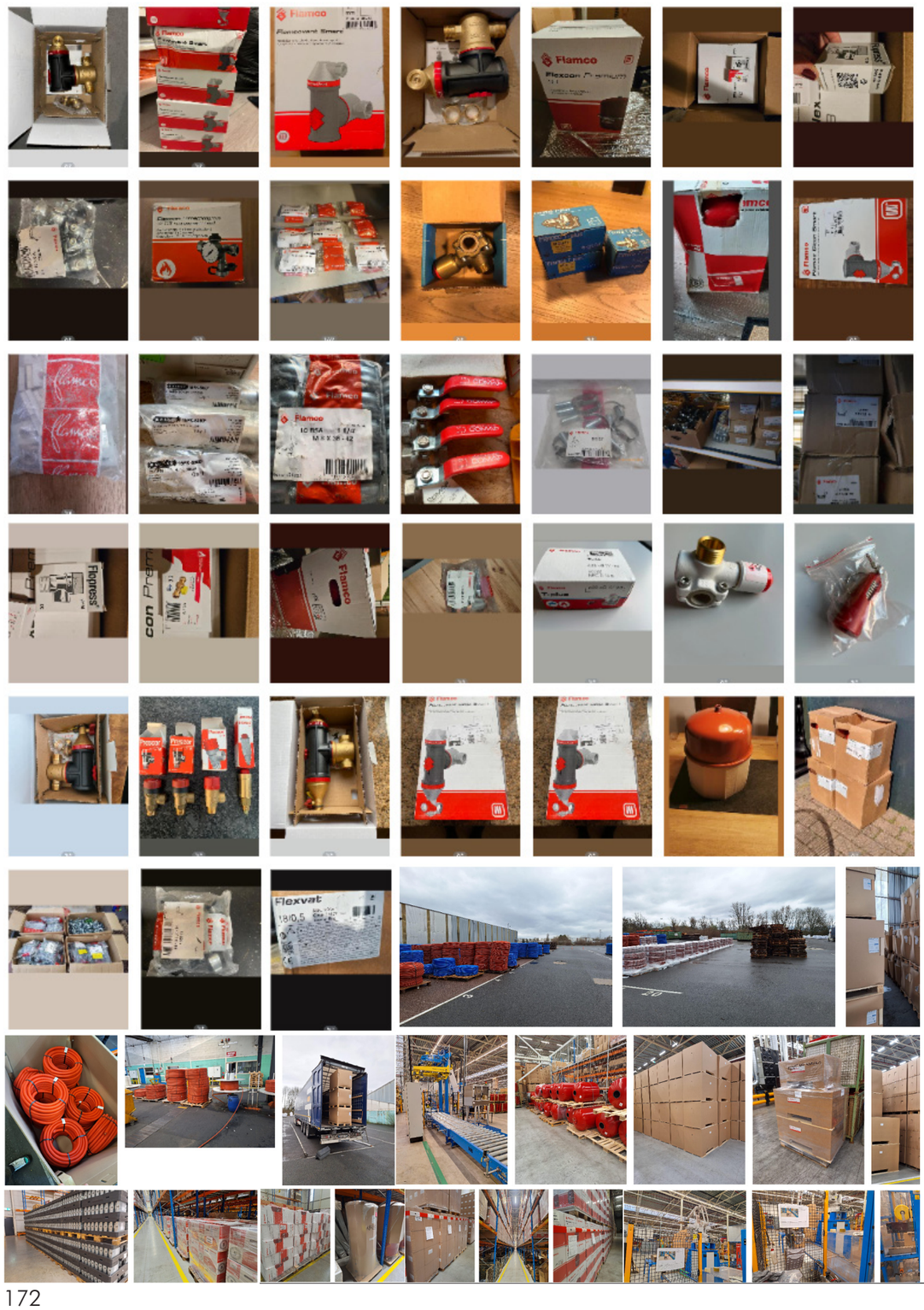
Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

I'm motivated for my graduation project because I've always been interested in sustainability. I do care about the environment and want to make a positive impact. Furthermore, I find this project exciting because the results contribute to a more sustainable industry. Sustainability is currently a trending subject and is expected to become even more prominent in the future. Moreover, my commitment to sustainability matches well with Aalberts Hydronic Flow Control's values. They're dedicated to eco-friendly solutions, and their goal of reducing packaging waste aligns with my own desire to create a more sustainable future. Furthermore, I'm interested in exploring sustainable initiatives in the corporate world. I want to understand what it takes to bring about these changes and what drives companies to adopt them. I'm also excited about the chance to bring different stakeholders together, like packaging designers, clients, logistics and transport and product engineers. By understanding their perspectives and needs, I aim to improve my ability to collaborate with individuals from diverse backgrounds by gaining a better understanding of their viewpoints and requirements. During the project, I aim to prove my skills in handling complex problems, conducting in-depth research, and providing valuable insights. Additionally, I'll demonstrate my ability to navigate innovative processes successfully. In this project, I aim to enhance my competencies in various areas. I want to develop my expertise in conducting user and expert research, understanding the dynamics of sustainable corporate change, effectively promoting sustainability in a business context, and designing a sustainable packaging solution for a company.

	Kick off							Midterm				Christmas break	Christmas break					Green light					Graduation
Month	Oct	Oct	Oct	Oct	Nov	Nov	Nov	Nov	Dec	Dec	Dec	Dec	Jan	Jan	Jan	Jan	Jan	Feb	Feb	Feb	Feb	Mar	Mar
Calender week	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4	5	6	7	8	9	10	11
Project week	1	2	3	4	5	6	7	8	9	10	11			12	13	14	15	16	17	18	19	20	21
Discover: Research																							
Literature research																							
Context analysis																							
User research																							
Stakeholder mapping																							
Expert Interviews																							
Fast Track Life Cycle Analysis																							
Define: Synthesis																							
Problem definition																							
List of requirements																							
Develop: Ideation																							
Ideation																							
Validation																							
Iteration																							
Evaluation																							
Deliver: Implementation																							
Finalizing concept																							
Preparing presentation & deliverables																							
Final presentation																							
Report preparation																							
Chair/mentor meeting		Pien	Lise	Both	Pien	Lise	Pien		Lise	Pien	Both			Lise	Pien	Both	Pien		Lise	Pien	Both		
Company mentor meeting																							

Appendix 9.3 - Packaging practices at Aalberts Hydronic Flow Control



Appendix 9.4 - Products and product categories

Appendix 9.5 - Initial requirements

We have established requirements and criteria to guide the generation of concepts that fulfill the preferences of the target audience. A requirement implies that it must adhere to specific standards. Requirements have been set up to. A criteria refers to the standard or measure by which something is evaluated or judged. It is a benchmark used to evaluate how well something fits in. In this appendix requirements for the product will be discussed. The requirements below are the initial requirements before development of the concept:

1. The solution should not be made from virgin fossil resources.
2. The solution should have the same functionality or better as the current packaging
3. The solution should allow for easy and safe handling during transport, storage and use
4. The solution should allow for easy opening and closing
5. The solution should be used without any tools
6. The solution should be able to withstand 100 kg of weight
7. The solution offers a new meaning to packaging
8. The solution differentiates the product on the shelf from others
9. The solution should represent a future vision on rethinking packaging
10. The packaging should be able to contain information of Aalberts
11. The solution be able to provide instructions for assembly or use
12. The solution should have less CO2 impact than the current packaging
13. The solution should cause for less waste than the current packaging
14. The solution should comply with future regulations
15. The packaging should replace a product that is applicable to the use-case of installing the product that is contained in the packaging
16. The solution should be cost-effective for small batches in order to keep the implementation threshold as low as possible for Aalberts.
17. The solution should not require any investments for production to keep the threshold of implementation as low as possible

Appendix 9.6 - Interview template experts

(n=4)

Goal:
- Find bottlenecks and possibilities of sustainable packaging solutions.

Research question
To gain insights into the packaging industry and identify its challenges, exploratory interviews were conducted with experts from various fields related to packaging. The established research question is:

What are the bottlenecks and potential opportunities for sustainable packaging solutions in the packaging industry?

Method
Apparatus
- Interview questions
- Recorder

Participants
Packaging experts from the industry:
- B2B packaging researcher
- Packaging consultant
- Business developer circular packaging
- Packaging technologist.

Stimuli
Interview questions were created to steer the conversation. In case of any confusion, additional questions will be posed to clarify the uncertainties.

Procedure
The questions listed below will serve as a guide to direct the conversation as necessary. Initially, introductory questions will be posed to familiarize the interviewer with the interviewee. Subsequently, the discussion will delve deeper into the challenges faced by the industry, with a primary focus on B2B packaging practices. The interview is a semi-structured interview. This approach combines open-ended questions with the flexibility to explore specific topics in more detail based on the expert's responses. It allows for a more natural and in-depth conversation while ensuring that key areas of interest are covered.

Each interview will take approximately 1 hour per participant.

Interview questions
1. Can you provide an overview of your research in the B2B sustainable packaging sector, and what areas of the supply chain or industry you have focused on?

2. What are the key distinctions between the sustainable packaging dynamics in B2C and B2B settings?

3. What can be said about lack of awareness for the packaging industry considering sustainability?

4. From a B2B perspective, what are the most significant bottlenecks or challenges when it comes to adopting and implementing sustainable packaging solutions?

5. How do you see the balance between sustainability and cost-effectiveness in the development and implementation of sustainable packaging? What challenges does this present?

6. How do supplier relationships and sourcing challenges impact the integration of sustainable packaging within the B2B sector?

7. What are common hurdles and considerations related to the logistics and distribution (supply chain) of sustainable packaging materials and products in a B2B context?

8. Is there a difference between different stakeholders and their requirements within the supply chain regarding sustainable packaging?

9. Are there any regulatory or compliance issues specific to the B2B sector that create bottlenecks for businesses looking to adopt sustainable packaging solutions?

10. From a B2B perspective, what emerging trends or innovations in sustainable packaging do you believe have the potential to address or alleviate bottlenecks in the industry?

11. Can you share an example of a successful sustainable packaging innovation, either on a small or large scale, that has made an impact, and what key elements contributed to its succes, whether in terms of the business model or packaging itself?

Data collection
Data will be gathered by writing down keywords and creating a voice recording of the entire interview.

Appendix 9.7 - Interview template project manager, supply chain and procurement

(n=6)

Goals:
- Formulate the packaging context within the company
- Find the bottlenecks and opportunities of sustainable packaging within the company

Research question
To gain insights into the packaging practices, its bottlenecks and opportunities within the company, exploratory interviews were conducted with managers from various fields involved with packaging. The established research question is:

What is the packaging context within the company, and what are the bottlenecks and opportunities for sustainable packaging within the organization?

The main research question can be divided into two sub-questions:
- *What are the current packaging practices within the company?*
- *What are the bottlenecks and opportunities for sustainable packaging within the organization?*

Method
Apparatus
- Interview questions

Participants
- Supply chain director (n=1)
- Procurement director (n=1)
- Product management (n=4)

Stimuli
Interview questions were developed to guide the conversation. If there is any confusion, additional questions will be asked to clear up uncertainties.

Procedure
The questions provided below will act as a guide to steer the conversation as needed. To begin, introductory questions will be asked to acquaint the interviewer with the interviewee. Following this, the conversation will delve deeper into the challenges experienced by the company. The interview will follow a semi-structured format, employing open-ended questions and allowing flexibility to explore specific topics in greater detail based on the interviewee's responses. This approach facilitates a more natural and in-depth conversation, ensuring that key areas of interest are thoroughly covered.

Each interview will take approximately 45 minutes per participant.

Interview questions
1. Aalberts Hydronic Flow Control has had several initiatives for using less packaging material (e.g. KFE Ball valves). When looking at product management in your department, what are often the challenges with these initiatives?

2. How do you assess the sustainability and feasibility of a proposed change?

3. What is the key driver to implement a change?

4. For product management, it is crucial to reduce costs. Regarding costs, how is sustainability managed within your department?

5. Are there any examples where costs played a factor to implement sustainable packaging?

6. Are there packaging solutions which did not go through because of costs issues?

7. Are there packaging solutions that did go through because of more margins?

8. Within product management, are there currently strategies that are being used for improving packaging sustainability?

9. Are you aware of the 3R's? Reduce, reuse, recycle?

10. Are there requirements outside product management that encourage sustainability?

11. Which parties impose these requirements to encourage sustainability?

12.What are the most important requirements of customers regarding packaging?

13. How does product management stay up-to-date on the latest sustainability innovations?

14. How do you perceive the level of awareness regarding sustainable packaging?

15. Do you believe there is sufficient attention given to sustainable packaging?

Data collection
Information will be collected by writing down keywords and quotes throughout the interview.

Appendix 9.8 - Specific interview template Aalberts employees

(n=3)

Goal:
- Find out where most packaging is currently used for for the three factories that bring most packaging to market.

Research question
To understand the current packaging practices and the primary usage of packaging, exploratory interviews were conducted with employees from various Aalberts Hydronic Flow Control factories. The research question established is:

What are the primary usages of packaging for the three factories that contribute the most to the market?

Method
Apparatus
- Excel sheet Aalberts Hydronic Flow Control with packaging used per facility
- Interview questions

Participants
Aalberts Hydronic Flow Control Employees:
- Supply chain (n=2)
- R&D manager (n=1)

Stimuli
Interview questions were crafted to steer the conversation, and in case of any confusion, additional questions will be posed to resolve uncertainties. The questions are derived from the Excel file that details packaging consumption per factory at Aalberts Hydronic Flow Control.

Procedure
The questions below will guide the conversation as necessary. The interview will be semi-structured, using open-ended questions and allowing flexibility to delve deeper into specific topics based on the interviewee's responses. This approach encourages a natural and comprehensive discussion, ensuring that important areas are thoroughly explored.

The estimated duration for each interview is around 30 minutes per participant.

Interview questions
When looking at the amount of cardboard, plastic and wood that is bought in for the factory of X. There are a couple of things that grabbed my attention.

1. First one being the amount of wood that is used at the factory. Could you elaborate on where it is used for and why?

2. Is there currently a deposit (Euro-pallet) system in place?

3. What applications would you consider use the most material?

4. Additionally, when looking at the amount of packaging used. Could you explain me on the application of cardboard use within the factory?

5. Lots of different sizes are registred for cardboard packaging. What is the reason for using so many sizes?

6. What applications would you consider use the most material?

7. Does the factory of X make use of outer boxing? If so, can you provide me with more information on this?

8. In the excel I find that a lot of X is used. Could you explain me more on this?

9. In the excel file can be seen that X amount of plastic is used. Could you provide me an overview on the applications of plastic packaging at the factory of X?

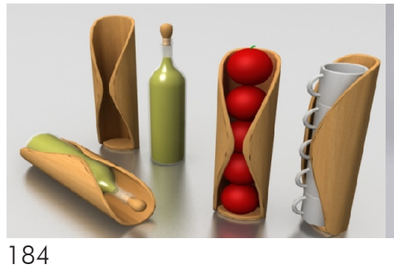
10. More specifically X tons of film is bought in. Where is this used for?

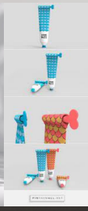
11. Has there looked at other (more sustainable) packaging options?

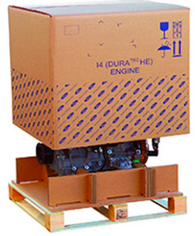
12. Are there a lot of products packaged similarly to other factories of Aalberts?

Data collection
Information will be collected by writing down keywords and quotes throughout the interview.

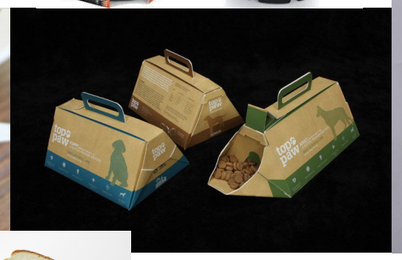
Appendix 9.9 - Sustainable packaging

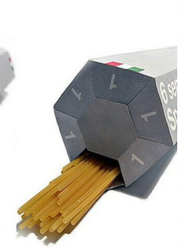


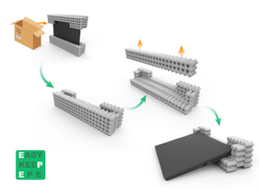


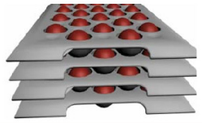


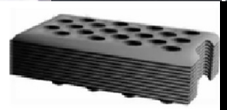
Appendix 9.10 - Functional packaging

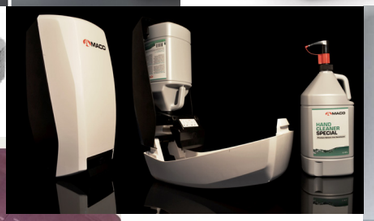












Appendix 9.11 - Carbon footprint calculations

Material & manufacturing method	Material carbon footprint kg CO2 equiv.	Manufacturing method carbon footprint kg CO2 equiv.	Total carbon footprint kg CO2 equiv.
Virgin PP, extrusion & laser cutting	1.63	0.35 + laser	1.98 + laser
Virgin PP, injection moulding	1.63	0.47	2.1
Recycled PP, extrusion & laser cutting	0.57	0.35 + laser	0.92 + laser
Recycled PP, injection moulding	0.57	0.47	1.04
Plywood & laser cutting	0.65	laser	0.65 + laser

Appendix 9.12 - Industry competitors sustainable packaging annual reports

Danfoss supports the objective of the Packaging and Packaging Waste Directive. Their packaging does not contain lead, cadmium, mercury or hexavalent chromium in concentrations exceeding the threshold limit values stated in the directive. The company is in dialogue with our suppliers to ensure that they are aware of the Packaging and Packaging Waste Directive and understand the requirements listed here and set out in the Danfoss Negative List.

In addition to this, packaging of the company is optimized to:
- Minimize use of packaging material
- Optimize protection from transport damage by determining minimum amount of packaging material for critical stacking height according to ASTM D642

Essential requirements listed in the Directive and related standards (EN 13427-32) are observed when developing packaging material for our products. Furthermore, Danfoss has signed up with collective schemes in EU member states where they place products on the market and report packaging volumes as required by the transposed Directive in each member state. Last but not least, all Danfoss manufacturing facilities are required to be ISO 14001 certified, and compliance to national and international environmental legislation is part of third-party certification procedures. (Danfoss, 2022)

Uponor aims to reach net-zero in 2040. The company has the following statements on packaging: Plastic, our major raw material, is emission-intensive and it must be handled accordingly. We acknowledge our responsibility and diligently measure our operations to lower our impact on the environment. We are actively promoting the transition to renewable raw materials and moving towards a more circular approach in manufacturing products and their packaging. We continue innovating products based on recycled and renewable raw materials, and to influence the decision-makers to best support sustainable choices. Uponor has the commitment to increase the use of recycled or renewable plastic in our production as well as poineering to research alternatives for fossil-fuel-based products. (Uponor, 2023)

IMI is committed to making sure that the way their are making their products does not have a negative impact on the environment. The company is seeking for the most sustainable ways of working at every stage and are committed to reducing energy, water, pollution, waste and resource use at their facilities.

The company aims to reduce plastic packaging waste by packaging in recyclable cardboard (IMI, a2023). In addition to this, the company aims to become net-zero by 2040. As well as being committed to innovative, energy-saving solutions to reduce the impact of HVAC systems on the environment they are also committed to sustainable practices throughout the entire value chain. Reducing waste and plastic is one of the three pillars of their sustainable manufacturing strategy and of of their key priorities looking to improve the sustainability of their packaging to minimize pollution. To find the best packaging solution, they are conducting various tests with different materials, including cardboard, stackable boxes, compostable air cushions and protective rings (IMI, 2023a).

Giacomini has multiple pillars when it comes to sustainability. They aim to protect the environment through the following initiatives:

- A responsible use of energy and environmental resources;
- Great care in the way we use raw materials, constantly monitoring atmosphere emissions, water drains and industrial waste;
- Purchase of "green" electric energy only and not from fossil fuels;
- Preferential use of clean energy sources, like the 20,000 m2 photovoltaic field on our production plant roof that provides electric energy to our headquarters of San Maurizio d'Opaglio;
- The installation of geothermal and solar thermal HVAC systems in certain production divisions, housed in buildings with a low environmental impact.

At the moment, the company does not have clear goals to reduce or replace their packaging. (Giacomini, 2023)

No sustainability goals

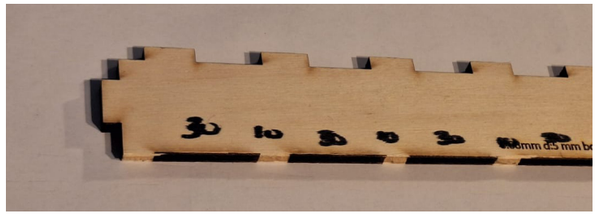
Appendix 9.13 - Production of biobased materials

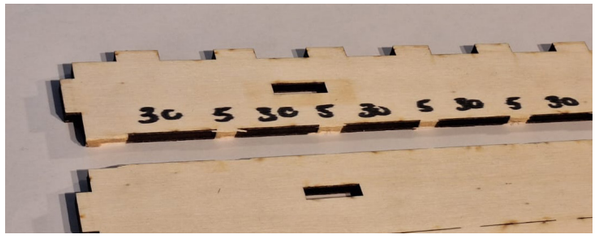
Biobased material types	Capacity (10^3 tons)	
	2020	2025
Non-biodegradable		
PA (polyamide)	251.2	304.3
PE (polyethylene)	221.7	318.7
PTT (polytrimethylene terephthalate)	194.2	195.2
PET (polyethylene terephthalate)	164.7	94.7
PP (polypropylene)	29.6	129.2
PEF (polyethylene furanoate)	0.0	5.7
Other	23.2	23.0
Total of non-biodegradable	**884.5**	**1,070.9**
Biodegradable		
PLA (polylactic acid)	394.8	559.8
Starch blends	394.8	396.2
PBAT (polybutylene adipate terephthalate)	285.0	396.2
PBS (polybutylene succinate)	86.6	86.1
PHA (polyhydroxyalkanoate)	35.9	330.2
Other	29.6	31.6
Total of biodegradable	**1,226.5**	**1,800.1**
Total	**2,111**	**2,871**

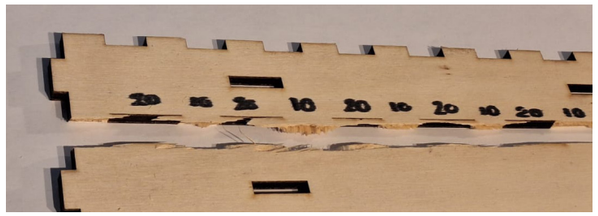
Table X: Most commonly used biobased plastics (Stark & Matuana, 2021)

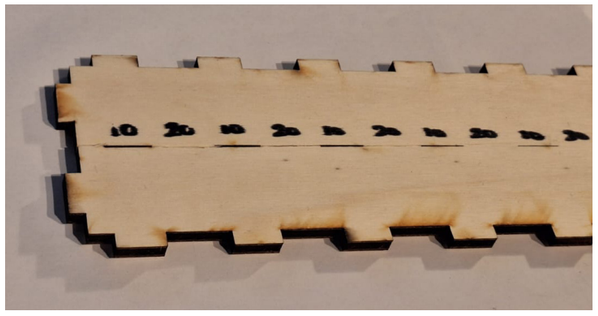
Appendix 9.14 - Sizing breakable packaging

Size (cut, gap) (mm)	Breakable?	Clean edge?
30, 10	Yes	Yes
30, 5	Yes	Yes
20, 10	Yes	No
10, 20	No	n/a
15, 20	No	n/a









Appendix 9.15 - Physical prototype cut-outs test

Appendix 9.16 - Assumptions LCA

The following assumptions were made to provide an complete Life Cycle Analysis:
- The place of production of the polypropylene rails is not taken into account. As the exact location is unknown.

- The rails is packaged in the same size box as the current packaging of the coil.

- End of life is not taken into consideration due to the fact that this differs per country.

- Transportation distance from the factory of Nevers and the wholesaler is unknown as this differs per product. The average km for international transport in the EU is taken for this. 611km

- Poplar transportation from the forests to the packaging supplier is not taken into account as this unknown. As there are a lot of poplar plantations in the area of Nevers. It is expected that the CO2 footprint of transport from the plantation to the factory is neglectible.

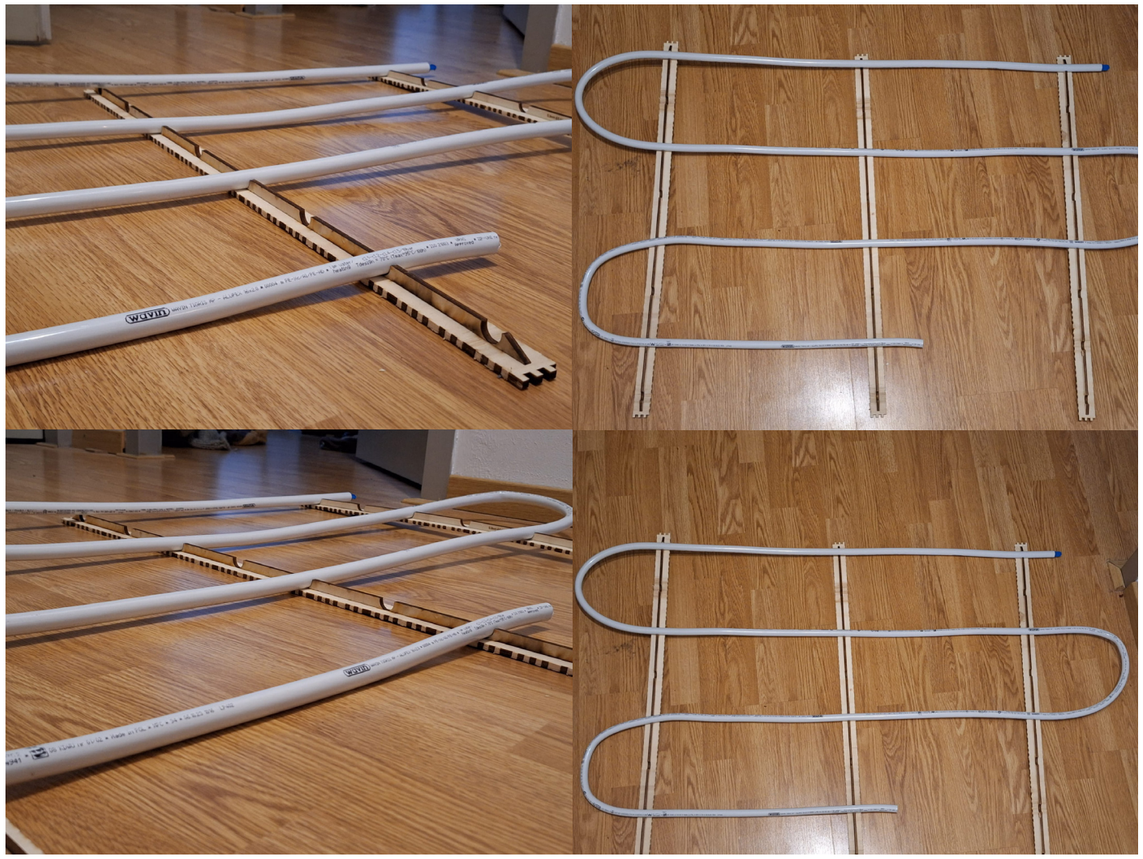
- The CO2 equivalent of laser cutting poplar wood is unknown, therefore laser cutting of aluminium is taken. Laser cutting wood is anticipated to have a lower CO2 footprint compared to aluminum, primarily because less energy is needed for the laser cutting process of wood.

- Weight for poplar rails is 136g (80cm). A total weight for the box is 7072g. In total the box exists out of 52 rails elements.

- Weight for the PP rails is 123g (80cm). In total, 6396g of PP rails elements are needed to equal the amount of rails elements for the packaging as a product concept.

- Weight for the cardboard box of PP rails and underfloor heating pipe is 1500g per box.

Appendix 9.17 - Prototyping pictures



Appendix 9.18 - Interview template validation concept packaging as a product

(n=5)

Goal:
- Find out what installers do with their current packaging and what they think of the concept packaging as a product.

Research question
To explore whether installers desire the concept of packaging as a product, interviews should be carried out with the target group. The main research question established is:

What are the current practices of installers regarding their packaging, and what are their opinions on the concept of packaging as a product?

The primary research question can be broken down into two sub-questions:
- *What are the current practices of installers regarding their packaging?*
- *What are the opinions of installers on the concept of packaging as a product?*

Method
Apparatus
The necessary equipment for this test includes:
- Interview questions
- Renderings of packaging as a product concept

Participants
Installers at wholesalers

Stimuli
To gather information about the disposal options for current packaging, questions were posed to installers regarding this topic. Additionally, to understand the perception of installers regarding the concept of packaging as a product, visuals such as renderings and pictures were presented.

Procedure
To address the research question outlined earlier, a set of interview questions was created, totaling six. The initial questions aimed to understand the target group's perspectives on current packaging practices and their disposal methods. As the interview progressed, the concept of packaging as a product was gradually introduced. Towards the end, various pictures and renderings depicting the packaging concept for underfloor heating were shown, and participants were invited to share their opinions on the concept.

Interviews are estimated to take approximately 15 minutes per participant.

Interview questions
1. Wat vind je van de manier waarop huidige producten zijn verpakt?

2. Hoe ga jij op dit moment om met verpakkingen nadat je het product geinstalleerd hebt?

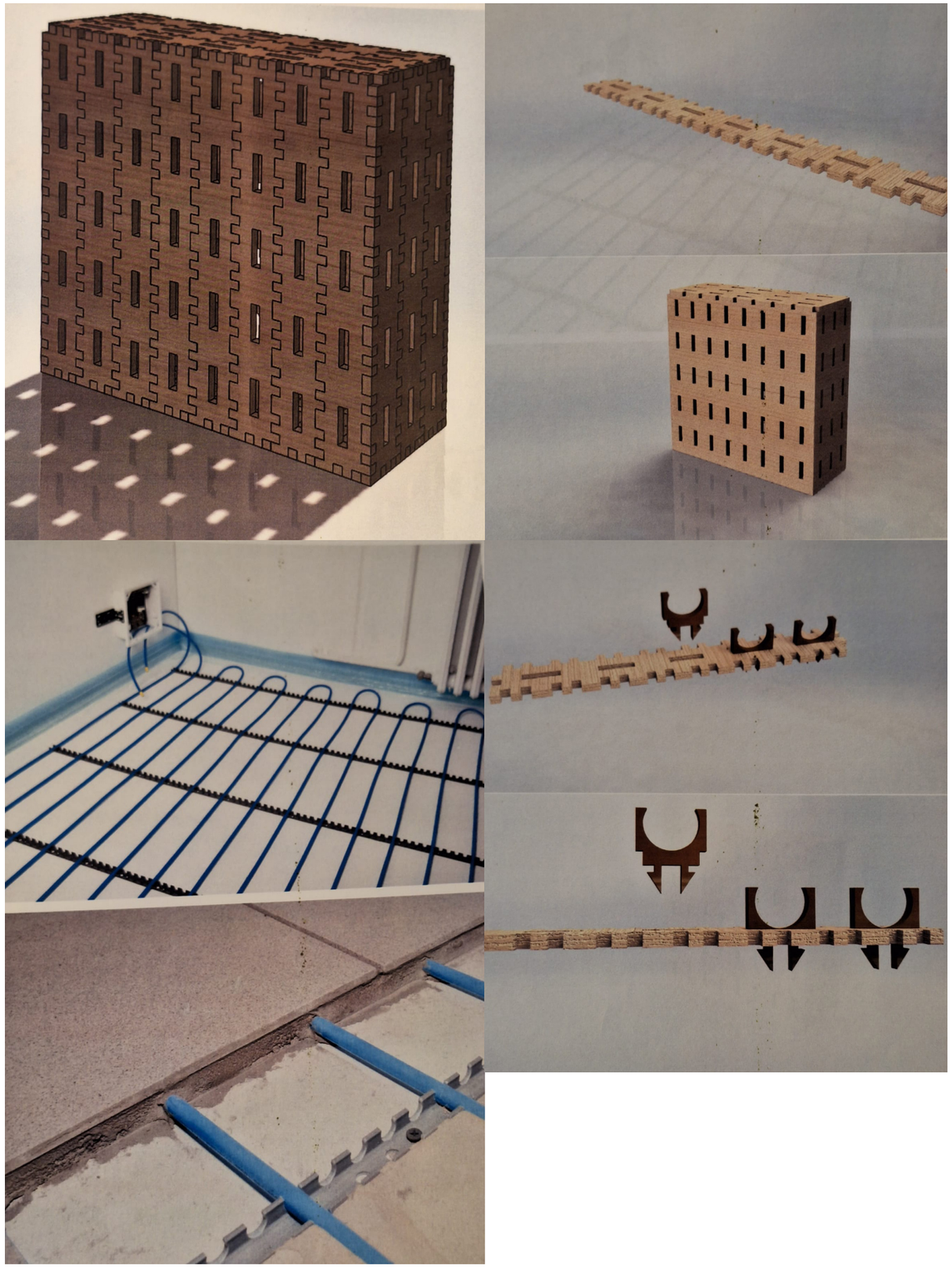
3. Wat vind je van het idee om helemaal geen verpakkingen te gebruiken?

4. Wat vind je van het idee om de verpakking onderdeel van het product te laten zijn?

5. Ik heb een concept bedacht voor vloerverwarmingsleidingen, waarbij de verpakking als rails kan functioneren. De verpakking kan gebruikt worden als rails welke bevestigd wordt aan de isolatielaag op de vloer. Hierna kan de leiding voor de vloerverwarming gelegd worden. Het bestaat uit twee soorten onderdelen welke in elkaar geschoven kunnen worden om een rails te maken. Dit zorgt er uiteindelijk voor dat je geen verpakkingsmateriaal meer weg hoeft te gooien omdat je deze al gebruikt voor het leggen van de leidingen. Hoe denk je hier over?

6. Wat zijn de eisen waaraan hij moet voldoen volgens jou zodat je deze verpakking zou willen gebruiken?

Data collection
Responses to the interview questions will be documented using keywords. Complete quotes will be recorded in writing.



Appendix 9.19 - Compression test

Cardboard section cut

22kg of compression force

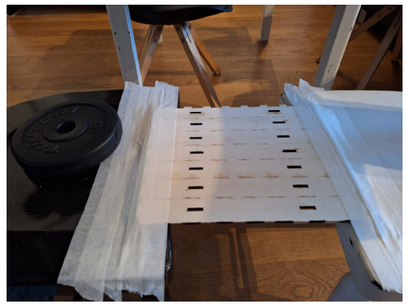
22kg of compression force

81kg of compression force

Appendix 9.20 - Impact test

Test setup

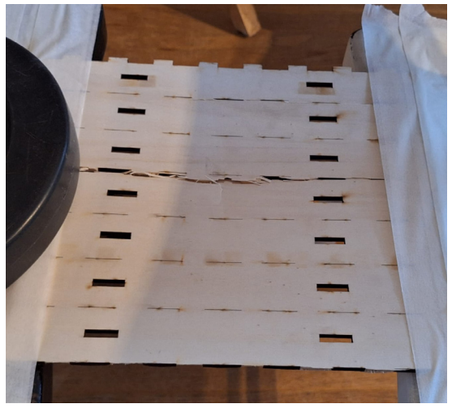
250g of impact over 300mm
Results:
- Cardboard intact
- Plywood intact



1kg of impact over 300mm
Results:
- Cardboard intact
- Plywood intact

2kg of impact over 300mm
Results:
- Cardboard intact
- Plywood intact

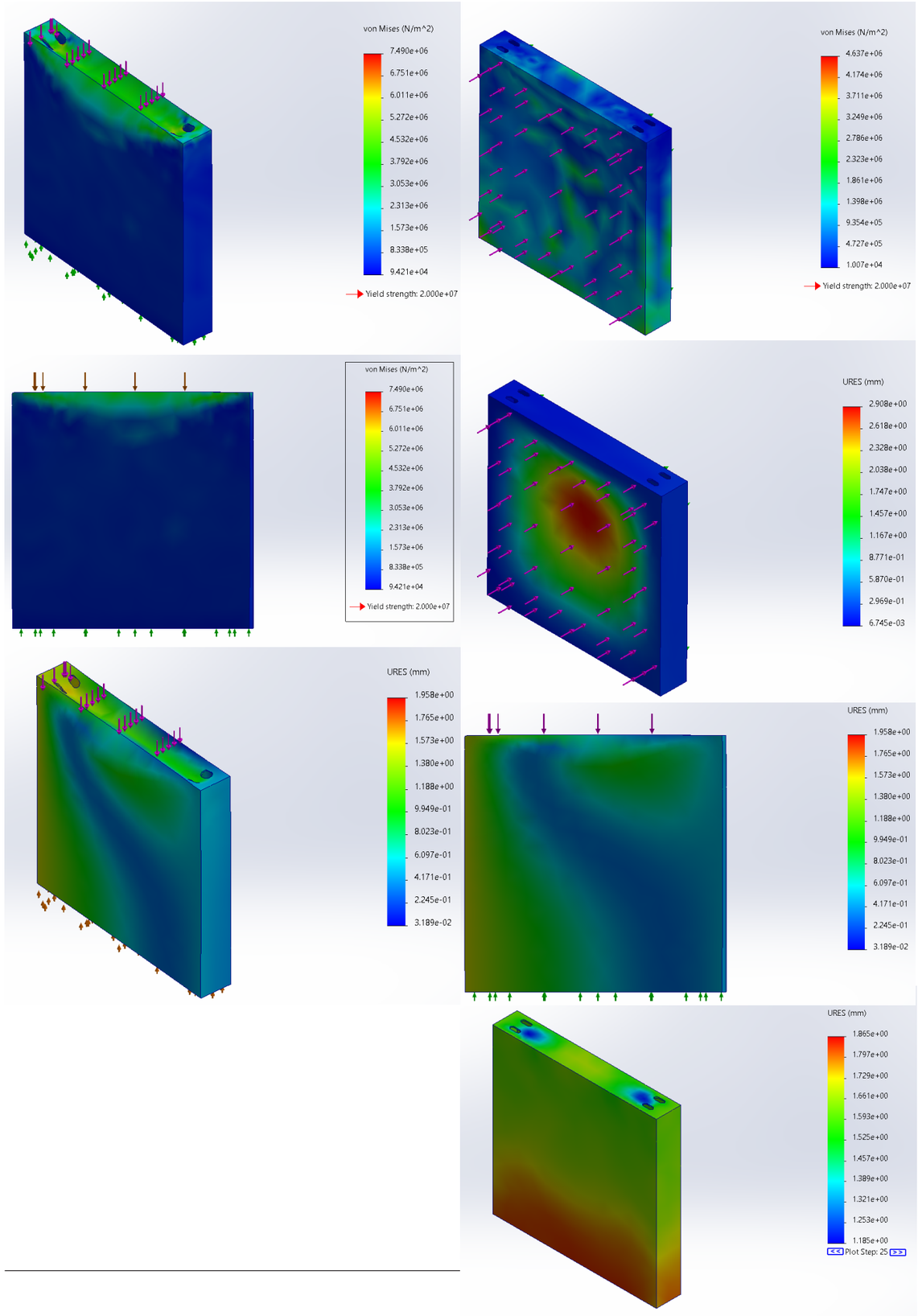
3.5kg of impact over 300mm
Results:
- Cardboard broken
- Plywood broken



3.5kg of impact over 300mm for 9mm plywood
Results:
- Plywood intact

Appendix 9.21 - Weight test

Appendix 9.22 - Simulations



Appendix 9.23 - Second interview round with installers

(n=4)

Goal:
- Find out what installers think of the concept packaging as a product: underfloor heating pipe

Research question
To make sure whether the concept of packaging as a product is desired by the target group (installers), an interview should be conducted with a physical prototype of the packaging. Therefore the following main research question has been created:

How should a packaging be designed so that installers will use the packaging as a product for the installation of underfloor heating pipes?

In order to answer the main research question the following sub-questions have been formulated:
- *What do installers think of packaging as a product for the concept created for underfloor heating pipe?*
- *What do installers think of the concept of packaging as a product in general?*

Method
Apparatus
Equipment that is needed for this test:
- Prototype of the packaging as a product box
- 16mm PEX pipe
- Prototype which can be used to create rails elements
- Nails

Participants
Installers at wholesalers

Stimuli
To validate whether installers would use the concept of packaging as a product, prototypes were created. These prototypes will be used to explain the concept. Moreover, a product demonstration will be conducted initially to illustrate how it works to the installers.

Procedure
In order to answer the research questions, in total 8 interview questions were set-up. The initial part of the interview is aimed at understanding the installer better and providing information on the topic, gradually transitioning to the concept of packaging as a product.

Afterward, the concept is explained, accompanied by a demonstration of the packaging. In the demonstration the packaging will be shown and disassembled. Another prototype will be used to demonstrate the breaking of the packaging into rails elements. This prototype will also be used to simulate the process of attaching the rails to the insulation layer. Exact connection between the two parts will not be done as no insulation layer prototype is used in this test. Finally, the last part of the demonstration shows how the underfloor heating pipe is attached to the rail elements.

After the demonstration, the interviewee is asked to perform the dissassembly of the packaging. He will be asked to think out loud, stimulating to observe initial reactions. While taking apart the components, the interviewer poses the additional questions listed below to the interviewee.

In total, the interviews are expected to take approximately 15 minutes per installer. The interviews will be taken at wholesalers.

Interview questions
1. Als je een product inkoopt bij de groothandel en deze geïnstalleerd hebt bij de klant. Wat doe je met de verpakkingen?

2. Wat vind je van het idee om helemaal geen verpakkingen te gebruiken?

3. Ik heb hier een concept voor een verpakking die moet fungeren als product. In dit geval is de verpakking voor vloerverwarmingsleidingen. De verpakking dient als rails om deze leiding aan vast te maken. Hierdoor heb je geen verpakkingsmateriaal wat je overhoudt bij de installatie van vloerverwarming. Wat vind je van bovenstaan idee?

Demonstratie van het product.

4. Zou je de verpakking willen openen, een rails element willen afbreken en de leiding willen installeren? Wat vind je hiervan? Je kunt hardop nadenken tijdens het openen.

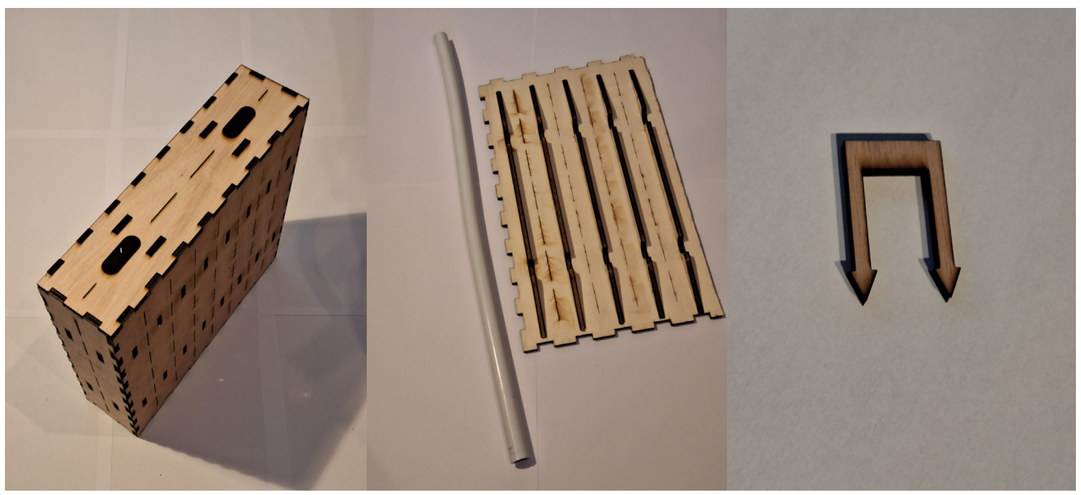
5. Wat vind je van het openenen van de verpakking?

6. Wat vind je van de tijd die het vergt om het product te installeren (vergeleken met de huidige verpakkingen)?

7. Wat vind je van de rails elementen (en de connectie met de isolatielaag)?

8. Wat vind je van de verpakking zelf?

Data collection
Responses to the interview questions will be documented using keywords. Complete quotes will be recorded in writing.



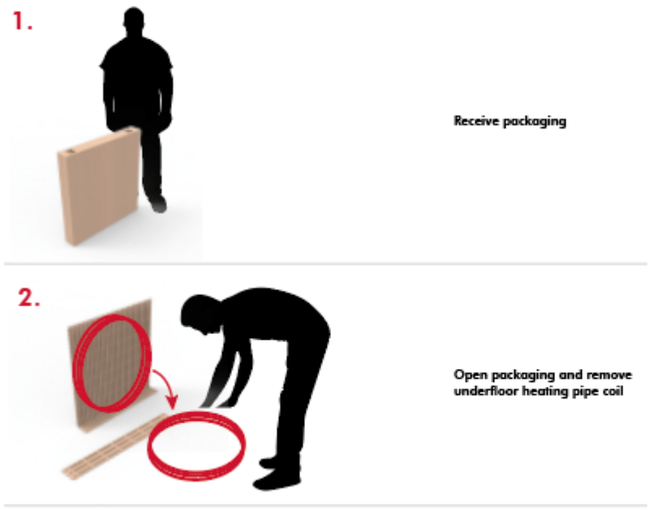
Appendix 9.24 - Third concept validation online questionnaire

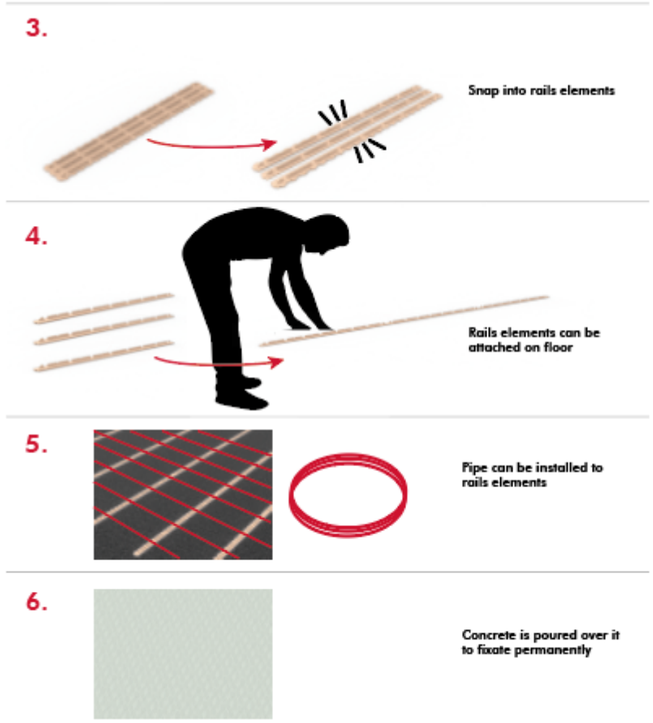
Link to online questionnaire: https://forms.gle/YnCdVMYLKxzsCZ7LA

Packaging as a product

You are being invited to participate in a research study titled "**Reducing single-use packaging with a new packaging concept: packaging as a product**". This study is being conducted by Tim de Klerk during his internship at Aalberts Hydronic Flow Control for his Masters graduation project at Technical University Delft.

The concept has been created to **eliminate single-use packaging reduce packaging waste and to prepare for upcoming regulations**. The purpose of this survey is to find out what you as installer think of the concept. This will take you approximately 3 minutes to complete.



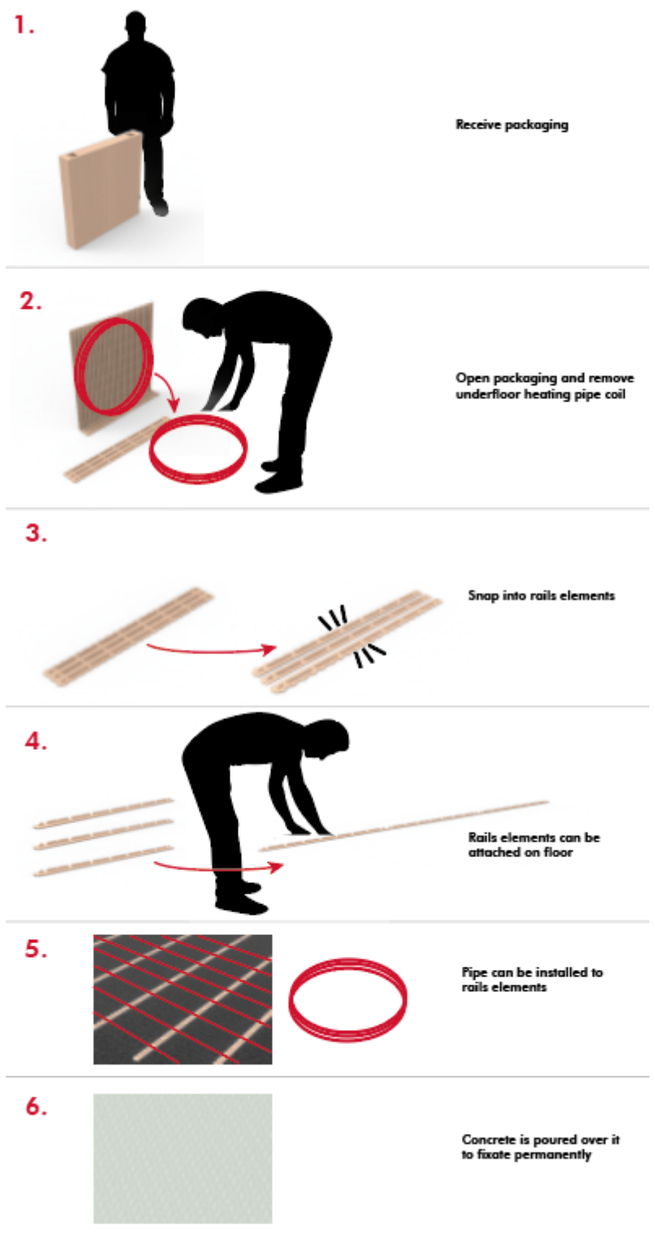


Consent *

I have read and understood the study information dated 21/03/2024. I consent voluntarily to be a participant in this study

Packaging as a product

The packaging concept is a new idea to eliminate single-use packaging. The packaging will be redesigned so that it replaces another product while functioning as product. The packaging will function as packaging and another product, eliminating the need for single-use packaging. Below you can see a demonstration.



Did you understand the packaging described above? *

- ◯ Yes
- ◯ No
- ◯ Anders: _____

How likely are you to choose this type of packaging over another "traditional" packaging? *

- ◯ Very likely
- ◯ Likely
- ◯ Neither likely or unlikely
- ◯ Unlikely
- ◯ Very unlikely

Is there a reason why you **would** choose this type of packaging over a "traditional" packaging?

Jouw antwoord

Is there a reason why you **would not** choose this type of packaging over a "traditional" packaging?

Jouw antwoord

A packaging can also be used as a bracket or insulation in the heating industry. What do you think of the concept of using packaging as a product in general to eliminate single-use packaging? *

- ◯ Very positive
- ◯ Positive
- ◯ Neutral
- ◯ Negative
- ◯ Very negative

General background questions

What is your profession? *

-

How many years of experience do you have in your current profession? *

- ◯ <3
- ◯ 3-6
- ◯ >6

What is your age? *

- ◯ <35
- ◯ 35-59
- ◯ >59

Where are you currently based? *

- ◯ Western Europe
- ◯ Eastern Europe
- ◯ North America
- ◯ Anders:

What do you think of current product packaging used in the industry?

Very satisfied

Appendix 9.25 - Third concept validation questionnaire

U wordt uitgenodigd om deel te nemen aan een onderzoek met de titel “Het reduceren van eenmalig gebruik van verpakkingen met een nieuw verpakkingsconcept: verpakking als product”. Dit onderzoek wordt uitgevoerd door Tim de Klerk tijdens zijn stage bij Aalberts HFC voor zijn Masters afstudeerproject aan de TU Delft.

Het doel van deze enquête is om erachter te komen wat installateurs van het concept vinden. Het meedoen aan het onderzoek duurt ongeveer 10 minuten. De gegevens zullen worden gebruikt voor het afstudeerproject, dat zal worden gepubliceerd in de TU Delft repository. Wij vragen u 7 vragen te beantwoorden.

Zoals bij elke online activiteit is het risico op een inbreuk altijd mogelijk. Voor zover wij kunnen, zullen uw antwoorden in dit onderzoek vertrouwelijk blijven. We minimaliseren eventuele risico's door uw gegevens veilig op te slaan en de vertrouwelijkheid wordt gewaarborgd door de volgende maatregelen:

- Alle verzamelde gegevens worden opgeslagen op beveiligde servers met beperkte toegang tot geautoriseerd personeel.
- Er worden geen persoonlijke identificatiegegevens verzameld.

Uw deelname aan dit onderzoek is geheel vrijwillig en u kunt zich op ieder moment terugtrekken. Het staat u vrij om eventuele vragen achterwege te laten. Gegevens worden gedurende een periode van maximaal 7 jaar bewaard binnen gespecialiseerde educatieve tools en applicaties, met name op het Brightspace-platform.

Contactgegevens onderzoeker:

☐ Ik heb de studieinformatie gedateerd 19/03/2024 gelezen en begrepen. Ik geef vrijwillig toestemming om deel te nemen aan dit onderzoek

1. Verpakking als product vragen

1.1 Wat vindt u van het gebruik en de interactie met het product?

☐ Erg tevreden ☐ Tevreden ☐ Neutraal ☐ Ontevreden ☐ Erg ontevreden

1.2 Wat vindt u van dit concept waarbij de verpakking als rails wordt gebruikt?

☐ Erg tevreden ☐ Tevreden ☐ Neutraal ☐ Ontevreden ☐ Erg ontevreden

1.3 Zou u dit product kiezen in plaats van een traditionele verpakking?

☐ Ja, zeker ☐ Ja ☐ Weet ik niet ☐ Nee ☐ Zeker niet

1.4 Is er een reden waarom je deze verpakking **wel** zult kiezen in plaats van een traditionele verpakking?

_____

_____

1.5 Is er een reden waarom je deze verpakking **niet** zult kiezen in plaats van een traditionele verpakking?

_____

_____

1.6 Wat vindt u van het concept om de verpakking als product te gebruiken?

☐ Erg tevreden ☐ Tevreden ☐ Neutraal ☐ Ontevreden ☐ Erg ontevreden

2. Algemene vragen

2.1 Hoeveel jaar ervaring heeft u in uw beroep?

☐ 0-1 ☐ 2-3 ☐ 4-5 ☐ >5

2.2 Wat is uw leeftijd?

☐ <20 ☐ 20-29 ☐ 30-39 ☐ 40-49 ☐ 50-59 ☐ 60-69 ☐ >70

2.3 Hoe denkt u over de huidige verpakkingen voor producten?

_____

_____