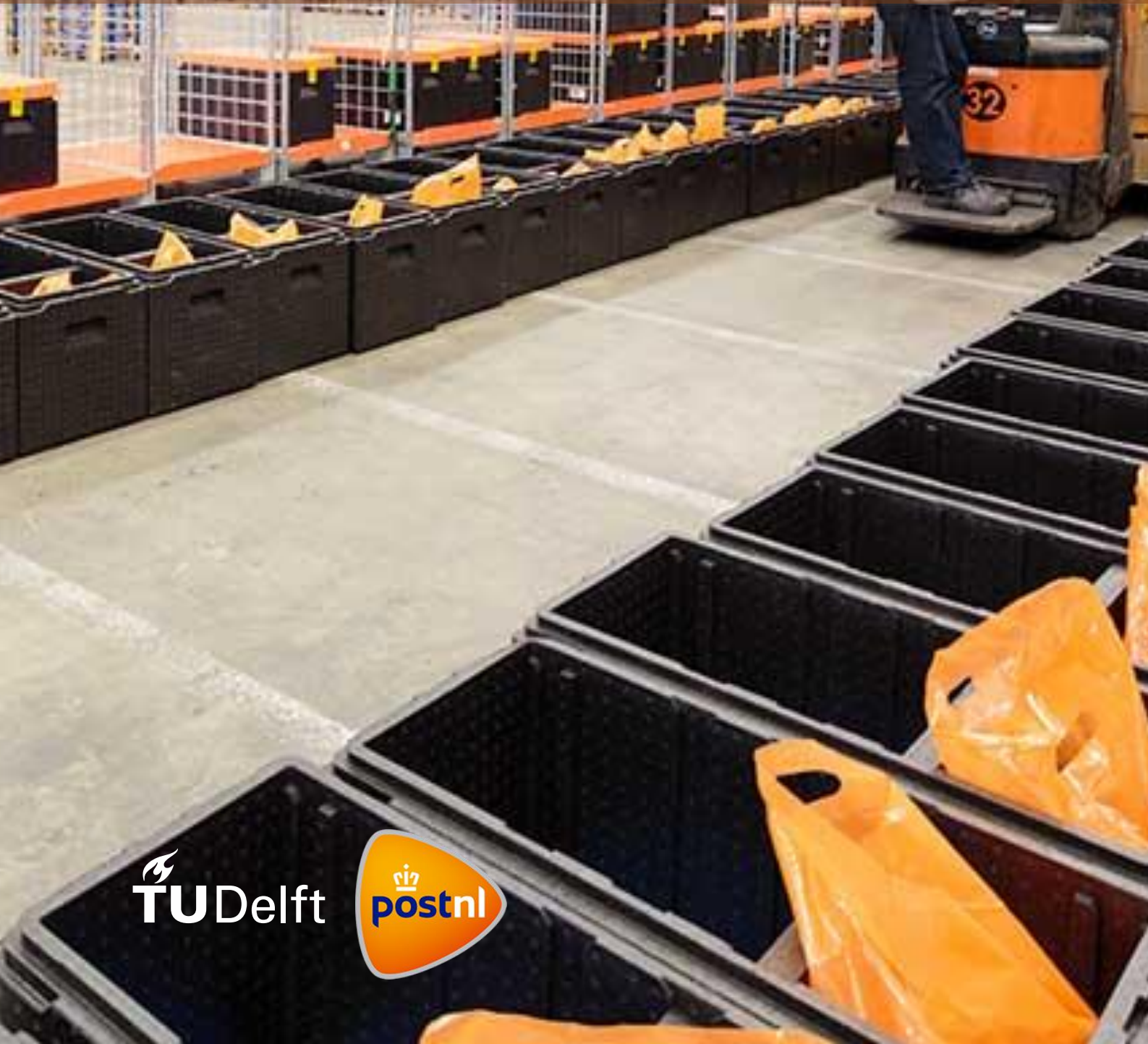


S.G.L. Aelfers

# Analysing sustainable transport packaging solutions for the home delivery of dry groceries

A case study at PostNL





# Analysing sustainable transport packaging solutions for the home delivery of dry groceries

## A case study at PostNL

By

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## Preface

This thesis presents the final results of my master research as part of the Master programme Transport, Infrastructure and Logistics at Delft University of Technology. The topic of this research is sustainable transport packaging solutions for the home delivery of dry groceries. This research was conducted at PostNL, the main logistics service provider in the Netherlands. The report contains recommendations for PostNL, but also a general framework to assess transport packaging solutions.

I would like to thank PostNL for giving me the opportunity to conduct this research, as well as the warm welcome I received. I am very grateful for being part of the PostNL food team for half a year. Especially I would like to thank my company supervisor Karlijn Pennarts and my manager Daan Koek for always supporting me during my research. Without their support, this research would not have been possible.

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*Sanne Aelfers,  
Delft, July 2017*

## Executive Summary

Logistics plays an important role in e-commerce and so in the online grocery market. Some supermarkets deliver groceries themselves, others use a logistics service provider. For the delivery cooled vans can be used, or normal vans in combination with cool boxes. PostNL is an example of a logistics service provider, who delivers groceries for online supermarkets. They developed their own cool box. However, next to chilled products, also dry groceries have to be delivered. There is no standard transport packaging for the delivering of dry groceries yet. Some retailers use cardboard boxes, others use plastic trays and also the cool box is used by some retailers for the delivery of the dry groceries.

The aim of this research is to analyse different transport packaging solutions for the home delivery of dry groceries. Insights into the effects of several transport packaging have been gained. A case study has been applied to PostNL, to find the best alternative for the delivery of dry groceries in their supply chain. The most important actors in this supply chain are PostNL, retailers, consumers and packaging suppliers.

From this goal, the following research question has been formulated:

*'What are sustainable transport packaging solutions for the home delivery of dry groceries and how can their effects be assessed on criteria related to customer wishes, financial efficiency and technical aspects of the logistical system?'*

Criteria on which the alternatives could be evaluated have been established and also constraints of the systems in which the transport packaging has to function in. The criteria are related to important aspects like environmental impact, costs, food safety, ergonomics and logistics performance. Weights have been identified to show the relative importance of the criteria. The identification of the importance of the weights has been done by conducting a questionnaire to actors in the food delivery supply chain of PostNL. The method which has been used for the determination of the weights is called the Best-Worst Method (BWM).

Different transport packaging used by retailers within the Netherlands and abroad have been analysed to identify the different aspects of the packaging. Five feasible alternatives have been formed based on this analysis and on the identified constraints. The first alternative is a cardboard box. The other alternatives are reusable trays. Two of the trays can be nested and two of the trays can be folded. The trays have different sizes.

The alternatives have been assessed on the criteria and compared to each other. This has been done conducting a Multi-Criteria Analysis (MCA). The scoring of the alternatives on the criteria has been done using interviews, questionnaires, calculations models and experiments. One of the calculations models is a Life Cycle Assessment (LCA) in which the environmental impact of the alternatives has been determined.

Within this research, it has become clear that the size of the alternative has a high impact on the performance of the alternative. It has an impact on the environmental performance, costs, ergonomics and the logistics performance. Also, it has become clear that the process with the highest overall impact on the costs and the environment is the delivery. The impact of the delivery is more than double the impact of the packaging,

transportation and handling combined. The cardboard box with a volume of 53 litres and a reusable, foldable plastic tray with a fixed lid at the short side of the tray and a volume of 45 litres, showed to be the most promising alternatives. The external dimensions of the cardboard box and the tray are almost the same.

The reusable tray gained the highest overall score. However, there are a few factors on which the cardboard box performed better. One of these factors is the handling efficiency of the alternative during fulfilment. The reason that the reusable tray gained a lower score is the lid at the short side of the tray, which showed not to be efficient. This is why it has been decided to change the lid from the short to the long side of the tray, to improve the performance. Within this research, the total costs of the cardboard box have been slightly lower than for the reusable tray. However, the research has shown that this is not the case anymore if the packaging prices decrease to 0.46 euro per cycle or less. Next to these aspects and the higher overall score of the reusable tray, it has become clear that reusable trays are preferred by consumers over the waste of cardboard boxes.

It can be concluded that the reusable tray is the best sustainable transport packaging alternative for the delivery of dry groceries by PostNL. The research has analysed and compared several transport packaging alternatives. Also, recommendations have been made for the implementation of the reusable tray to PostNL. First, the tray has to be produced. There are several options for the production where has to be decided on. Choices should be made on the branding or cheaper non-branded trays. After the trays are produced, they can be implemented to the retailers and PostNL. If the same processes and procedures will be used for the tray as the current processes of PostNL, not much has to be changed. Although, the current packaging which is used by every retailer should be compared with the reusable tray to see the differences. The most easy solution to organise the flows of trays is to introduce them the same as the cool box, by leasing them to the retailers.

A useful methodology, combining MCA, LCA and BWM, has been developed for the assessment of sustainable transport packaging solutions. The methodology of the research could also be applied to other cases and companies. However, the weight factors, specific criteria and alternatives are not directly applicable to other companies, since they are depending on the supply chain. Also, in general, it has been concluded that the size of the alternative is the most important factor to the performance of a transport packaging. Since the relatively high impact of the delivery, it is important to pay attention to the efficiency of the delivery to improve the overall performance of the supply chain. Standardisation of fulfilment processes at retailers could also contribute to a more efficient supply chain since transport packaging can be optimised to standardised processes than.

## Research Summary

E-commerce is growing fast. One of the e-commerce markets is food. This is a relatively new market, with a high growth potential. The online food market exists of three sub-markets; food box parties, supermarkets and nice parties. This research focusses on the supermarkets. For physical supermarkets, online channels are important to attract more customers. Also, some supermarkets are fully online retailers. In order to establish an efficient online channel, logistics is very important. Mainly the last mile logistics, which is often home delivery, is a very costly part of the logistics. The delivery of groceries is done by supermarkets themselves. Other supermarkets use logistics service providers for the home delivery of dry groceries. PostNL is an example of a logistics service provider who is offering this service.

An aspect of the last mile logistics is the transport packaging in which the products are delivered. At this moment, there is no standard transport packaging for the delivery of dry groceries. Cardboard boxes are an often used transport packaging for the delivery of dry groceries. However, these boxes seem to be unsustainable and unpractical. Also, reusable trays have been used by some retailers. The different transport packaging might have effects on the logistical process and actors along the supply chain. Reusable trays need organisational processes to manage the return of the trays. For example, a deposit system. Cardboard boxes have the undesired effect of cardboard waste which is left behind at consumers. This research has been performed to gain insights in transport packaging for the delivery of dry groceries. Several factors have been considered in order to reduce the negative impacts of transport packaging. Sustainability is of growing concern. Also, the transport packaging should function within a specific logistical system and actors along the supply chain should be satisfied. The economic profitability of the transport packaging is also kept in mind.

Therefore, the following research question has been formulated:

*'What are sustainable transport packaging solutions for the home delivery of dry groceries and how can their effects be assessed on criteria related to customer wishes, financial efficiency and technical aspects of the logistical system?'*

Literature research has shown the three aspects of sustainability: environmental, economic and social. This is also called the Triple Bottom Line. These aspects play a central role within this research. This research is relevant for literature since a methodology for the assessment of transport packaging on all these three aspects has been proposed. Actors along the whole transport packaging supply chain have been included. This enables sustainable supply chain management for transport packaging. Also, insights have been gained in the usefulness of the combination of Multi-Criteria analysis (MCA) and Life Cycle Assessment (LCA). Literature has addressed some combinations of these methods but never used the LCA as an input for the MCA considering all three aspects of sustainability as done in this research. This research has shown insights in the effects of different transport packaging and came up with a method to select the best alternative.

## Methodology

Within this research, a methodology has been developed to assess transport packaging alternatives on sustainability criteria. This methodology is a combination of Multi-Criteria Analysis, Best-Worst Method and Life Cycle Assessment. MCA and LCA have proved to be a useful combination in literature. However, the existing combinations use the LCA for a more deeply screening of the environmental impact after the MCA or the MCA as a tool to determine the weights of individual indicators of the LCA. In this thesis, the LCA and MCA have been combined differently. The LCA has been used as an input for the scoring of the alternatives on the environmental sustainability criterion within the MCA. A case study of the methodology has been applied to the home delivery of dry groceries for supermarkets by PostNL.

The Multi-criteria analysis started with the identification of alternatives and criteria. The criteria have been identified by conducting interviews with multiple actors within the grocery home delivery supply chain. The criteria are all related to the three aspects of sustainability. Also, constraints have been identified. The constraints are cut-off criteria on which the alternatives have been screened before they are evaluated on the other criteria. After the screening of the alternatives on constraints, only feasible alternatives remained.

In order to identify alternative transport packaging, first transport packaging of competitors has been compared. This comparison led to a set of aspects on which the transport packaging could vary. These aspects are material, size, the side walls, the lid and nestable or foldable. This comparison in combination with the functions the transport packaging should fulfil led to the set of theoretical alternatives. The functions of the transport packaging are protection and containment of groceries in order to establish efficient distribution and to prevent transport damage. The set of theoretical alternatives has been analysed on the constraints. This reduces the number of alternatives to only feasible alternatives. It should be mentioned that redesigning of packaging has not been considered. The theoretically feasible alternatives have been compared to existing alternatives. This resulted in a set of five alternatives who represent the main groups of existing feasible alternatives.

Weights have been determined for the identified set of criteria. This has been done using the Best-Worst Method. This method is used since it needs less comparison data and is more reliable than other pairwise comparison methods. A questionnaire has been designed to collect preference of actors within the supply chain of the criteria. Six respondents filled in the questionnaire for this research. Five of the respondents are employees of PostNL, the other from a retailer. The 'best' criterion has been selected first. Thereafter the 'worst' criterion has been selected. All the other criteria are compared to the best and worst criteria, using a scale between 1 and 9. Using the questionnaire, the optimal weights have been determined by linear programming. The final weights are a result of the average of all the obtained individual weights.

The scores of the alternatives have been determined based on Life Cycle Assessment, cost comparison and qualitative criteria. For the qualitative criteria, experiments have been performed to gather data. These experiments have been conducted at PostNL and a



retailer. The employees of the retailer and PostNL have determined the scores on a seven point Likert-Scale.

The Life Cycle Assessment (LCA) has been used for the scoring of the environmental sustainability criteria. A fast track method has been used based on eco-costs. Eco-costs is an indicator of the amount of environmental burden of a product or service based on the prevention of that burden. The reason for this choice is that LCA's can be very complex and time-consuming. This method is fast and not less accurate than a formal LCA. Data from packaging suppliers, internal data of PostNL and eco-costs values have been used to perform the LCA. The transport packaging alternatives have been analysed throughout their whole life cycle. The different phases of the life cycle have been listed, materials and processes quantified. This data has been entered into Excel in order to calculate the total eco-costs of the alternatives.

The costs comparison has followed the same approach as for the LCA. However, financial factors are used instead of eco-cost values. Costs throughout the packaging supply chain for the home delivery of groceries have been identified.

All the individual scores have been normalised in order to make the comparison of the alternatives and several criteria possible.

### Results

The results of this methodology have shown that the size of the transport packaging plays an important role in the performance of the packaging. The size has influences on the ergonomics, costs, logistics performance and the environmental impact. The size should not be optimised for sub processes, but along the whole chain. For the application of the case study in this research a reusable, foldable tray performed the best. The advantages of this alternative are that less volume is needed for the return transport due to the foldable aspect of the tray. This results in lower costs and eco-costs. For the lid of the tray, it became clear that a fixed lid at the long side of the tray is the easiest to handle, this contributes to the handling efficiency. Also, the size performs well along the supply chain. For example, the packaging fits on the order picking carts of retailers, on the roll container of the logistics service provider and on stacks in the delivery vans. The results of this research have shown that the delivery part of the supply chain (compared to the production, handling and transportation) has the most financial and environmental influence.

The results have also been validated. This validation has been performed based on sensitivity and scenario analyses. The sensitivity analysis analysed the robustness of the weight factors. The scenario analysis used historical and future scenarios, to test the robustness of the results in these scenarios. The results of this research have shown to be robust. Also, experiments have been performed at PostNL to validate this.

## Conclusions

Within this research, the current logistical system for the transportation of dry groceries has been analysed. Requirements for the transport packaging have been identified. Also, alternative transport packaging have been identified and analysed on the requirements. The case study has been applied to PostNL. The specific environment PostNL food is operating in has been analysed and the best alternative in their supply chain has been determined.

Finally, it has been concluded that a useful methodology for the assessment of sustainable transport packaging alternatives has been proposed in this research. The methodology, is an approach to analyse alternatives from a supply chain perspective on sustainability aspects of the triple bottom line. Multi-Criteria Analysis, Life Cycle Assessment and Best-Worst Method have shown to be an effective combination. The developed methodology contributes to scientific research on the combination of MCA and LCA techniques.

The research has identified several aspects for further research. Due to the high impact of the delivery, more research is needed to increase the efficiency of this. There are multiple ways, besides the choice of transport packaging, which can improve the costs and environmental impact related to the delivery. For example, by increasing the number of stops per route or decreasing the distance of the route. Another aspect which has been identified for further research is the standardisation of the fulfilment of retailers. The retailers do not have standardised order picking processes. Since all the retailers have other processes, it is hard to improve the supply chain for every retailer. For example, standardised picking carts make it possible that the size of the transport packaging can also be standardised to these carts. Further research is needed in order to determine the optimal picking cart.

Next to the recommendations for further research, recommendations for PostNL have been made. It is recommended for PostNL to implement the alternative which has obtained the highest score in this research. Specific recommendations for the production, implementation of the transport packaging in the processes of the retailers, implementation of the transport packaging in the processes of PostNL and the management of the transport packaging have been made.

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## List of Abbreviations

AH	Albert Heijn
AHP	Analytic Hierarchy Process
BWM	Best-Worst Method
DC	Distribution centre, also referred to as depot
EPS	Euro Pool System
LCA	Life Cycle Assessment
IDEF	Integrated Definition for function
ISO	International Organization for Standardization
HACCP	Hazard Analysis and Critical Control Points
MCA	Multi-Criteria Analysis
RC	Roll container
SCM	Supply Chain Management
SSCM	Sustainable Supply Chain Management
SPC	Sustainable Packaging Coalition
TBL	Triple Bottom Line



## 1 Introduction

That online expenses are growing will not surprise anybody. From the first quarter of 2015 to the first quarter of 2016 the online expenses increased with 22% (Thuiswinkel, 2016). The growth of the expenses on online food products was for the same period 57% (Thuiswinkel, 2016). The online food market, mainly the markets of food boxes, online supermarkets and niche parties are growing very fast. This is a result of the increase in online offers and omnichannel customers. For the future of groceries, e-commerce will play a crucial role in their profitability (McKinsey & Company, 2015). Online grocery channels will help to attract and keep omnichannel customers, which are the most valuable customers. Supermarkets with a good online platform perform also better in their physical stores (Deloitte, 2013). Rabobank (2016) expects that at least 25% of the groceries will be online in 2030.

Logistics is an important factor for e-groceries. The last mile is seen as the most costly part of the logistics. For online parties, the last mile is often home delivery (Siemens & Banerjee, 2015). The last mile home delivery can be done by the online companies themselves or by logistic service providers. Albert Heijn and Jumbo are examples of physical supermarkets in the Netherlands, who deliver the online food themselves. Picnic is an example of a fully online supermarket. They also deliver their products themselves. Smaller supermarkets (like Superunie members) mainly use logistic service providers. It is too expensive for them to have their own network. The benefits of the use of a logistic service provider are that a flexible, scalable and reliable logistics network can be used (McKinsey & Company, 2015).

PostNL is the largest logistic service provider for the delivery of mail and parcels in the Benelux (PostNL, 2016). Also, PostNL is the second largest in Italy and Germany. Next to the delivery of mail and parcels, PostNL has several additional services. One of these services is the delivery of food. PostNL is growing every month in the online food market. The ambition of PostNL is to have more customers for the next years and to become the e-food logistics service provider of the Benelux (PostNL, 2016). PostNL developed a logistic network with own Food IT and cooling boxes to deliver cooled and frozen products. For supermarkets also 'dry groceries' are delivery next to the cooled products. Currently, cardboard boxes are used for the delivery of dry groceries.

To attract customers, the food distribution service of the logistics service providers should fit the business model of the online food parties. Also, to grow the online grocery shopping home delivery should be cost efficient and punctual to gain consumer satisfaction (Deloitte, 2013). Sustainability is also an important factor to take into account. Not only the transportation can have a high impact on the environment, but also the packaging has influence (Bernstad Saraiva, et al., 2016). According to Hekker et al. (2000), CO<sub>2</sub> emissions can be reduced by 34% if changing to a reusable transport packaging.

In the figure below (Figure 1) the current food supply chain of PostNL can be found. However, it is expected that this process will change soon. Currently, the retailers are filling the cooling boxes with the cold and frozen goods and cardboard boxes with the dry groceries. PostNL picks up the boxes at the retailer or the retailers bring them to the

sorting location of PostNL in the morning. At the sorting location, the boxes are sorted for the five distribution centres (of the 18 DC's that are owned by PostNL) who are currently used for the food logistics. At the DC's the boxes are loaded into the right trucks for the home delivery to the consumers. The driver delivers the boxes to the consumer in the evening and returns the cooling boxes to the five food distribution centres. From the DC's the cooling boxes will go to a hub of PostNL in Dordrecht where they are stored until they go to the retailer. PostNL is the owner of the cooling boxes, but they don't produce the boxes. The retailer is leasing the boxes from PostNL. The cooling elements for the boxes have to be bought by the retailers themselves.

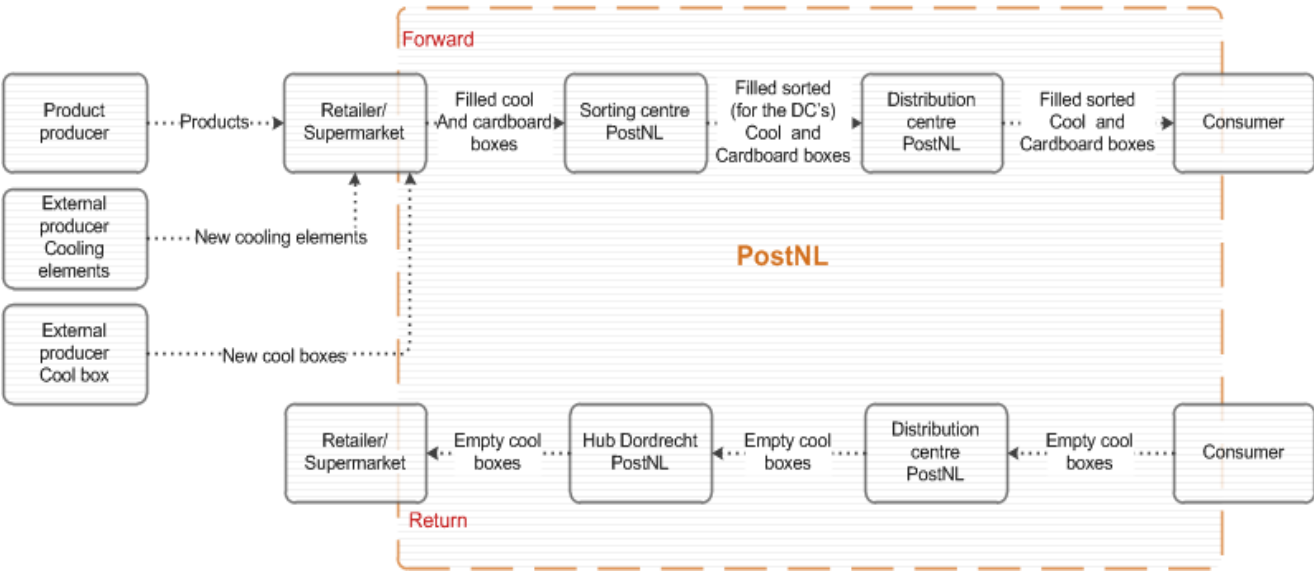


Figure 1. Overview Food system PostNL

**1.1 Problem Definition**

Currently, cardboard boxes are mostly used by PostNL for the delivery of dry groceries. These boxes seem to be unsustainable and unpractical. PostNL would like to have insights into the effects of the current system with cardboard boxes and alternative packaging systems. An alternative can have effects on the logistical process, the retailers, the consumers and the drivers. Also, this might influence the return flow of boxes and the way of managing boxes. The cardboard boxes are bought by the retailers and do not have to be returned. They cannot be reused. Consumers will receive a lot of cardboard if they always order their groceries online. This is an undesired effect of cardboard. At this moment, it is not known what the best way is to transport dry groceries. Therefore, this research has been performed.

**1.1.1 Research objectives**

The goal of this research is to reduce the negative impacts of transport packaging for the home delivery of dry groceries and to gain insights into the effects of transport packaging solutions. The framework which has been developed in this research helps to analyse and gain these insights.

### **1.1.2 Research questions**

What are sustainable transport packaging solutions for the home delivery of dry groceries and how can their effects be assessed on criteria related to customer wishes, financial efficiency and technical aspects of the logistical system?

*Generic sub questions:*

- What is the current logistical system for the transportation of dry groceries?
- What are the requirements for the transport packaging?  
There are several dimensions:
  - Technical
  - Social (Retailers, consumers, drivers..)
  - Food safety
  - Environment
  - Financial
- What are alternatives for transport packaging solutions for the home delivery of dry groceries?
- How to measure the effects of the transport packaging on the criteria?
- How is the food delivery supply chain affected by changing the transport packaging to the chosen alternative?

*Specific sub questions for PostNL:*

- What is the environment PostNL Food is operating in?
  - The market
  - The stakeholders
  - The supply chain
- What is the best sustainable transport packaging alternative for the home delivery of dry groceries by PostNL?

### **1.1.3 Scope**

The research focusses only on transport packaging solutions and the logistics system behind it. The scope of the logistical system is from the pick up of the filled boxes at the retailers to the consumers and back. Also, the trucks in which the goods are transported and the routeing of the trucks has been assumed as fixed. The focus of this research is mainly on short term solutions since it is preferred to implement a solution immediately. Also, the focus of this research is mainly for the Dutch market. Within the online food market, only supermarkets are taken into account. Since these are the online food parties, who want to transport dry groceries next to the frozen and cooled groceries.

## ***1.2 Relevance***

### **Scientific relevance**

It would be of scientific relevance to gain insight into the effects of alternative packaging concepts for the home delivery of dry groceries. At this moment, it is not known what the effects of different transport packaging are. It would be interesting to know which effects transport packaging can have to be aware of the consequences and make a good reasoning between them. This research developed a framework for the identification of the effects of transport packaging concepts. This framework may also be applicable to other home delivery markets than dry groceries. The proposed methodology combines Multi-Criteria Analysis with Life Cycle Assessment. This research gains insights in the usefulness of this combination.

### **Societal relevance**

Logistics is an important enabler for the growth of online food (Koek, 2017). To improve the logistics it is important to increase the efficiency and customer satisfaction in the home delivery of online food. To increase this, insights in the effects of several transport packaging options for the home delivery of dry groceries have to be known. In this way, it might be possible to make a good balance between several factors like sustainability, cost efficiency and customer satisfaction. So, this research is not only important for logistic service providers like PostNL, but also for the retailers who are very interested in finding a good solution for the home delivery of dry groceries.

### **Deliverables**

The deliverable of this research is a thesis containing a methodology framework for the identification of the effects of transport packaging alternatives for the home delivery of dry groceries. It contains analyses of the current system and possible alternatives. The methodology framework can be used for the selection of a transport packaging alternative for the home delivery of dry groceries. The thesis presents results of literature study, field study, interviews with retailers, consumers and drivers, data analysis and calculation models for the assessment of alternative packaging concepts on selected criteria. It also contains recommendations for PostNL on which a case study of PostNL of the framework has been applied.

## ***1.3 Research Framework***

This research is based on the System Engineering approach (Dym & Little, 2004). This is a good systematic way of going from a problem to the design of solutions. The method starts with analysing the problem. The table (Table 1) below shows the five main phases of this approach, in combination with the steps which have been followed and the used research methods. The steps are based on the sub questions.

Table 1. Research Framework

<b>Phases</b>	<b>Steps</b>	<b>Research Methods</b>
Problem Definition	Background analysis of the environment of the system	Stakeholder and supply chain analysis
	Exploring existing scientific concepts related to sustainability, supply chain management and packaging	Literature research
Conceptual Design	Analysis of the current logistical system	Field study, Process analysis
	Identification requirements: <ul style="list-style-type: none"> <li>- Social</li> <li>- Technical</li> <li>- Food Safety</li> <li>- Financial</li> <li>- Environment</li> </ul>	Requirement analysis (Multiple interviews: retailers, consumers, drivers and operations manager) and literature review
	Identification transport packaging alternatives	Competitors analysis
	Evaluation alternatives on requirements	LCA, Cost calculation model and experiments
	Comparison of alternatives	Multi-criteria analysis
	Validation of the assessment	Sensitivity analysis
Preliminary Design	Testing effects of the design of chosen alternative	Real-life experiments
Detailed Design	Refining and optimising design	
Design communication	Conclusions, Discussion and Recommendations	

First, it is of importance to know the environment in which the system for dry groceries has to function in. The specific market, stakeholders and supply chain are identified. Also, it might be useful to know the costs in the supply chain. This has been done by desk research and internal interviews (Appendix A, B, C).

A literature research has been performed to identify the most important concepts and definitions related to the sustainable assessment of transport packaging. The literature review can be found in Chapter 2.

In Chapter 3 a methodology is proposed to analyse and compare alternative transport packaging for the delivery of dry groceries based on the literature review and background analysis. This methodology is a combination of a Multi-Criteria Analysis and Life Cycle Assessment in which the Best Worst Method is used as weighting method.

The conceptual design phase, and so the analysis (Chapter 4) starts with analysing the current system, to know how it is functioning and to identify strong and weak points of this system. The process analyses of the current system can be done by field study and visualised using a flowchart or IDEF0-diagram (Honing, Kolschoten, & Warnier, 2012). An advantage of IDEF0-diagrams is that not only physical activities can be shown, but also means and information. The advantage of a flowchart is that it can also show choice moments. This is not needed for this research, so an IDEF0-diagram suits better. This

results in a description of the environment of PostNL Food and the way they transport dry groceries. This information has been gathered using available documentation of PostNL and interviews. This analysis can be found in Appendix E and has been used as input for the identification of requirements and function of the transport packaging.

The requirements for the transportation of dry groceries are of importance for the design of a good functioning system. There are technical boundaries to the system. For example, there are maximum sizes for the box to fit in the sorting system and other logistical processes. These sizes are constraints for the system. Next to constraints, there are also desired requirements. These requirements can be identified by several methods. To gain consumer satisfaction, interviews with consumers can be used to identify their wishes. To fit the system to the business model of the supermarkets, interviews can be used to identify their needs for the system. Examples of requirements can be environmental impact and costs of the system. Requirements and constraints can be selected using the requirements analysis method described by Ludema (2015). Since this method has proven to be useful in earlier projects. The identification of the requirements has been described in section 4.2.1.

The conceptual design phase includes the generation of alternatives, which can be done by brainstorming and based on literature. This can be found in section 4.2.2. The alternatives might have potential to improve the weak points of cardboard. For example, a tray which can be reused might have less environmental impact than new cardboard boxes. The alternatives may not only differ in material but also on types (box, bag etc.), return options and other options. The alternatives can be generated analysing transport packaging of competitors (see Appendix D), taken into account the functions the packaging should fulfil.

The current system and the alternatives have to be assessed on the earlier identified criteria. It is preferred to have mostly quantitative criteria, but qualitative criteria are also possible. Calculation models have been created to assess the criteria. An example of a quantitative assessment is the method of Bernstad Saraiva et al. (2016) who performed a life cycle assessment to determine the environmental impact of polyethylene/natural fibre-composite and cardboard for the packaging of mango. This method can also be used for the determination of the environmental impacts of packaging for dry groceries in a qualitative way. The calculation models can be created using Excel, Matlab or simulation models. The best method per requirement depends on the selected requirements and available data. Excel might be easy to use but cannot handle very complex models. Matlab can better handle complex calculations. Simulation models can take a long time to create and run but can have a more detailed output. Experiments can be used to gather the missing data and assess the alternatives on the criteria. Within this research, Excel has been used as a tool for the calculations. The reason for this is that in similar studies also Excel has been used and that the excel calculation model can also be used as a tool for PostNL for further research. The alternatives can be compared with each other after their evaluation on criteria. This can be done using a multi-criteria analysis (MCA). In Chapter 4 the MCA is performed and in Chapter 5 the results are shown.

To validate the assessment, the robustness of the assessment has to be tested. Sensitivity analysis has to be performed. In the sensitivity analysis, values can be changed with a certain percentage and effects of this be analysed. Next to this, scenario analysis in which several future scenarios have to be applied to the alternatives to analyse the differences. The validation of this research has been described in Chapter 5.

After the assessment of the alternatives. The best alternative can be designed in detail. A consequence of the alternative might be that the logistical system has to be adapted. Current processes might change and new processes might be added. This has been reviewed in cooperation with the operations manager of PostNL Food. Now the preliminary design is finished, it is time to test a prototype in the system. This makes it possible to test the real effects of the system and to refine and optimise it. This can be done by real-life experiments. It is not only important to test if the alternative is properly working within the logistical system, but also if it gives the expected outputs. For example, are the consumers and retailers satisfied with the alternative?

Finally, conclusions on the effects of transport packaging alternatives for the delivery of dry groceries can be formed and recommendation for PostNL been made. This is discussed in Chapter 6.

## 2 Literature Review

This literature research has been done to review existing methods of designing sustainable transport packaging in a supply chain perspective. The main research topics are; supply chain management, sustainability, packaging and online food retailing.

First supply chain management is explained (2.1). After that, sustainability concepts are reviewed (2.2). These two aspects can be combined for sustainable supply chain management (2.3). Transport packaging is part of the supply chain and elaborated on in paragraph 2.4. Also, the specific case of transport packaging for the online food supply chain is described in this paragraph. In paragraph 2.5 several assessment methods for sustainable supply chain management are compared. The last paragraph (2.6) shows the scientific contribution of this research.

### **2.1 Supply Chain Management**

A supply chain is defined by Christopher (2016) as: *'a network of connected and interdependent organisations of mutually and co-operatively working together to control, manage and improve the flow of materials and information from suppliers to end users'*. In general, a supply chain consists of suppliers, manufacturers, distributors and customers.

The management of the supply chain is supply chain management. More specific supply chain management (SCM) is defined by Mentzer et al. (2001) as: *'the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole'*. The seven main SCM activities are integrated behaviour, information sharing, risks and rewards sharing, cooperation, same goal and focus on serving customers, integration of processes and long-term relationships. This will result in flows of products, services, information, financial resources, demand and forecasts along the chain.

Supply chain management can contribute to competitive advantages (Christopher, 2016). Better supply chain management can lead to cost advantages by more efficiency and productivity along the chain. Also, supply chain management can create value by providing additional services and creating relationships with customers.

#### In the Food industry

Within the food industry, the general food supply chain is built of: producers, who are also called farmers, manufacturers, who are the producers of food and other products, distributors, who are the retailers and the consumers. The supply chain has been visualised as in Figure 2.





Figure 2. Direct food supply chain

This supply chain can be extended by wholesalers, fulfilment parties and logistic service providers if the distribution is not done by the retailers themselves. It is possible to include one or more of these actors. This is visualised in Figure 3.



Figure 3. Extended food supply chain

## 2.2 Sustainability

Sustainability should be everyone's concern. Consumers are more and more aware of this. Half of the Dutch consumers takes sustainability into account for their purchases (VanderMolenE.I.S., 2016). This asks for sustainable development of companies and their support on sustainability to consumers.

The most quoted definition of sustainable development is the one of Brundtland (1987), namely: *"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: the concept of needs, in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs."*

Sustainability has three main pillars, named the triple bottom line (TBL): economic, social and environment (Elkington, 1997). These dimensions are also called the three P's of sustainability: people, planet and profit or prosperity (Elkington, 1997). These dimensions should be integrated to increase sustainability.

Environment refers to aspects like; land use, resource consumption and waste management. This also includes climate change and air quality. Aspects of social performance are fair trade, employee welfare, charitable contribution, health and safety. Growth, revenue and cost are economic aspects. These aspects on their own are not sustainability, but an integration of them can create sustainability. This is visualised in Figure 4. Sustainable supply chain management can be used to increase sustainability.

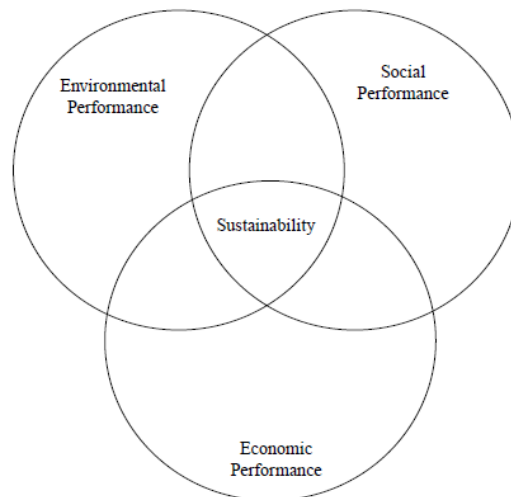


Figure 4. The three dimensions of sustainability (Carter & Rogers, 2008)

### ***2.3 Sustainable supply chain management***

Sustainability is of increasing importance, also in supply chain management. In sustainable supply chain management (SSCM) the three dimensions of sustainability; social, environmental and economic, have to be implemented in SCM. Therefore, SSCM can be defined as: *'the strategic, transparent integration and achievement of an organization's social, environmental, and economic goals in the systemic coordination of key interorganizational business processes for improving the long-term economic performance of the individual company and its supply chains'* (Carter & Rogers, 2008).

Next to SSCM, 124 Green supply chain management (GSCM) articles are reviewed by Ahi and Searcy (2013) for the period of 1997 until 2012. Often SSCM and GSCM are used simultaneously. However, GSCM does only include the environmental sustainability aspect. Therefore, GSCM is not elaborated further on in this research.

As can be seen in Figure 5 environmental and social goals can only be considered taken into account the financial aspects of a company. Real sustainability only occurs at the intersection of environmental, social and economic.

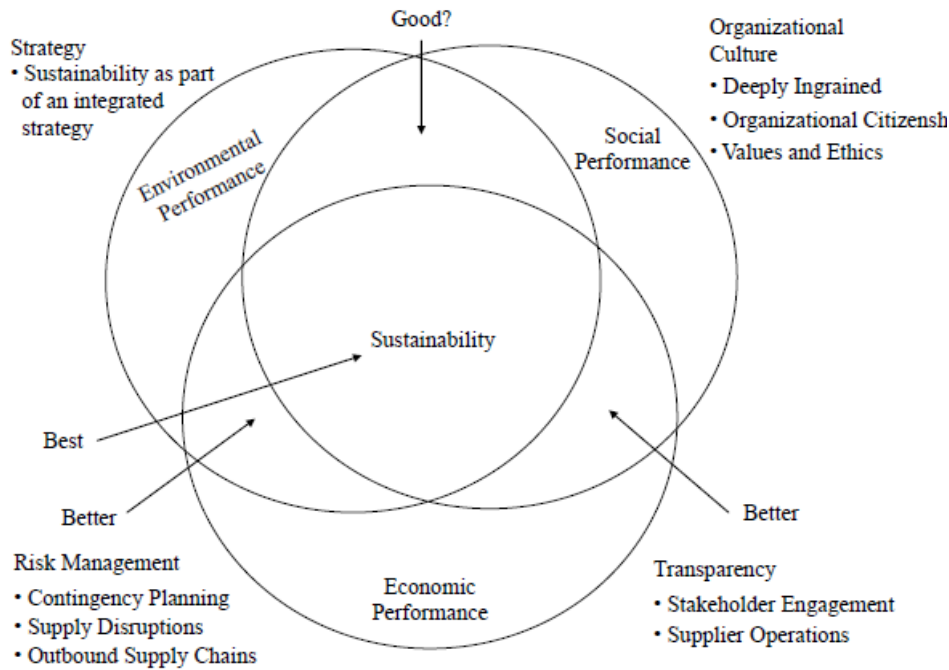


Figure 5. Sustainable supply chain management (Carter & Rogers, 2008)

### In the Food industry

Several barriers for the food industry have been identified (Chkanikova & Mont, 2015). Food retailers see several barriers in SSCM. Missing financial resources and knowledge are the most important ones. This does also lead to market barriers as higher product prices will arise. Regulations can be drivers for SSCM, but it can be a restriction to innovation as well. Also, there is no clear framework to identify the most important sustainability impacts.

## **2.4 Transport packaging as part of the supply chain**

In several steps in a supply chain goods are transported. For example, from the supplier to the manufacturer, from the manufacturer to the distributor and from the distributor to the customer. Instead of transporting loose goods, transport packaging is often used for the transportation. The main functions of packaging are: protecting, containing, preserving and communicating the product (Hellström & Saghir, 2007). There are several types of packaging, namely: primary, secondary and tertiary. Primary packaging is the packaging direct in contact with the product. Secondary packaging contains several primary packages. Tertiary packaging is a number of packed primary and secondary items assembled. Transport packaging can be secondary or tertiary packaging to handle, transport and store a number of primary or secondary packages to provide efficient distribution and prevent transport damage (Jönson, 2000).

Transport packaging is an important factor for the optimisation of a supply chain. The better the size of the transport packaging, the more efficient space can be used. This will increase the utilisation of trucks which can lead to a reduction of CO<sub>2</sub> emissions. Not only the size but also the material of the transport packaging can be of importance. Packaging is a strategic supply chain component that contributes to the overall supply chain performance (Hellström & Nilsson, 2011). Sub-optimisations in packaging should be

avoided instead the total impact along the supply chain should be considered. There is a lack of packaging design studies from a supply chain approach perspective (Garcia-Arca & Prado Pardo, 2008).

Transport packaging is interacting with several supply chain processes. Examples of this can be found in Table 2.

Table 2. Transport packaging and supply chain interactions (Hellström & Saghir, 2007)

<b>Supply chain process</b>	<b>Interacting packaging aspect</b>
Filling by the manufacturer	Handling efficiency Packing line efficiency Stackability
Warehousing	Handling efficiency Protection Stackability
Transport	Space utilization Stackability Weight and Height Stability
Receiving at distribution centre	Stability Identification
Picking	Handling efficiency Identification Ergonomics Protection Stability Handling efficiency Material
Receiving by the retailer	Handling efficiency Material Stability
Replenishing	Sale promotion Handling efficiency Production identification Ergonomics
Reuse and recycle	Handling efficiency Material

Brody et al. (2008) stated the definition from the Sustainable Packaging Coalition (SPC) as the most accepted definition for sustainable packaging. Sustainable packaging has to:

- Be beneficial, safe, and healthy for individuals and communities throughout its life cycle.
- Meet market criteria for performance and cost.
- Be sourced, manufactured, transported, and recycled using renewable energy.
- Maximise the use of renewable or recycled source materials.
- Be manufactured using clean production technologies and best practices.
- Be made from materials healthy in all probable end-of-life scenarios.

- Be designed to optimise materials and energy.
- Be recovered effectively and used in biological and/or industrial cradle-to-cradle cycles.

Within this definition, several TBL aspects can be recognised. The first and sixth point are related to social sustainability. The second point is related to economic sustainability. The other points can be part of environmental sustainability. However, within this definition, it is not sure whether the whole supply chain is included.

In the online food industry

For the online grocery market, a totally different packaging is needed compared to traditional retailers. The items don't need to be displayed in stores. So, the communication function will be different. Also, the online grocery market asks for a new type of packaging. Namely, transport packaging (also called distribution packaging) for the home delivery of the groceries from the retailers to the consumers.

In the case of the last mile delivery, the primary packaging is something like a bottle or carton package directly around the product. The secondary packaging can be a bag or carton boxes around multiple products. These bags or boxes can be put into the transport packaging. It is not always necessary to have all the packaging types. The secondary packaging can be the transport packaging or the primary packaging and loose items can go in the transport packaging directly. During the distribution process, it could also be handy to put several transport packaging onto a tertiary packaging like a roll container. The different packaging types are visualized in Figure 6. In this thesis, transport packaging has been referred to as packaging. There is a lack of packaging design studies from a supply chain approach perspective.

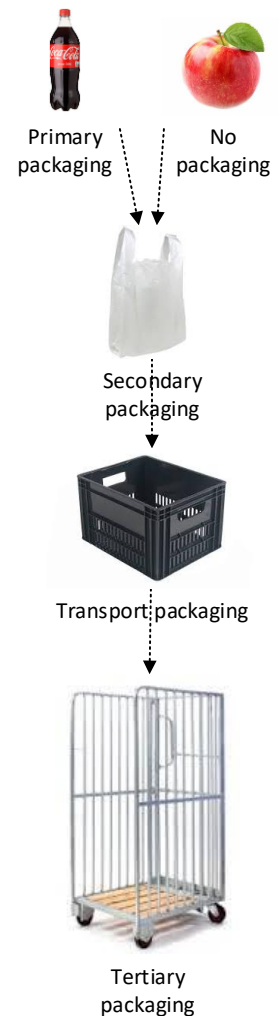


Figure 6. Packaging types

## ***2.5 Assessment of sustainable supply chain management***

Packaging can have a large impact on sustainability. Previous studies show that packaging can account for a significant amount of greenhouse gas emission. For example, Van Loon et al. (2014) shows that if 100g cardboard packaging is used this can result in 181g CO<sub>2</sub> equivalent. Cardboard bags only have a small impact, since the average weight of a bag is only 8g. This results in 11g CO<sub>2</sub> equivalent per bag. This is an example of environmental sustainability effects of packaging.

Seuring (2013) reviewed 309 sustainable supply chain management papers. These papers are published between 1990 and 2010. Only 36 of these papers apply quantitative models. The existing modelling approaches for sustainable supply chain management can be classified into; life-cycle assessment (LCA) based models, equilibrium model, multi-criteria decision making and application of the analytical hierarchy process (Seuring, 2013).

Life-cycle assessment models typically assess environmental impacts along a supply chain and minimize them. LCA models are often part of the other approaches. Equilibrium models balance environmental and economic factors. Multi-criteria decision making optimises mainly economic and environmental criteria. Analytical hierarchy process structures decision processes and obtains a solution based on semi-quantitative criteria and respective weights.

These models do not include all aspects of the triple bottom line. The missing aspects in these assessment methods are social sustainability aspects.

LCA is a model that can be used for the assessment of environmental sustainability. It can be used to evaluate the resource usage and environmental effects in all stages of a product, process or activity, to aid environmental decision-making.

The general life cycle consists of: Materials acquisition, materials processing, manufacturing, assembly, packaging, transportation/distribution, product use, reuse/recycle/disposal.

The LCA method consists of three phases: inventory, impact assessment and improvement assessment. The inventory is about quantifying energy, raw material requirements and environmental releases throughout all stages of the supply chain. Impact assessment is about the characterisation and assessment of the effects of resource requirements and environmental loadings. Improvement assessment evaluates the needs and opportunities to reduce environmental impacts associated throughout the whole cycle.

Life cycle cost analyses (LCC) can be used to assess the economic sustainability. Vogtländer (2004) applied an LCA and LCC for the comparison of corrugated board boxes and plastic container systems. Including LCC, LCA and social factors into a multi-criteria analysis can combine society, economy and environment into one sustainability analysis.

## ***2.6 Contribution of this research***

This thesis looks into sustainable supply chain management for transport packaging. The focus is on the online food industry. Within previous studies, there is a lack of packaging studies from a supply chain perspective. In this thesis, many different supply chain actors are involved. Information is gathered from packaging manufacturers, food retailers, logistic service providers and consumers. Also, there is no literature about transport packaging assessment methods. Sustainable supply chain management papers are often about specific cases with very limited data. This research is based on data from multiple players in the supply chain.

Current sustainability assessment approaches do often not include all aspects of the triple bottom line. Social sustainability aspects are mostly missing. Within this thesis, an approach is developed which includes all the aspects of the triple bottom line.

So, it can be concluded that this research contributes to literature on several aspects. It developed a framework for sustainable supply chain management based on the triple bottom line, the whole supply chain and sufficient data. The framework consists of the unique combination of Multi-Criteria Analysis and Life Cycle Assessment, this is explained in the next chapter.

### 3. Methodology

This chapter describes the methodology used to analyse and compare alternative transport packaging for the delivery of dry groceries based on the literature review (Chapter 2). The main research question says that alternatives for transport packaging have to be evaluated on sustainability and technical criteria along the whole supply chain. As stated in the literature review there are several ways for the assessment of sustainability. All the aspects of the TBL (social, environmental and economic) have to be included. Next to sustainability, packaging alternatives also have to be assessed on technical logistics performance criteria. Since there is no method which can evaluate all these different aspects, a combination of several methods has to be used. Recchia et al. (2011) show that a combination of MCA and LCA techniques can be useful. The best worst method is chosen as the method to obtain the weights of the criteria within the MCA. The several chosen techniques are explained in detail in the next paragraphs.

#### 3.1 Multi-criteria analysis (MCA) – Best Worst Method (BWM)

The first method which is applied is a Multi-criteria analysis. This method is used to evaluate several alternatives on multiple criteria.

A typical MCA consist of 5 phases (Recchia, et al., 2011):

- 1: Problem identification and Objectives definition.
- 2: Alternatives identification and Criteria definition.

In this research, the alternatives are identified by first analysing packaging of competitors to determine the differences between the packaging. The differences on several aspects of the packaging, are options which could be combined in order to generate theoretical alternatives. The criteria are identified by a requirement analysis. The requirements can be divided into constraints and criteria. The constraints are cut-off criteria on which the alternatives have been screened before they are evaluated on the other criteria. If the constraints are not met, the alternative is not taken into account further. This reduced the number of theoretical alternatives to a smaller number of feasible theoretical alternatives. Thereafter, these remaining alternatives are compared to existing alternatives in order to reduce the number of alternatives to feasible existing alternatives which can be analysed in the research.

The set of criteria  $\{c_1, c_2, \dots, c_n\}$  and feasible alternatives  $\{a_1, a_2, \dots, a_m\}$  can be shown as a matrix, as follows:

$$A = \begin{matrix} & c_1 & c_2 & \cdots & c_n \\ \begin{matrix} a_1 \\ a_2 \\ \vdots \\ a_m \end{matrix} & \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mn} \end{pmatrix} \end{matrix}$$



The scores of each alternative  $i$  on the criteria  $j$  is represented by  $p_{ij}$ . These scores have been identified in the next phase.

- 3: Scoring and Weighting.

The scoring of the alternatives can be both qualitative or quantitative. There are different weighting techniques. The most common used weighting techniques in multi-criteria decision making are: Weighted Sum Model (WSM), Analytic Hierarchy Process (AHP), Revised AHP, Weighted Product Model (WPM) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Triantaphyllou, Shu, Sanchez, & Ray, 1998). However, in this research, the Best Worst Method (BWM) is used. This is a new method proposed by Rezaei (2015). Although it is a relatively new method, it has been applied in many different fields. For example, in the management of water scarcity by Chitsaz and Azarnivand (2017). Also, Gupta (2017) applied the BWM to evaluate the service quality of the airline industry. Other fields in which this method has been used are; the combination of individual and group decision making (Hafezalkotob & Hafezalkotob, 2017), web service selection (Serrai, Abdelli, Mokdad, & Hammal, 2017) and airports evaluations (Shojaei, Haeri, & Mohammadi, 2017). Moreover, the BWM is also used in combination with sustainability. This is done by Ren et al. (2017) on the sustainability assessment of technologies for the treatment of urban sewage sludge and by Wan Ahmad et al. (2017) for the assessment of important forces to sustainable supply chain management in the oil and gas industry and by Rezaei et al. (2016) for the selection of suppliers in the edible oils industry.

The advantages of the BWM compared to the earlier mentioned methods are that it is more reliable and needs less comparison data (Rezaei J. , 2015). This is the reason that BWM is used for this research.

BWM has five main steps (Rezaei J. , 2016):

- Step 1: Determine set of decision criteria.  
In this research, the criteria already have been identified in phase 2 of the MCA method.
- Step 2: Determine the best and worst criteria.
- Step 3: Determine the preference of the best criterion over all the other criteria.  
A number between 1 and 9 is used for this. This results in the best-to-others (BO) vector:  $A_B = (a_{B1}, a_{B2}, \dots, a_{Bn})$ .  $a_{Bj}$  indicates the preference of the best criterion B over criterion j.
- Step 4: Determine the preference of all the criteria over the worst criterion.  
A number between 1 and 9 is also used for this. This results in the others-to-worst (OW) vector:  $A_W = (a_{1W}, a_{2W}, \dots, a_{nW})^T$ .  $a_{jW}$  indicates the preference of criterion j over the worst criterion W.
- Step 5: Find the optimal weights.

The optimal weights ( $w_1^*, w_2^*, \dots, w_n^*$ ) of the criteria have to be determined such that the absolute differences for all criteria are minimized. The sum of the weights has to be one. Also, the weights cannot be negative. This is shown in the following minmax model:

$$\begin{aligned} \min \max_j & \left\{ \left| \frac{W_B}{W_j} - a_{Bj} \right|, \left| \frac{W_j}{W_W} - a_{jW} \right| \right\} \\ \text{s.t.} & \sum_j w_j = 1 \\ & w_j \geq 0, \text{ for all } j \end{aligned}$$

To solve this problem, linear programming can be used. The minmax model can be transferred to:

$$\begin{aligned} \min & \xi \\ \text{s.t.} & \left| \frac{W_B}{W_j} - a_{Bj} \right| \leq \xi, \text{ for all } j \\ & \left| \frac{W_j}{W_W} - a_{jW} \right| \leq \xi, \text{ for all } j \\ & \sum_j w_j = 1 \\ & w_j \geq 0, \text{ for all } j \end{aligned}$$

Solving this problem, the optimal weights and  $\xi^*$  are obtained.  $\xi^*$  shows the reliability of the weights. This is based on the consistency of the comparisons. The more the value to zero, the higher the consistency and thereby the reliability of the comparisons. Full consistency of the comparison is reached when  $a_{Bj} * a_{jW} = a_{BW}$  for all  $j$ .

- 4: Results aggregation and Results analysis.
- 5: Discussion and Negotiation.

Within the MCA it is not only possible to assess monetary criteria, but also qualitative criteria. As input for the MCA, an LCA and LCC have been performed. This has been used as input for the assessment of the environmental and economic criteria. Before the assessment on the criteria, the alternatives have been screened on technical constraints. The MCA has been used to compare the most interesting alternatives which followed from the screening, on all the three aspects of sustainability.

### **3.2 Life-cycle Analysis (LCA)**

It is not easy to assess sustainability criteria. As input for the assessment of sustainability criteria in the MCA, life-cycle analyses can be used. Sonneveld (2000) shows that LCA can be a useful tool for the environmental consequences of packaging over the entire life cycle. The advantage of this method is that environmental performances of the total supply chain can be balanced.

LCA is the only environmental system analysis method which includes the whole life-cycle. All the influences from and to the natural systems must be taken into account.

Although LCA's can be very complex and time-consuming, this doesn't have to. A fast track LCA method is described by Vogtländer (2012). Since the time for this research is limited, this method will be used. This method is not less accurate than a formal LCA.

There are several types of LCA (Vogtländer, 2012):

- Cradle to gate: from the mines to the gate at a warehouse
- Gate to gate: within a manufacturing facility
- Gate to grave: from the warehouse to end of life
- Cradle to grave: total product system to end of life
- Cradle to cradle: total product system including closing loop

For this research, the cradle to grave method has been used. The reason for this is that the whole life cycle from the production of the transport packaging until the end of life has been included. The cradle to cradle type is only applicable if 100% of the life cycle is recycled, so no material depletion and land fill will occur. This is not the case in this research.

Vogtländer (2012) describes 5 LCA main steps:

1. Establish the scope and the goal of your analysis.  
Within this research, the goal is to compare several transport packaging on environmental characteristics.
2. Establishment of "Functional Unit" and Boundary Limits  
Within this step, the functions of the transport packaging and the life cycle have to be described.
3. Quantify materials, use of energy, etc. in the system  
Data on the several system aspects have to be collected in this step.
4. Enter the data in an Excel calculation sheet (or another tool)  
Excel has been used as a tool for the LCA in this research. Since this tool is easily available and the fast track method of Vogtländer is based on Excel. Other tools can be very expensive and are not flexible to personal adjustments.
5. Interpret the results and draw your conclusions

The single-indicator eco-costs is chosen. This indicator shows the amount of environmental burden of a product on basis of prevention of that burden. Eco-costs are easy to understand and the calculations are transparent. Multi-indicator approaches have the disadvantage that the weighting of the many different damages is subjective. The eco-costs are the sum of multiple eco-costs factors; human health, exo-toxicity, resource depletion and carbon footprint (Delft University of Technology, 2016). The aspects are shown in the formulas below.

$$\text{eco} - \text{costs} = \text{eco} - \text{costs of human health} + \text{eco} - \text{costs of exo} - \text{toxicity} + \text{eco} - \text{costs of resource depletion} + \text{eco} - \text{costs of carbon footprint}$$

$$\begin{aligned} \text{eco} - \text{cost of human health} \\ = \text{photochemical oxidant formation} + \text{fine dust} \\ + \text{human toxicity (carcinogens)} \end{aligned}$$

*eco – costs of exo – toxicity*  
 = *acidification + eutrophication + aquatic ecotoxicity*

*eco – costs of resource depletion*  
 = *metals depletion + oil&gas depletion + waste + land*  
 – *use natural forests + water scarcity*

In the table below an example of the Excel sheet is shown. First, the life cycle stages have to be filled in, followed by the type of materials or process included in the stages. After this stage, the amount of material is filled in and the unit. The eco-costs for this material or process have to be looked up and filled in. The final step is to multiply the Amount by the Eco-cost factor to get the final score.

Table 3. Example table LCA

<b>Life cycle stage</b>	<b>Type of material or process</b>	<b>Amount</b>	<b>Unit</b>	<b>Eco-costs factor</b>	<b>Unit</b>	<b>Score</b>
Raw materials						=Amount * Eco-cost factor
Production						
Transport						
Use						

There are also existing tools to perform LCA's. However, these tools are very expensive. For example, the Packaging Impact Quick Evaluation Tool (PIQET). This is a streamlined LCA tool for optimising environmental performance of packaging designs. Prices to use this tool start at €4500 per year (PIQET, n.d.). PIQET and the fast track LCA method are both based on the ISO 14040 and ISO 14044 standards for life cycle assessment.

The Life Cycle Cost Comparison uses almost the same approach as the MCA (see Figure 7). Although, instead of eco-costs factor financial parameters are used. Also, all the activities in the chain are identified to specify the related costs. However, the same general specifications, functional unit and boundary limits are used in the LCA and LCC

### 3.3 Combined methodology

An overview of the combined methods is visualised in Figure 7. This figure shows the connection between the several methods. Within the MCA, BWM is used as the method to obtain the weights for the criteria. The LCC, LCA and real-life experiments in combination with a survey for the qualitative criteria are used as input for the determination of the scores of the alternatives on the criteria. All the scores are first normalised to scores between 0 and 1 before they are multiplied by the weights of the criteria to obtain the results. The used formula for the normalisation is:

$$x^{norm} = \begin{cases} \frac{X - \min\{x\}}{\max\{x\} - \min\{x\}}, & \text{if a higher value of } x \text{ is better} \\ 1 - \frac{X - \min\{x\}}{\max\{x\} - \min\{x\}}, & \text{if a lower value of } x \text{ is better} \end{cases}$$

There are not many studies who combine LCA and MCA. Recchia et al. (2011) described a combination of multi criteria analysis and LCA techniques. However, this method uses MCA as a first screening to identify more suitable alternatives before applying the LCA to evaluate the environmental impact more deeply. The case studies of Recchia et al. have been fixed only considering environmental and economic sustainability. Social sustainability is not considered. For their MCA it is assumed that both environmental and economic have equal weights. Pineda-Henson and Culaba (2004) and Hermann et al. (2007) researched a combination of LCA and AHP. They used AHP to determine weights of the individual indicators within the LCA.

Within this thesis, all the three aspects; economic social and environmental are considered. Also, weights have been determined for all the criteria. The LCA is used as input for the MCA and not after the MCA. The LCA uses the single-indicator eco-costs, so no weighting within the LCA is needed.

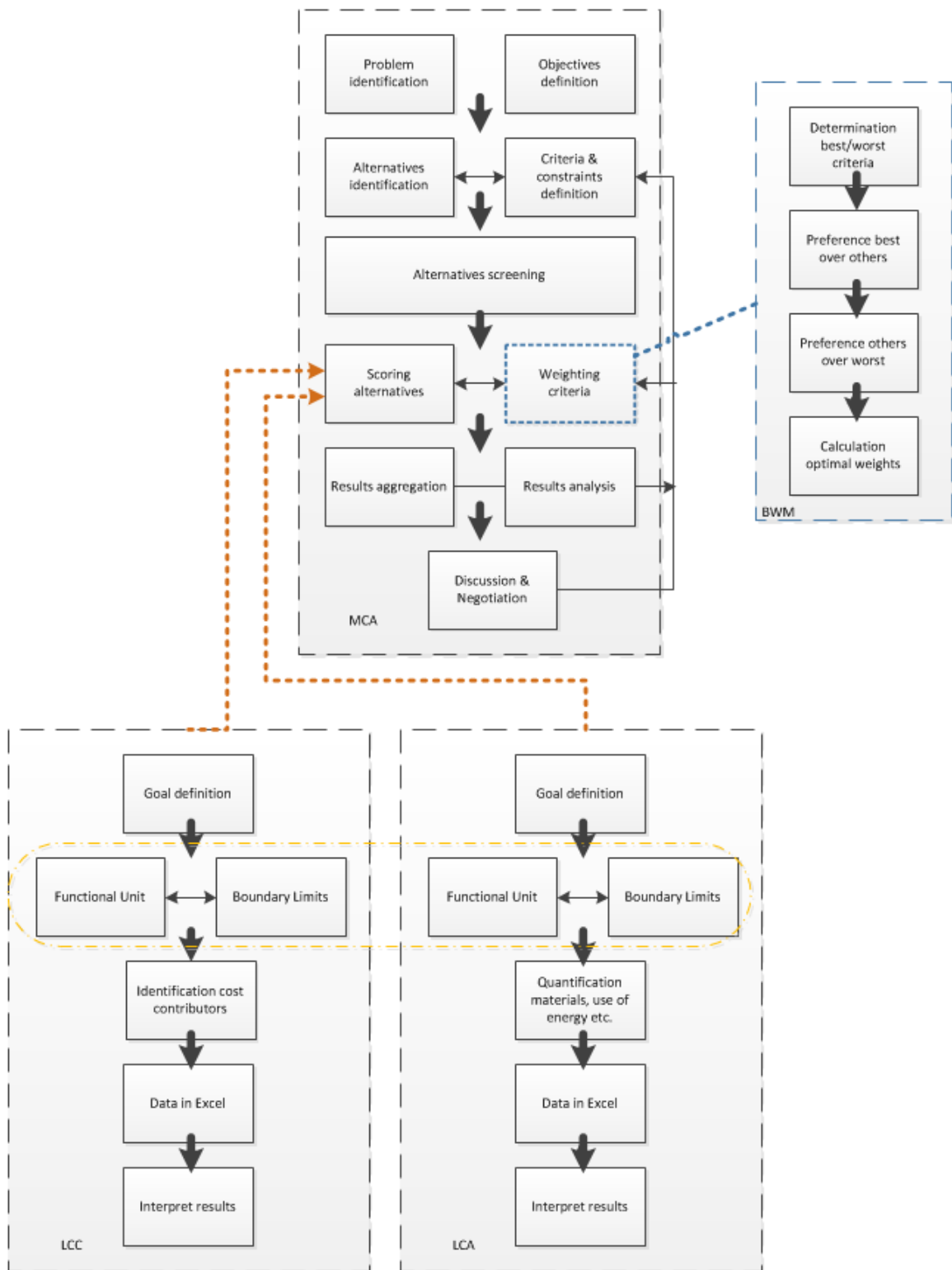


Figure 7. Overview methodology

## 4. Analysis

This chapter describes the data collection (4.1) and the application of the proposed methodology described in Chapter 3 to analyse and compare alternative transport packaging for the delivery of dry groceries. The criteria, weight factors and alternatives have been determined in paragraph 4.2. The alternatives have been assessed on the main criteria environmental (4.3), economic (4.4) and social (4.5) sustainability.

### **4.1 Data collection**

To make sure information of the whole supply chain is included, data is collected from multiple actors within the supply chain. Appendix B and C show analysis about the most important actors and the supply chain of the packaging. Data is mainly collected from packaging suppliers, retailers, logistics service provider (PostNL) and consumers. This data can be primary or secondary. Primary data is data collected by the researcher of the project. The secondary data is collected for other research purposes. In this research, both primary and secondary data has been used.

The primary data is gathered by interviews and surveys within PostNL and external parties within the supply chain for the home delivery of food by PostNL. The face-to-face interviews are conducted both structured and non-structured. An overview of the interviewed people can be found in Appendix A. Also, data is gathered by doing experiments. The experiments are conducted at PostNL and retailers. The secondary data is mainly collected by literature study. The collected data for the several aspects of the described methodology in chapter 3 is described in this subsection.

For the creation of the requirements, literature is used and data is gathered by conducting interviews at PostNL and retailers.

A survey is developed to gather data for weighting the criteria, using the BWM. The survey can be found in Appendix F. The survey consists of 12 questions. As described in the BWM a scale between 1 and 9 is used to determine the importance of the criteria. The survey is completed by 6 respondents. 5 respondents are from PostNL and one from a retailer. Information about the respondents can be found in Appendix G. On average the survey took 10 minutes to complete.

The assessment of the alternatives on the criteria can be divided into, qualitative assessment, life cycle assessment and cost comparison.

For the qualitative criteria, experiments are performed to gather data. These experiments are conducted at PostNL and a retailer. Details about the experiments can be found in Appendix H. Scoring of the alternatives on the qualitative criteria is done based on these experiments by employees of the retailer and PostNL. To structure the scoring, a questionnaire is developed. This questionnaire can be found in Appendix I. A Likert-scale is used to score the alternatives on the criteria. A seven-point scale is chosen to get a wide range of information.

Data from packaging suppliers is used for the life cycle assessment. This is mainly data about specifications of the packaging. Also, Idemat 2016 data is used as eco-costs values. Eco-costs express the amount of environmental burden of a product or service on the

basis of prevention of that burden. The eco-costs of an alternative are the sum of all eco-costs of emissions and use of materials and energy during the entire life cycle of the alternative. The PostNL Transport Information System is used to gather data about the transportation flows.

For the economic assessment, the same data sources are used as for the life cycle assessment. Financial data, originating from PostNL and packaging suppliers, has been added to this.

## **4.2 Application MCA**

### **4.2.1 Requirements**

In the following paragraph requirements for the analysis of the alternatives are explained. The requirements originate from wishes from multiple actors in the supply chain. The whole supply chain is analysed to identify aspects on which the transport packaging can have influence. Interviews with the multiple actors can be found in Appendix A. Also, the criteria for sustainable packaging in the literature review are taken into account (see paragraph 2.4). This divides the requirements into social sustainability, economic sustainability and environmental sustainability. As mentioned above the requirements can be divided into criteria and constraints (paragraph 3.1.1). The requirements can have both a criterion and a constraint. In that case, the constraint is a certain minimal or maximum value, which the alternative has to meet to be feasible. The criteria can be met to a certain degree.

#### Constraints:

- *Closed unit:* There are several reasons why the transport packaging should be possible to close. This is for the safety of the products, that no products will fall out, also for the food safety regulations related to HACCP (Hazard Analysis and Critical Control Points). If the packaging is stacked onto each other and the top of the packaging is not closed, there might be the danger that dirt of the bottom of the top packaging falls into the bottom packaging on the products. The probability that the primary packaging of products will break is also higher if the top of the transport packaging is not closed. Another possible danger to the products is rain which can have an influence on the products if the top of the packaging is not closed. So, a closed top of the transport packaging is a constraint.
- *Not exceeding dimensions of 1 by 1 meter:* The transport packaging should not be larger than one by one by one meter because this does not fit through the entry of the sorting machine. This is a constraint to the size.
- *Fit on roll container:* The transport packaging should not be larger than the dimensions of the bottom of the roll container. The dimensions of the bottom of the roll containers of PostNL are 80 by 80 centimetres. This is a constraint to the fit of the packaging on roll container.
- *Labelling possibility:* It should be possible to stick a label on the transport packaging.



- *Weight:* In the law on working conditions (Dutch: 'Arbowet'), there is no specific weight that employees are allowed to carry. However, PostNL states a maximum weight of 30 kg.

### Environmental Sustainability Requirements

*Low environmental impact:* The impact of the transport packaging on the environment has to be as low as possible. A Life Cycle Assessment can be used to assess the environmental impact of the alternatives. Environmental aspects as reuse ability and footprint of the material are taken into account.

### Economic Sustainability Requirements

- *Low costs:* The costs within the whole supply chain should be as low as possible. This is not only the investment costs but also all the other costs within the supply chain on which the transport packaging might have influence. A cost comparison analysis is used to assess the alternatives on costs during the whole supply chain.
- *Logistics performance:*
  - *Fit on roll container:* During transportation, multiple transport packaging are placed on roll containers. The transport packaging has to fit efficiently on the current roll containers. Next to the fit of the transport packaging on the roll container. The combination of the cool boxes and transport packaging on the roll container is preferred to be efficient.
  - *Handling during fulfilment:* The transport packaging should be easy to handle during the picking of the groceries. It should fit on the picking carts of the retailers.
  - *Filling buses:* The transport packaging should be efficient to fit in the busses for the home delivery of the groceries. It should be possible to stack the transport packaging in such way that it will not fall down.
  - *Space:* During several processes, like the return flow or storage less as possible transport packaging is preferred. So, transport packaging which can be reduced in size if not needed is preferred. Examples of size reducing features are folding or nesting.
  - *Capacity:* The transport packaging should have enough capacity to carry the groceries. Also, there can be a difference in how easy groceries fit into the transport packaging.
  - *Labelling:* It should be easy to put a label on the transport packaging. Also, the label should be easy to scan by the sorting machine. Otherwise, it is not possible to know the destination for the groceries and to sort it. The label should also be easy to remove after return.

### Social Sustainability Requirements

- *Food safety:* Food safety is a growing concern as the food supply chain becomes more global (Deloitte, 2013). At every step in the supply chain, it is possible that food will become contaminated. Especially for online food, it is important for

consumers to prove that the food is safe. This can be done by the use of for example sealing.

- *Ergonomics*: The transport packaging should be easy to handle for the driver. It should not be too big or too heavy to carry it. This also accounts of the order pickers of the retailers.

#### **4.2.2 Alternatives**

As described in the literature review (see section 2.4) the functions of the transport packaging are protecting and containing the groceries in order to establish efficient distribution and prevent transport damage. These functions should be considered in order to generate alternatives. It should be mentioned that redesign is not considered for the generation of alternatives in this research. An analysis of the current transport packaging of competitors is used to determine several options for the alternatives. This analysis can be found in Appendix D. The analysis shows that there are 4 main aspects on which the trays differ; size, the side walls, the lid and nestable or foldable. Next to these aspects, transport packaging can also be made of different materials.

##### *Material*

A Plastic tray is the most used transport packaging by online retailers. Next to reusable trays, other packaging that might contain groceries are cardboard boxes and bags. However, experiences with a bag show that this option is not easy to handle in the whole supply chain. So, bags has not been elaborated further on.

##### *Size*

To contain groceries, packaging of a certain size is needed. Transport packaging can be made in every dimension, but there are three main dimensions identified; 'AH', 'Euronorm' and the size of the cool box of PostNL. The dimension which is used by large supermarkets in the Netherlands like Albert Heijn (AH) is 35 x 52 x 26.5 cm. Another very common dimension is 40 x 60 cm. This is called 'Euronorm'. This size is for example used by Euro Pool System (EPS), but also outside the food industry. The third dimension is the dimension of the cool box of PostNL: 37.5 x 64 x 37.9 cm.

##### *Side walls*

The side walls of the packaging can be closed or with holes. The function of the side walls is to ensure that the groceries stay inside the packaging and will not be damaged.

##### *Lid*

To protect the groceries and make sure that the groceries stay inside the packaging a lid can be used to cover the top. The alternatives differ in no lid at all, a fixed lid or a loose lid.

##### *Nestable/Foldable*

To ensure efficient return transport and storage some packaging can be nested or folded, but there are also packaging which cannot be folded. Next to this, stackability of the packaging is important for the efficiency of the transport and storage.

Alternatives can be formed by different combinations of options of each aspect. Since there are many options and aspects this will lead to a large number of alternatives. 108 alternatives are too many alternatives to assess them all in detail. This is why the alternatives are first screened on the in section 4.2.1 mentioned constraints. This reduces the number of alternatives and only feasible alternatives will remain.

Closed unit is the first constraint. This removes the option 'no lid'. Otherwise, it will not be possible to use the sorting machine for the sorting of the groceries and the food safety will not be ensured. This will not be a feasible alternative. The second constraint is the dimension of the transport packaging: 1 by 1 by 1 meter. Within every alternative this is the case, so this aspect has not reduced the number of feasible alternatives. Interviews with the retailers show that the size of the cool box is too big for the pick carts for the fulfilment of dry groceries. So, this option is also removed. Also, only packaging that can be reduced in space (nested or folded) are considered since otherwise there is not enough space available to store the packaging. This reduces the number of theoretical alternatives to 32 (see Figure 8).

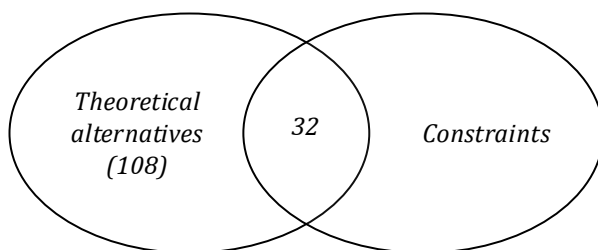


Figure 8. Reduction number of theoretical alternatives to theoretical feasible alternatives

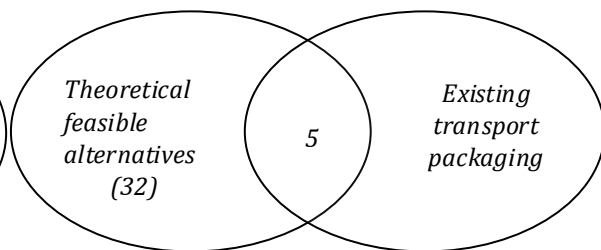


Figure 9. Reduction of theoretical feasible alternatives to existing feasible alternatives

The resulting theoretical alternatives have been compared to existing alternatives within the Netherlands (see Figure 9). There are five main groups of alternatives identified which can be represented by the following 5 alternatives:

- *Alternative 1: Cardboard box*  
This alternative is a box made of cardboard. It is a single use packaging. The boxes can be folded and stacked. There are no holes in the side walls of the box. The chosen cardboard box for the comparison in this analysis has the dimensions of the AH box, but also variations with other sizes have been analysed. The results of this can be found in Appendix J.
- *Alternative 2: Foldable plastic tray without holes*  
This alternative is a reusable plastic tray without holes in the side walls. It has a fixed lid at the long side of the tray. The tray is foldable and stackable. This is a Euronorm size box.
- *Alternative 3: Nestable plastic tray with fixed lid*  
This alternative is a reusable plastic tray without holes in the sidewalls. The trays can be nested in each other. The lid is fixed to the tray at the long side. The size of this tray is around the Euronorm.

- *Alternative 4: Foldable plastic tray with holes*  
This alternative is a reusable plastic tray with holes in the sidewalls. It has a fixed lid on the short side of the tray. The tray is foldable and stackable. This box has the dimensions of an AH tray.
- *Alternative 5: Nestable plastic tray with loose lid*  
This alternative is a reusable plastic tray without holes in the sidewalls. The trays can be nested in each other. The lid is not fixed to the tray. This tray has almost the same dimensions as the AH tray. The quality of this tray is less than the other trays since it is not designed for the transportation of goods.

Examples of the alternatives are visualised in Figure 10. These alternatives are evaluated further in this research to gain insights into the preferences in the several aspects of the different aspects of the transport packaging. An overview of the specifications of the alternatives can be found in Table 4.

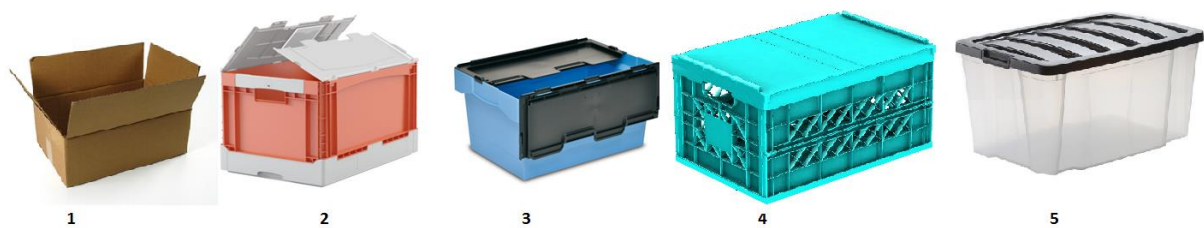


Figure 10. Alternatives transport packaging for the delivery of dry groceries

Table 4. General specifications alternatives

<i>Material</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>
External size (cm)	54x36x29	60x40x28.5	61x40x29.0	53x35.4x30.4	54x38x26.5
Internal size (cm)	53x35x28	60x40x28.5	50x32x25	50x32x27	45x30x25
Volume (L)	53	58	47	45	46
Weight (kg)	1.086	3.0	5.0	1.75	1.4

#### 4.2.3 Weighting of the criteria

After the identification of the set of alternatives and criteria, the weights for the criteria can be identified using the Best-Worst method. A questionnaire has been designed to collect data about the importance of the criteria. The questionnaire can be found in Appendix F. The 'best' criterion is selected first. This is the most important criterion according to the respondent. Thereafter the 'worst' criterion is selected. All the other criteria are compared to the best and worst criteria. The questionnaire is filled in by multiple actors within the supply chain. The detailed results of the questionnaires and the BWM can be found in Appendix G. An average is taken of all the obtained individual weights, these average weights per criterion and sub-criterion are presented in the Table below.

Table 5. Weights of the criteria

<b>Main criteria</b>	<b>Local weights</b>	<b>Sub-criteria</b>	<b>Local weights</b>	<b>Sub-sub-criteria</b>	<b>Local weights</b>	<b>Global weights</b>
Environmental	0.32	-	-	-	-	0.32
Economic	0.46	Costs	0.43	-	-	0.18
		Logistic Performance	0.57	Fit on RC	0.25	0.07
				Fulfilment	0.18	0.05
				Busses	0.15	0.04
				Space	0.19	0.05
				Capacity	0.11	0.03
				Labelling	0.11	0.03
Social	0.22	Food safety	0.69	-	-	0.15
		Ergonomic	0.31	-	-	0.07

The average consistency indicator ( $\xi^*$ ) for the comparison of the main criteria is 0.20. For the sub-criteria, the average consistency indicator varies between 0 and 0.14. Since the consistency indicator is close to zero, this indicates a high consistency. However, it could be argued whether respondent 3, which has a lower consistency than the other respondents, should be left out. The individual consistency indicators can be found in Appendix G.

The weights are reflected by PostNL. Their vision is always on the intersection of environment and economic. Also, in conversations between PostNL and customers, environmental sustainability is always mentioned by the customers (retailers). The social criteria are related to legal aspects which should be considered. In the end, of course always economic feasibility is the most important factor, this can be seen in the weights as well. The weight factors as stated here are recognisable for PostNL. The sustainable orientated mindset of PostNL Food and the retailers clarify the relatively high importance of the environmental criterion.

### 4.3 Environmental assessment

Five different transport packaging are compared in the LCA to compare their overall environmental impact. The functional unit of the transport packaging is containment and transport of dry groceries per litre transported groceries. The system boundary is from the door of the retailers to the door of the consumers. This is visualised in Figure 11 for reusable packaging and in Figure 12 for the packaging that is not being reused. The arrows show the flow of the packaging. Although, there is no return flow of packaging for the non-reusable packaging there still is a return flow for the roll container on which the packaging was transported. Here has been elaborated on further in the transportation section below.

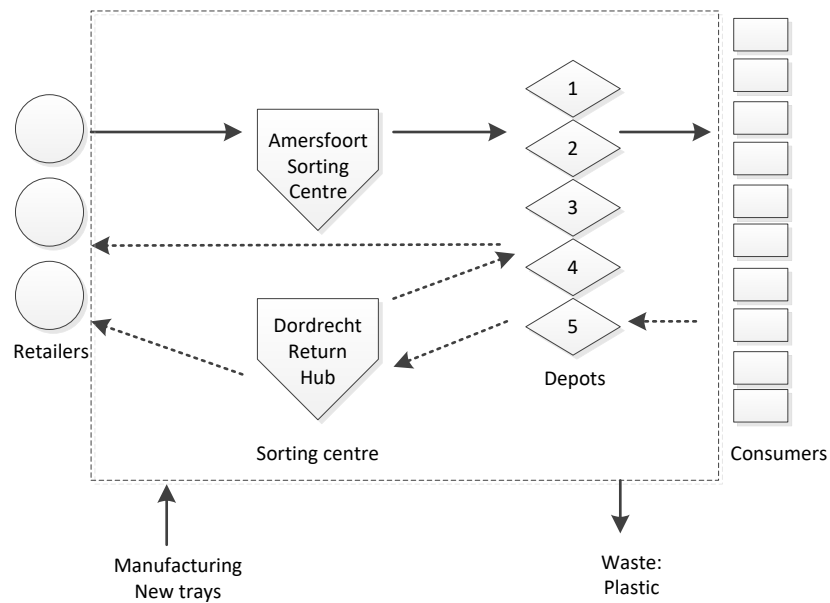


Figure 11. System definition reusable packaging

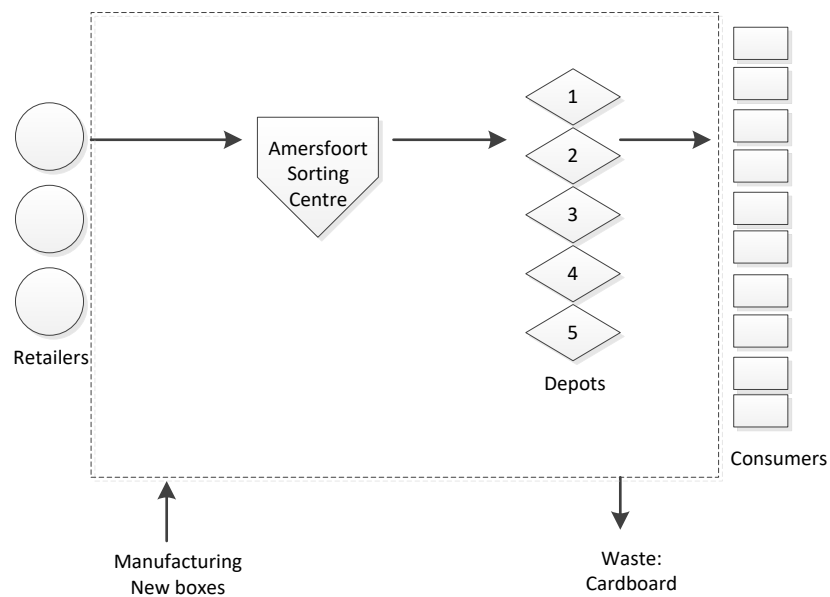


Figure 12. System definition one-time packaging

As described in the methodology in Chapter 3 eco-costs are used as an indicator to assess the sustainability of the packaging alternatives. Only eco-costs which account for more than five percent of the total eco-costs are considered. All eco-costs values in this section originate from Idemat 2016 (Delft University of Technology, 2016).

### *Production*

The first phase of the life cycle is the production of the packaging. The material and production process can have an environmental impact. The used material, production processes and associated eco-costs for the several alternatives are identified.

*Table 6. Eco-costs values material per alternative*

<i>Alternative</i>	<i>Material</i>	<i>Eco-costs (€/kg)</i>
1	Cardboard	0.325
2	Polypropylene	1.073
3	Polypropylene	1.073
4	Polypropylene	1.073
	Steel	0.637
5	Polypropylene	1.073

The eco-costs related to the production of the reusable packaging is divided by the number of cycles the packaging can make before its end of life. Same as for the FEFCO research (Vogtländer, 2004), it is assumed that the reusable packaging alternatives can make 20 cycles. Since the fifth alternative is of less quality, it is assumed that it can make only 10 cycles. Also, it is assumed that 3% of all the trays get lost before the end of life. Next to the above-mentioned materials, also the eco-costs of paper bags should be considered for the reusable alternatives. The paper bags are used inside the trays. The paper bags with groceries are given to the consumers and the trays are returned immediately. The eco-costs values for these paper bags are 0.126 €/kg.

### *Transportation*

As can be seen in the described system above the fulfilment of the groceries is outside the borders of the defined the system. So the next phase to consider, after the production, is the transportation of the packaging including groceries. There are four main transport legs. The average distances can be found in Table 7. The average distance from the distribution centre of the retailers to the sorting centre is calculated by the weighted average of the distance of the retailers to the sorting centre and the transported volume. So, for retailers who are transporting more volume, the distance is taken more into account than for smaller retailers. Almost the same method is used to calculate the average distance from the hub to the retailers. However, this leg is a little bit more complicated. Some of the transport is first going to one or two other depots from the hub before being transported to the retailer. This is also taken into account to calculate the overall average. The average distance between the sorting centre and the depot and between the depot and the hub is calculated by the average distance of the 5 depots to the hub and sorting centre multiplied by the average distributed volume per depot.

Table 7. Transport legs

<i>From-to</i>	<i>Average distance (km)</i>
Retailer – Sorting Centre	69.11
Sorting Centre – Depot	70.30
Depot – Hub	82.09
Hub- Retailer	89.05

The eco-costs related to the transportation can be calculated by the eco-costs value of the truck, the transport distance and the volume which has to be transported. The eco-costs value of a standard 40 tonnes truck European (euro 5) is 0.35€/km and 0.0091 €/m<sup>3</sup>.km if the load factor of the truck is 50% (Vogtländer, 2012).

One truck can transport 48 full roll containers and 180 empty roll containers. This standard truck can transport 24 tonne or 75 m<sup>3</sup>. For a full truck, this means that the eco-costs per roll container are 0.0073 €/RC.km.

To calculate the eco-costs of a transport leg the eco-costs per roll container is multiplied by the distance of the transport leg and the number of roll containers that have to be transported.

For the return transport legs, this method has to be adapted slightly. The returnable packaging alternatives can be folded or nested, this means that less space is needed to transport the empty packaging. The percentages of the remaining packaging volume per alternative can be found in Table 8.

Table 8. Returnable empty packaging volume compared to full packaging volume

<i>Alternative</i>	<i>Return packaging volume</i>
1	0%
2	25%
3	33%
4	20%
5	40%

Next to the packaging which has to be returned, the roll containers have to be returned to the retailers. This is also the case for the non-reusable packaging. However, for empty roll containers, 73% less space is needed than for full roll containers. So, the eco-costs for the return transport leg can be calculated by:

$$\begin{aligned} \text{eco – costs return transport} \\ = \text{eco – costs per rc. km} * \text{distance (km)} * (\text{nr. of full return rc's} \\ + (\text{nr. of empty rc's} * 27\%)) \end{aligned}$$

Where:

$$\text{nr. of full return rc's} = \text{nr. of rc's} * \text{percentage returnpackaging volume}$$

$$\text{nr. of empty rc's} = \text{nr. of rc's} - \text{nr. of full return rc's}$$

Another transportation aspect is the delivery of the groceries from the depot to the consumer and back to the depot. The average distance of this route is 190 km. The eco-costs value of the used delivery vans is 0.123 €/km. On average, there are 16 stops in one route. The average number of boxes per stop is; 1.2.



The cleaning of the reusable packaging is not considered. Brantjes (1999) showed that this doesn't have a significant impact on the eco-costs (less than one percent). The reason for this is mainly that fresh water is not really scarce in the Netherlands.

*End of Life*

After the usage of the packaging, the packaging will be reused, thrown away or recycled. After twenty times, it is expected that the reusable packaging cannot be reused anymore. It is not known exactly what will happen with the packaging after this. ISO states that if the end of life process is not exactly known, it should be assumed that everything is waste. So, all the packaging will be municipal waste then. The plastic waste of the trays can be incinerated with electricity. The same accounts for paper and cardboard. Although waste incineration of paper and cardboard has a positive effect on the eco-costs and for polypropylene a negative effect. Steel cannot be incinerated and will end up as landfill. The transport related to the waste collection is not considered since the transport distances are not known and it accounts for less than five percent of the total eco-costs. Next to this scenario with waste treatment, it is also possible to make a scenario with recycling. The eco-costs values for the several materials and the waste and recycling processes can be found in Table 9.

*Table 9. Eco-costs values end-of-life and recycling*

<i>Material</i>	<i>Process</i>	<i>Eco-costs (€/kg)</i>
Polypropylene	Waste incineration with electricity	0.281
	Recycling	-0.468
Steel	Landfill	0.118
	Recycling	-0.322
Paper/Cardboard	Waste incineration with electricity	-0.108

In the LCA the eco-costs of several aspects of the life cycle of transport packaging for the containment and transportation of dry groceries have been analysed. In Figure 13 and Table 10 the eco-costs (in euro per litre) per alternative are shown. It shows that alternative 4 has the lowest environmental impact. Alternative 3 has the highest eco-costs. The graph also shows the eco-costs per life-cycle stage. In the graph, it becomes clear that the higher eco-cost for alternative 3 is a result of higher material and transportation costs. The higher material costs for this alternative are related to the relatively high weight of the tray. The transportation costs are related to the size of the tray, only 6 trays of this alternative and alternative 2 fit on one roll container, compared to 12 trays for the other alternatives. It also becomes clear from the graph that the delivery has the most impact on the overall eco-costs. So, increasing efficiency in the delivery may have a high impact on the eco-costs.

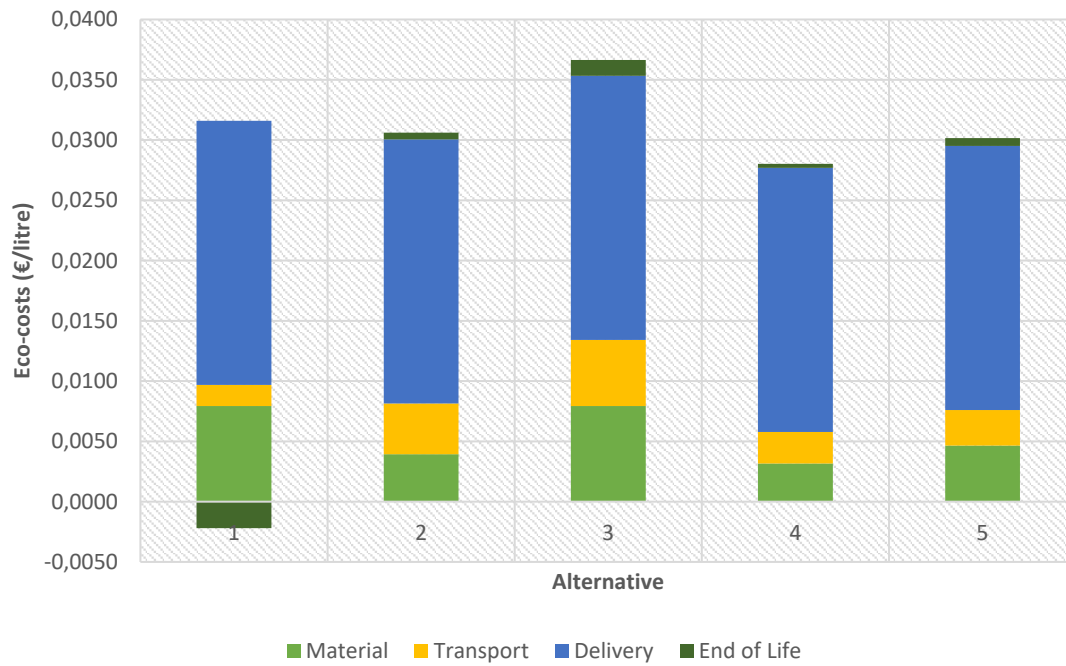


Figure 13. Eco-costs (€/L) per alternative

Table 10. Scores criterion: Environment

	<b>ALT. 1</b>	<b>ALT. 2</b>	<b>ALT. 3</b>	<b>ALT. 4</b>	<b>ALT 5.</b>
<b>SCORE (*)</b>	€0.0298	€0.0306	€0.0366	€0.0280	€0.0302
<b>NORM. SCORE</b>	0.80	0.70	0.00	1.00	0.75

\*Eco-costs in euro per litre

## **4.4 Economic assessment**

The alternatives have been assessed on the economic criteria. This is done based on collected data by interviews and internal data of PostNL and retailers. If the data was not enough to assess the alternative on the criteria, experiments have been performed to test it. Also, tests are performed to verify the theoretical assessed criteria. The tests can be found in Appendix H. The scores of the alternatives on the qualitative criteria are based on these tests.

### **4.4.1 Costs analysis**

The alternatives are compared on the economic criterion costs using a cost comparison. This comparison is done using excel. An identification of general costs aspects in the packaging supply chain is analysed in Appendix C. The cost types that are taken into account are:

- Production costs of the packaging
- Transportation costs:
  - From retailer to the sorting centre
  - From the sorting centre to a depot
  - From the depot to the hub
  - From the hub to the retailer
- Handling costs:
  - Sorting costs
  - Loading and unloading costs of the packaging into the trucks
  - Cleaning of the reusable packaging costs
- Costs for the home delivery of the groceries
- Variable administration costs

Fixed costs which are the same in every alternative have not been considered. These costs do not have an influence on the comparison of the alternatives. Examples of these costs are; costs of the process manager, planner and plan office.

For the cost comparison, the same general specifications of the different alternatives are used as for the LCA (see paragraph 4.3).

#### *Production*

The production costs of the packaging are the price of the packaging divided by the number of cycles the packaging can make, multiplied by the of packaging loss rate of 3%. Also for the costs, the prices of the paper bags which must be used inside the reusable packaging should be considered. The price of the paper bags is €0.10. The price of a cardboard box of 53L is 1.18€ (Cardboard packaging supplier, personal communication, June 6, 2017). The exact price of the trays is unknown but to make a comparison it is assumed that the price of a tray is 10€. Same as for the FEFCO research (Vogtländer, 2004), it is assumed that the reusable packaging alternatives can make 20 cycles. Only for the fifth alternative, it is assumed that it can make only 10 cycles, since this alternative has less quality. Also, the loss rate of 3% of the trays if considered. The price per cycle of the packaging is shown in Table 11. Since the exact production costs of the reusable trays are not known, it has also been analysed what the maximum production costs for each alternative should be to be profitable. The results of this are discussed in Chapter 5.

Table 11. Assumed production costs per alternative (except paper bags)

<i>Alternative</i>	<i>Production costs packaging per cycle</i>
1	€ 1.18
2	€ 0.52
3	€ 0.52
4	€ 0.52
5	€ 1.03

### *Transportation*

The transport legs already have been mentioned in paragraph 4.3. The costs related to these legs are based on data of costs of transport between the sorting centre and the depots, between the depots and the hub and distribution of the volume over the several depots. Average costs for one roll container per kilometre are calculated out of this. For every alternative, the number of roll container which must be transported can be multiplied by the average costs and the distance of the specific transport leg. For the transportation from the retailer to the sorting centre and from the hub to the retailer, no costs are known. An average is taken of the average costs per roll container per kilometre of the two know transport legs (see Table 12). For the return transport legs, the same approach as in the LCA (see paragraph 4.3) is applied. The number of boxes is multiplied by the volume reduction factor to calculated the needed space for the packaging. The resulting roll containers are multiplied by 27% to calculate the transport volume of the empty roll containers.

Table 12. Average transportation costs per roll container per kilometre

<i>From-to</i>	<i>Average costs per RC (€/km)</i>
Retailer – Sorting Centre	0.04
Sorting Centre – Depot	0.03
Depot – Hub	0.04
Hub- Retailer	0.04

### *Handling*

One of the handling aspects of the packaging is the sorting of the orders. There are multiple times when sorting takes place. First, the orders are sorted in the sorting centre on depot and route. The related costs are 3,33 €/RC. The other moment when sorting takes place is at the return hub. There the empty packaging is sorted on the retailers. This costs 0.99 €/RC.

Between the several transport legs and locations, the packaging has to be loaded and unloaded on and from the roll containers. On average, 3.6 roll container can be loaded and unloaded in one minute. This costs 0.09€ per box.

The debriefing of boxes after the delivery route takes 10 seconds per box and costs 0.07€ per box.

The reusable packaging must be cleaned after usage. This costs on average 0.07€ per cycle per tray.

### *Delivery*

The delivery costs depend on the time the driver needs to deliver the groceries and finish the route. The average costs for a delivery route are taken from five weeks of data. These costs are 140.40€ per route. On average, there are 16 stops on one route and there are 19 boxes delivered. Every extra box which is delivered per stops takes 30 seconds more time. The delivery of more than the average of 1.2 boxes, costs 0.20€ per extra box. So, the costs for the delivery can be calculated by:

#### *Delivery costs*

$$= \text{average delivery costs per route} * \text{nr. of routes} + \text{nr. of extra boxes} * 0.20$$

Where:

*Nr. of extra boxes*

$$= \text{nr. of boxes of the alternative} - \text{nr. of boxes standard volume}$$

### *Administration*

The variable administration costs are the administration costs of the boxes at the depots. This includes also the switching on of the mobile phones and the IT application, which is used for the delivery. As well as the guidance of the drivers. It takes on average 5,5min/route. These costs depend on the number of routes, the number of boxes per route and the total number of boxes. On average these costs are 0.12€ per box.

The production, transportation, sorting, handling, delivery and administration costs per order per alternative are shown in the graph in Figure 14. Table 13 shows the total costs per alternative per litre of groceries. Alternative 1 has the lowest costs, but the difference is small with the fourth alternative. If the production price is lower than the assumed 0.52€/cycle it might be that this alternative becomes cheaper than alternative 1. As described earlier this is also analysed, the results of this are presented in chapter 5. Alternative 3 has, the same as for the eco-costs, the highest total costs. The main reason for this is again that only six trays fit on one roll container during the transportation. Also, it is remarkable that the same as for the eco-costs, the delivery has the highest impact on the total costs. The shape of the graph is comparable with the graph of the eco-costs (Figure 13). However, in the eco-costs graph, there are no eco-costs related to the sorting, handling and administration since there are no eco-costs related to human labour in the Netherlands. The results of further comparison between the costs and eco-costs per alternative are discussed in Chapter 5.

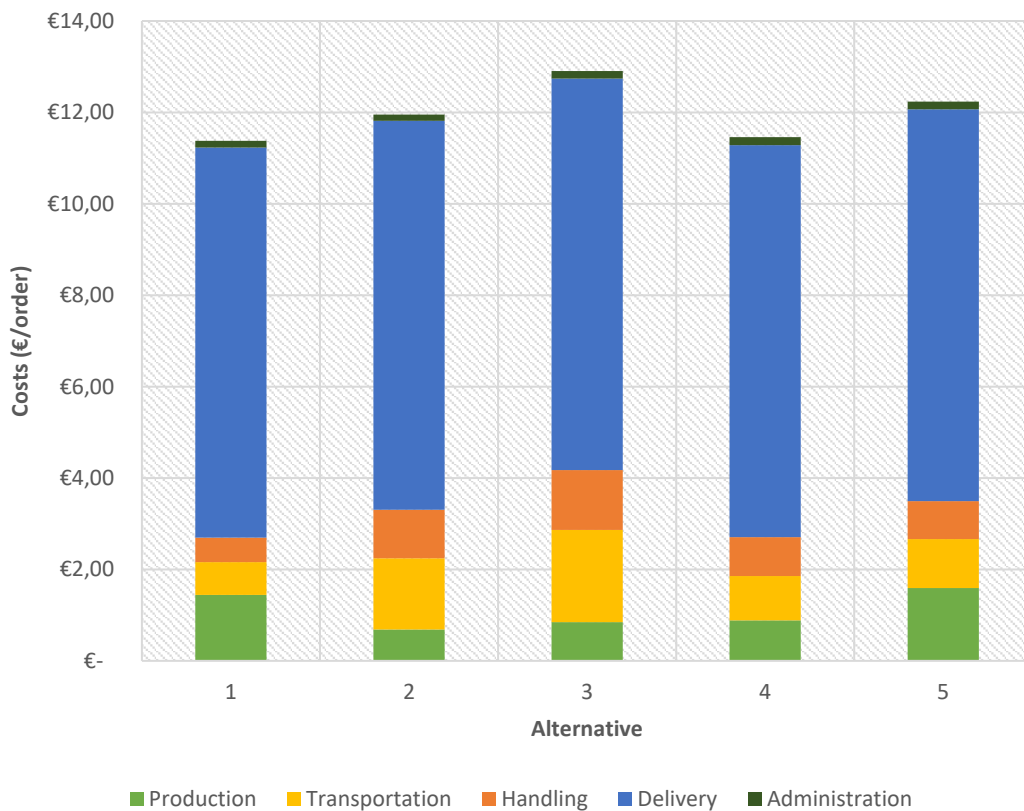


Figure 14. Costs (€/order) per alternative

Table 13. Scores criterion: Costs

	ALT. 1	ALT. 2	ALT. 3	ALT. 4	ALT. 5.
<b>SCORE (*)</b>	€ 0.176	€ 0.184	€ 0.199	€ 0.177	€ 0.189
<b>NORM. SCORE</b>	1.00	0.62	0.00	0.95	0.44

\* Costs in euro per litre

#### 4.4.2 Logistic performance

The assessment of the alternatives on logistic performance criteria has been done based on internal gather data, surveys and interviews. Also, experiments have been performed to gather the not available data and to validate the data. The experiments can be found in Appendix H Experiments.

##### Fit on trolley

How well the alternatives fit on the trollies of PostNL is related to the size of the transport packaging. The outer size is 80 x 80 x 190 centimetres. However, it appeared that the inner dimensions of the trolley are only 79 x 78 x 169 centimetres (see Figure 15). Also, the combination of cool boxes next to the transport packaging of dry groceries should fit on the trollies. The size of the cool box is 64 x 37.5 x 37.9 centimetres (see Figure 16). 10 cool boxes do fit on one trolley. If the transport packaging for dry groceries has the same size

as the cool boxes, this would fit optimal on the trolley. However, this size is not optimal for other processes.



Figure 15. Trolley with push handle

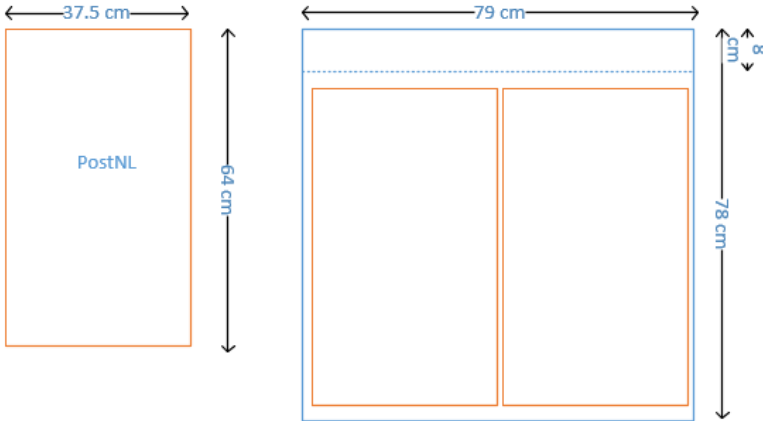


Figure 16. Top view PostNL box on roll container

The Euronorm size which is for example used by Euro Pool Systems (EPS) of 60 x 40 x 24 centimetres does fit next to the cool box on the trolley (see Figure 17). Looking just theoretically at the sizes of two EPS trays they don't fit within the inner dimensions of the trolley. However, if the direction of the trays is changed, it is almost possible to fit two EPS trays next to each other onto the trolley. There is a stretch out of 2 centimetres. The problem of this is the higher border of the roll container which makes that the trays cannot be stacked in a straight line and the change of damage to the trays. Also, some of the trollies have a push handle (see Figure 15 and Figure 16) which is around 8 centimetres to the inside. In the case of this trolley, two boxes don't fit next to each other at all at the height of the push handle.

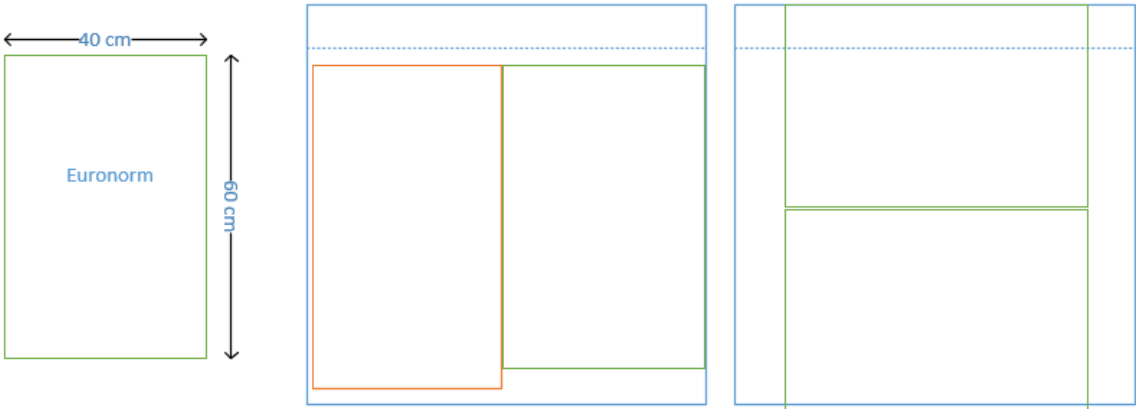


Figure 17. Top view Euronorm box and combined with PostNL box

Another size which is used within the Dutch retail market is the size: 53 x 35.4 x 26.5 centimetres, used by Albert Heijn (AH). This size does fit easily on the trolley next to the

cool box and also next to each other. In height 7 trays fit onto each other. This makes a total of 14 trays on one trolley or 7 trays and 5 cool boxes.

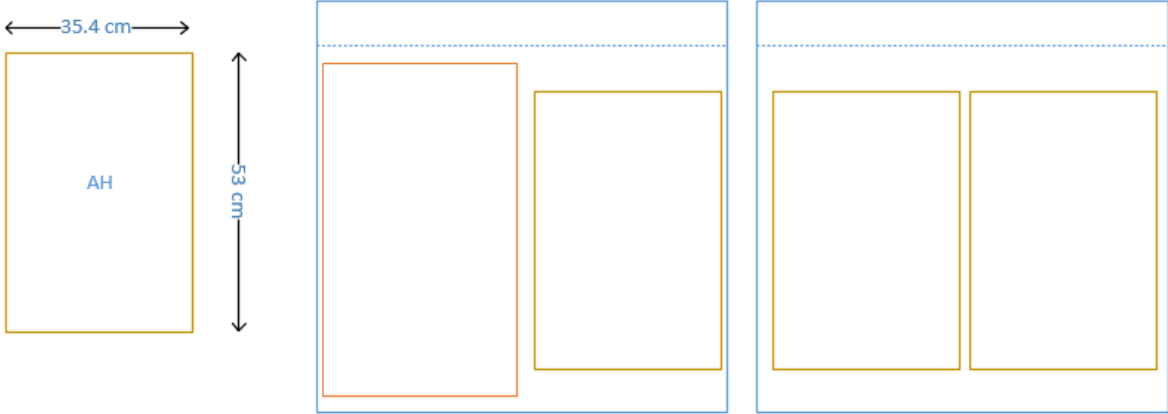


Figure 18. Top view AH box and combined with PostNL box

Alternative 1: Every size is possible, so the optimal size can be chosen. The maximum dimensions of this box should not exceed a width of 38 centimetres and a length of 64 centimetres. However, the specified dimensions of this alternative have the same size as the AH tray. So, the box fits easy on the roll container, but there is also much space left.

Alternative 2: The experiments showed that two Euronorm boxes do not fit properly next to each other at the roll container. It is a problem if the boxes don't fit completely on the roll container because they cannot be stacked in a straight line and there is a chance of damage to the packaging if they collide with each other. So, only one stack of boxes can be placed on the roll container.

Alternative 3: This box has the same width as alternative 2, so there is also only the possibility for one stack of boxes.

Alternative 4: This alternative has AH size, so fits easy on the roll container but also much space is left.

Alternative 5: This alternative has almost the same dimensions as the AH size. The dimensions are 54 by 38 centimetres, so two stacks of these boxes fit easily on the roll container.

Table 14. Scores criterion: Fit on trolley

	ALT. 1	ALT. 2	ALT. 3	ALT. 4	ALT 5.
<b>SCORE</b>	5	2	2	5	5
<b>NORM. SCORE</b>	0.67	0.17	0.17	0.67	0.67

Handling during fulfilment

The transport packaging has to fit well on the pick cart of the retailers and has to be easy to handle during the rest of the fulfilment process. It has to be effortless to fold/unfold the tray if necessary. It also has to be uncomplicated to open and close the lid of the box. The assessment of this criterion is tested in practice. However, retailers have different pick carts and processes. In general, packaging wider than 40 centimetres and longer than 610 centimetres doesn't fit on the pick carts. Also, a maximum size of 30 centimetres is



preferred since there has to be enough space left between the tray and the next layer of trays to pick the groceries into the tray.

Alternative 1: This alternative takes more handling compared to a reusable tray. The box has to be unfolded and taped. Also, to close the box tape is needed. Another disadvantage of picking into this box is that is hard to pick into a box with closed walls since the pickers cannot see what they are exactly doing. The size of the box fits well on the pick cart.

Alternative 2: This alternative also has to be unfolded, but it is easier to unfold this plastic tray than a cardboard box. It does fit well on the pick cart.

Alternative 3: This alternative doesn't have to be unfolded, but it has to be taken apart from the other trays. This can be a struggle if the trays stick together. It does not fit well on the pick cart since the tray is wider on top.

Alternative 4: This alternative has to be unfolded. The tests showed that it is not easy to handle a tray with a lid on the short side. This is because mainly women are working in the distribution centre. These women are not long enough to easily take off the tray from the top. So, the handle is always needed to take the tray of the cart by them. This alternative fits well on the pick cart.

Alternative 5: This alternative doesn't have to be unfolded, but it has to be taken apart from the other trays. This can be a struggle if the trays stick together. Also, there has to be a separate flow for the lids, since they are not fixed to the tray. It is not workable to handle separate lid and tray flows. The dimensions of this alternative fit well on the pick cart.

Table 15. Scores criterion: Handling fulfilment

	ALT. 1	ALT. 2	ALT. 3	ALT. 4	ALT 5.
<b>SCORE</b>	3	7	1	2	1
<b>NORM. SCORE</b>	0.33	1.0	0.0	0.17	0.0

Filling buses

The delivery van has multiple carries attached to the wall. There are three carriers next to each other on one side and two on the side of the door. The size of one carrier is 110 by 40 centimetres. The more efficient the packaging fits on the carrier, the more efficient the delivery van can be loaded. So, two boxes with a maximum size of 55 by 40 centimetres fit on the carrier (see Figure 19). Also, if it is no problem that the boxes stretch out over the carrier, three boxes with a maximum width of 36 centimetres fit on the carrier. The more efficient the delivery vans are loaded, the more boxes can be transported in one delivery van.

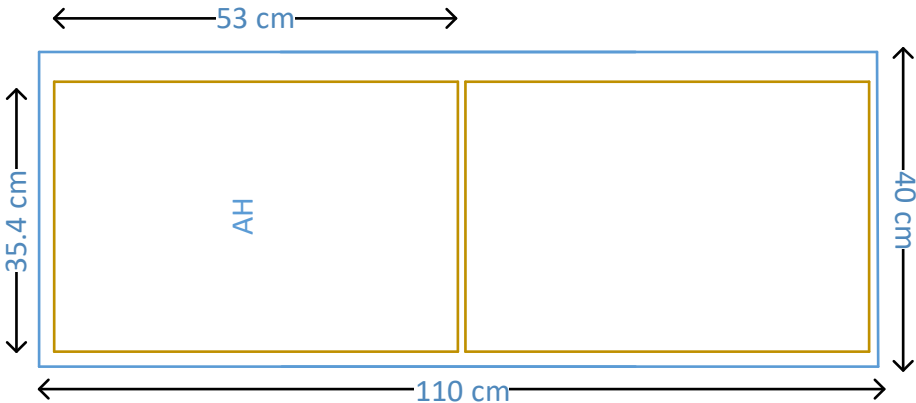


Figure 19. Two AH size boxes on carrier

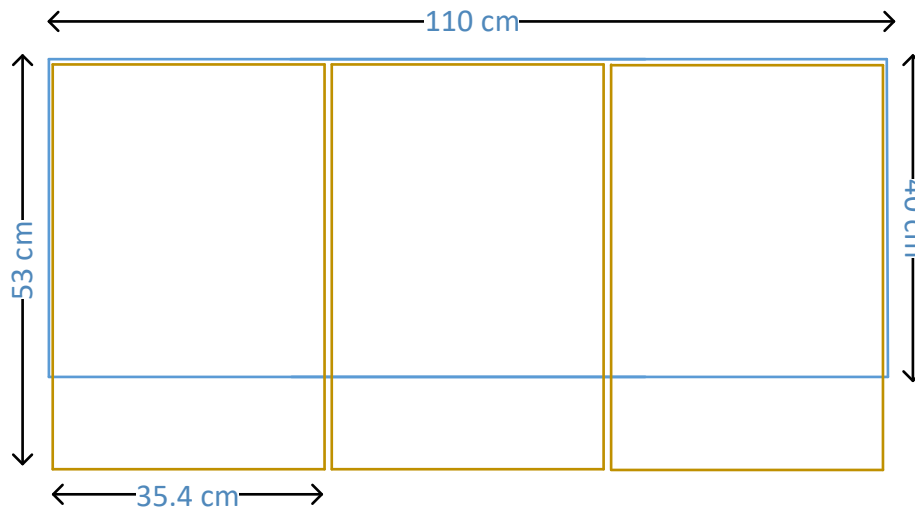


Figure 20. Three AH size boxes on carrier

Alternative 1: For boxes with maximum dimensions within the 55 by 40 centimetres two boxes fit next to each other on the carrier. This is the case for the dimensions of this alternatives. Also, for this alternative 3 boxes fit in the other direction.

Alternative 2: Only one tray fits on the carrier without stretching out. This alternative is also to width to fit three trays in the other direction.

Alternative 3: Only one tray fits on the carrier without stretching out. This alternative is also to width to fit three trays in the other direction.

Alternative 4: Two trays fit next to each other and three in the other direction (see Figure 19 and Figure 20).

Alternative 5: Two trays fit next to each other on the carrier, but the tray is to width to fit three trays in the other direction.

Table 16. Scores criterion: Filling buses

	ALT. 1	ALT. 2	ALT. 3	ALT. 4	ALT 5.
<b>SCORE</b>	7	4	4	7	6
<b>NORM. SCORE</b>	1.0	0.33	0.33	1.0	0.67

## Space

How space efficient the transport packaging is during the process depends on whether and how the transport packaging can be reduced in size to reduce the packaging volume in transport flows and during storage. Foldable transport packaging can be reduced in size the most. After foldable packaging, nestable packaging can also be reduced in size, but the minimum size of the height of one tray is always needed. Non-stackable and not nestable packaging cannot be reduced in size and is not efficient during the process.

Alternative 1: This alternative is folded before it is used. There is no return flow needed if the packaging is not reused. So, also no space is needed for the return. However, for the consumer, the cardboard needs additional space compared to reusable alternatives.

Alternative 2: This alternative can be folded. The space reduction of this tray is 75%.

Alternative 3: This alternative can be nested. The space reduction of this tray is 67% of the tray size. However, also the size of the bottom tray should be added to the total volume of the nested trays.

Alternative 4: This alternative can be folded. The space reduction of this tray is 80%.

Alternative 5: This alternative can be nested. The space reduction of this tray is 60%. However, also the size of the bottom tray should be added to the total volume of the nested trays. Besides this, there is also a separate flow and volume of the lids.

Table 17. Scores criterion: Space

	<b>ALT. 1</b>	<b>ALT. 2</b>	<b>ALT. 3</b>	<b>ALT. 4</b>	<b>ALT 5.</b>
<b>SCORE</b>	4	5	3	6	2
<b>NORM. SCORE</b>	0.5	0.67	0.33	0.83	0.17

## Capacity

The efficiency of the capacity depends on the size of the tray and the average product sizes and filling rates. The sizes of 6439 products of the retailer are known. This data is used to calculate the average size of the products and which percentage of the product fits into the packaging. The optimal height of the of the packaging for products is around 27 centimetres. 94,6% of the products fit in packaging lower than 27 centimetres and 95,7% in packaging lower than 28 centimetres. The products which are higher than this dimension are mainly bulk products. To give an impression, drink cartons are often around 23.5 centimetres. The average size of syrup is 25.5 centimetres and a bottle of detergent 26.5 centimetres.

Alternative 1: The volume of this alternative is 53L. Although a cardboard box of every size is possible and can be adjusted to the optimal size. This tray has an internal height of 28 centimetres, so most products fit in the tray.

Alternative 2: The volume of this alternative is 58L. This tray has an internal height of 28 centimetres, so most products fit in the tray.

Alternative 3: The volume of this alternative is 47L. The walls of this alternative are not straight. This makes that some part of the volume cannot be used. The internal height of this tray is 25 centimetres, this is not high enough for many products.

Alternative 4: The volume of this alternative is 45L. The height of this alternative is designed specially to fit products.

Alternative 5: The volume of this alternative is 46L. However, the walls are not straight. This makes that some part of the volume cannot be used. Also, the height of this tray (25 centimetres) is not large enough for many products.

Table 18. Scores criterion: Capacity

	<b>ALT. 1</b>	<b>ALT. 2</b>	<b>ALT. 3</b>	<b>ALT. 4</b>	<b>ALT 5.</b>
<b>SCORE</b>	5	6	2	4	1
<b>NORM. SCORE</b>	0.67	0.83	0.17	0.50	0.0

Labelling

The label can be scanned by the sorting machine at the top or right side of the packaging.

Alternative 1: It is possible to put a label on every side. Also, the label doesn't have to be removed since the box is not being reused.

Alternative 2: It is possible to stick a label on every side. There is no specific designed surface to stick the label on. However, there is a section at the lid in which the label can be placed.

Alternative 3: It is possible to stick a label on every side. There is no specific designed surface to stick the label on.

Alternative 4: The label can be put on top since the lid is a solid surface. It is not possible to put a label on the long side of the tray. It is possible to put a label on the short size of the tray. There is a special smooth surface to stick a label on, which makes it also easy to remove the label.

Alternative 5: It is not easy to put a label on top of this alternative since the lid does not have a solid surface. It is possible to stick a label to the side walls. There is no specific designed surface to stick the label on.

Table 19. Scores criterion: Labelling

	<b>ALT. 1</b>	<b>ALT. 2</b>	<b>ALT. 3</b>	<b>ALT. 4</b>	<b>ALT 5.</b>
<b>SCORE</b>	7	4	4	6	2
<b>NORM. SCORE</b>	1.00	0.5	0.5	0.83	0.17

## 4.5 Social assessment

### Food Safety

The more the transport packaging is closed, the less likely it is that the food will get contaminated during the process. Also, the possibility of sealing the transport packing can proof that the transport packaging has not been opened during the process. Sealing is possible on all the alternatives. In general, these alternatives are all safe, but some might have slightly more chance of danger than others.

Alternative 1: This alternative is completely closed. Although rain can have an effect on the cardboard and in the end also on the groceries, this is only the case if the transport packaging is left behind and standing in the rain for a while. Also, there is more chance that this packaging will break or that groceries get damaged.

Alternative 2: This alternative is closed, except the handle.

Alternative 3: This alternative is completely closed.

Alternative 4: This alternative has open side walls. Since paper bags are used inside the trays this will not be a problem.

Alternative 5: This alternative is completely closed.

Table 20. Scores criterion: Food Safety

	<b>ALT. 1</b>	<b>ALT. 2</b>	<b>ALT. 3</b>	<b>ALT. 4</b>	<b>ALT 5.</b>
<b>SCORE</b>	5	6	7	5	7
<b>NORM.</b>	0.67	0.83	1.0	0.67	1.0
<b>SCORE</b>					

### Ergonomics

The size, the weight, the shape of the transport packaging and handles contribute to the ergonomics of the transport packaging. The bigger the transport packaging, the harder it is to carry. This is the same for the weight of the transport packaging and groceries. There is a maximum weight of 30 kg. So, if the transport packaging is heavier, it can be filled with less weight of products. Bigger boxes can also be better than smaller boxes because it is harder to carrier two or more boxes instead of one. It takes a lot of time if the driver has to walk multiple times to take all the boxes. However, the driver can use a hand truck which makes it easier to carry multiple boxes. The ergonomics of the alternatives are tested by order pickers and drivers.

Alternative 1: Medium easy to carry. Cardboard handles are not that smooth as plastic handles are. The bigger the box, the more influence this has.

Alternative 2: Very easy to carry.

Alternative 3: Very easy to carry.

Alternative 4: Very easy to carry.

Alternative 5: Hard to carry, closed handles are not that easy to use than open handles.

Table 21. Scores criterion: Ergonomic

	<b>ALT. 1</b>	<b>ALT. 2</b>	<b>ALT. 3</b>	<b>ALT. 4</b>	<b>ALT 5.</b>
<b>SCORE</b>	4	7	7	7	2
<b>NORM. SCORE</b>	0.5	1.0	1.0	1.0	0.17

## 5 Results & Discussion

This chapter discusses the outcomes of the analysis of the alternatives on the several criteria. The initial results of the analysis are shown in paragraph 5.1. Paragraph 5.2 validates the robustness of the results. Furthermore, practical implications on the results have been stated in paragraph 5.3. Finally, the outcomes of the analysis are discussed in 5.4.

### 5.1 Initial Results

The results of separate parts of the analysis in Chapter 4 can be combined to get the results which can be used to compare the alternatives. The normalised scores are multiplied by the determined weight factors. The final scores per alternative are shown in Table 22. The table shows that alternative 4 has the highest score and alternative 3 by far the lowest. The differences in scores between alternative 1 and 4 are relatively small.

Table 22. Weighted scores alternatives on criteria

Criteria	Weight factor	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Food safety	0.15	0.100	0.125	0.150	0.100	0.150
Ergonomic	0.07	0.035	0.070	0.070	0.070	0.012
Costs	0.18	0.180	0.112	0.000	0.170	0.079
Fit on roll container	0.07	0.047	0.012	0.012	0.047	0.047
Handling fulfilment	0.05	0.017	0.050	0.000	0.008	0.000
Filling busses	0.04	0.040	0.013	0.013	0.040	0.027
Space efficient	0.05	0.025	0.033	0.017	0.042	0.008
Capacity	0.03	0.020	0.025	0.005	0.015	0.000
Labelling	0.03	0.030	0.015	0.015	0.025	0.005
Environment	0.32	0.256	0.224	0.000	0.320	0.241
<b>Total</b>		<b>0.749</b>	<b>0.679</b>	<b>0.282</b>	<b>0.837</b>	<b>0.568</b>

Note: The scores are normalised values. So, 0.000 does not mean that the actual value (for example costs) is 0.

#### Size & Volume of the alternative

Within the analysis, it became clear that the size of the alternative has a high impact on the score. However, the combination of the specifications of the alternative itself is more important, but to improve the alternative the volume of the alternative might be changed. Figure 21 shows the difference in eco-costs per alternative over different volumes of the alternative. The biggest difference is for alternative 3; 0.0047€/litre. This doesn't sound like a big difference, but this is 0.2556€/order and can be easily €2555 per week (if 10000 orders per week). It should be remarked that alternative 3 remains the 'worst' alternative in terms of eco-costs. For the alternative with the lowest eco-costs (alternative 4), the difference can be around €1015 per week.

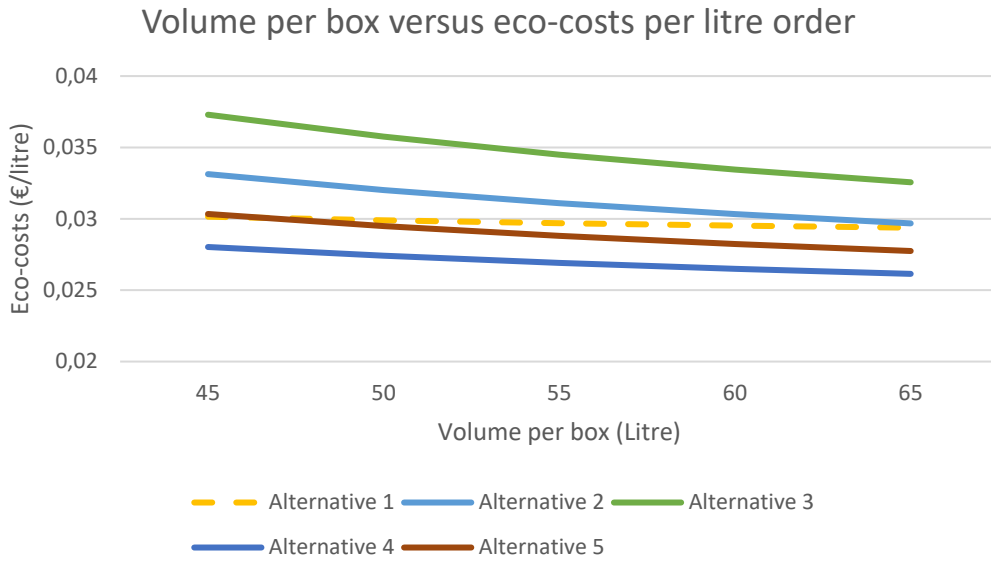


Figure 21. Eco-costs (€/Litre) per alternative at increasing volume

The analysis of the costs compared to the volume of the alternative shows the same trend as the eco-costs graph. However, the differences in costs are here even higher (see Figure 22). For alternative 4, the difference is 0.98€/order. So, this may be €9760 per week. Initially, alternative 1 (53 litres) has lower costs than alternative 4 (45 litres) (see Table 22). However, this graph shows that alternative 4 will be cheaper if the alternatives would have the same volume. Also, Appendix J (Table 36) shows that an increase of 2 litres of volume for alternative 4 will increase the overall score of the alternative.

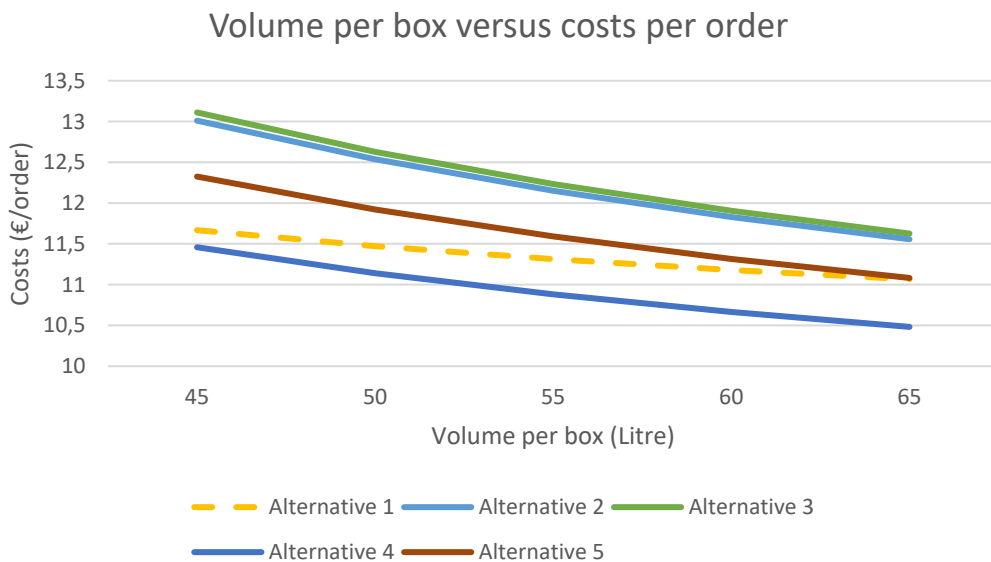


Figure 22. Costs (€/order) per alternative at increasing volume

It is also noteworthy that the volume has more impact on the eco-costs and costs of the trays than on the cardboard box (alternative 1). This is because the reusable trays have more return transport. If the trays are bigger, fewer trays have to be used and so less packaging has to be returned.



The cardboard boxes are easily adjustable in size. Different volumes and sizes between 45 and 68 litres have been analysed. All boxes with a higher volume than the initial volume of 53 litres for alternative one, show to have a higher score (see Appendix J, Table 35) and the box with 64 litres the highest score. However, the scores of the variations of the box remain lower than the score of alternative 4.

The volume and size of the packaging do not only have influences on the eco-cost and costs but also on the other criteria. The analysis showed that for the roll container the optimal size would be a length around 64 centimetres and a width of 38 centimetres. For the fulfilment, the dimensions of the packaging should be maximum 61 x 40 x 30 centimetres. The filling of the buses is the most efficient if the trays have a length of 55 centimetres and a width of 36 centimetres. The tray should have an internal height around 27 centimetres to fit most products in the transport packaging.

Production costs/price of the packaging

Table 22 already showed that alternative 4 (assuming a price of 0.52€/cycle for the tray) always has a higher score than the cardboard box. However, just looking economically alternative 4 is not better than the cardboard box. Figure 23 shows that alternative 2 and 3 will never be cheaper than the cardboard box. In Appendix J (Figure 46) also a graph is shown which shows the prices compared to the variations in the volume of the cardboard box. Alternative 5 is cheaper than alternative 1 until a price of 0.42 €/cycle. Alternative 4 is cheaper until a price of 0.46 €/cycle. Comparing the reusable trays with other volumes of cardboard boxes, the lower the volume of the cardboard box, the higher the costs per order so the trays can also be more expensive per cycle. For example, comparing alternative 4 with a cardboard box of 45 litres, alternative 4 will be cheaper until a price of 0.65€ per cycle. The packaging price per cycle can be decreased by a lower buying price of the packaging or by using it more cycles. This means that assuming a tray can make 20 cycles, the price of alternative 4 should be lower than 9€ in order to be cheaper than the cardboard box in this research.

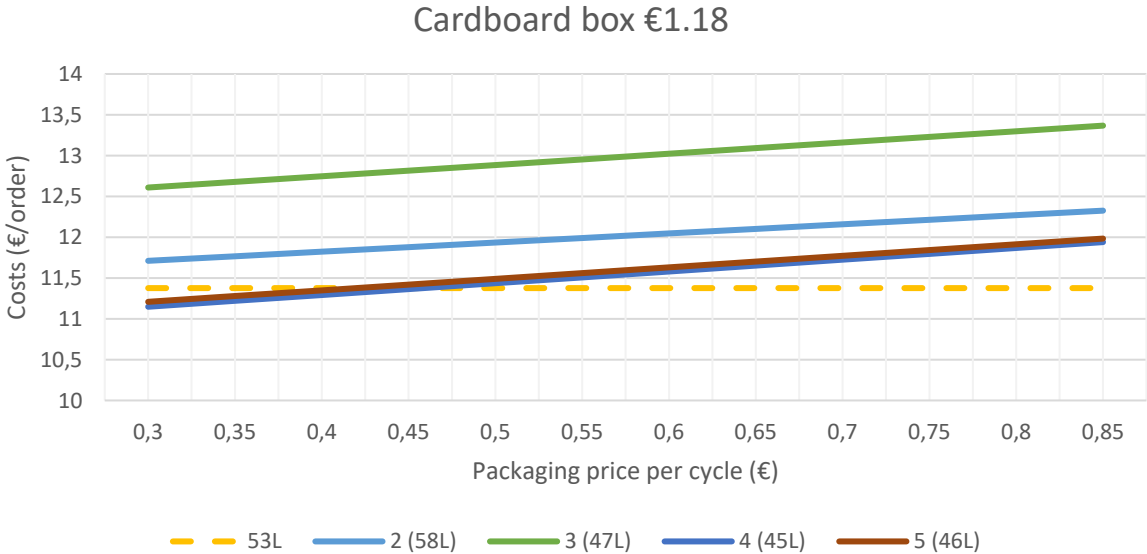


Figure 23. Determination maximum production price for the reusable trays to be economically efficient

If the volume of the reusable tray alternatives would be changed to the same volume as the cardboard box, the price per cycle could be higher. Alternative 4 would be cheaper until 0.85 €/cycle (see Figure 24).

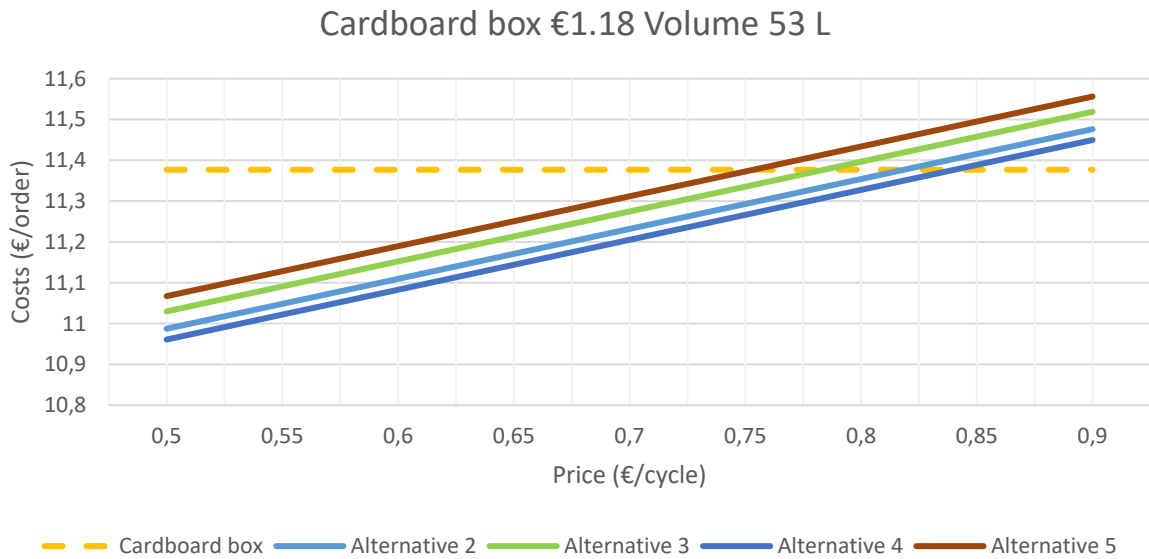


Figure 24. Costs related to packaging price per cycle if all alternatives have the same volume

However, even if the costs for alternative 4 are higher than for alternative 1 the overall score of alternative 4 will remain higher until a packaging price of 1.58€/cycle. Looking into packaging prices of trays it is not expected that the price will be that high.

### Eco-costs versus costs

The relationship between the eco-costs and costs is visualised in Figure 25. The first part of the lines from zero to the first point is the eco-costs and costs related to the packaging. The line from the first dot to the second dot shows the eco-costs and costs for the transportation. From the second dot to the third dot the costs for the handling are shown. The eco-costs are zero for this part of the graph since there are no eco-costs related to the human labour. The last part of the line is the home delivery of the groceries. This part of the line involves the biggest part of the overall eco-costs and costs. These cumulative lines show the performance of the alternatives in terms of eco-costs and costs. The last point on the lines is the total eco-costs and costs of the alternative in euro per litre transported groceries. The graph shows that alternative 4 performs slightly better than the other alternatives.

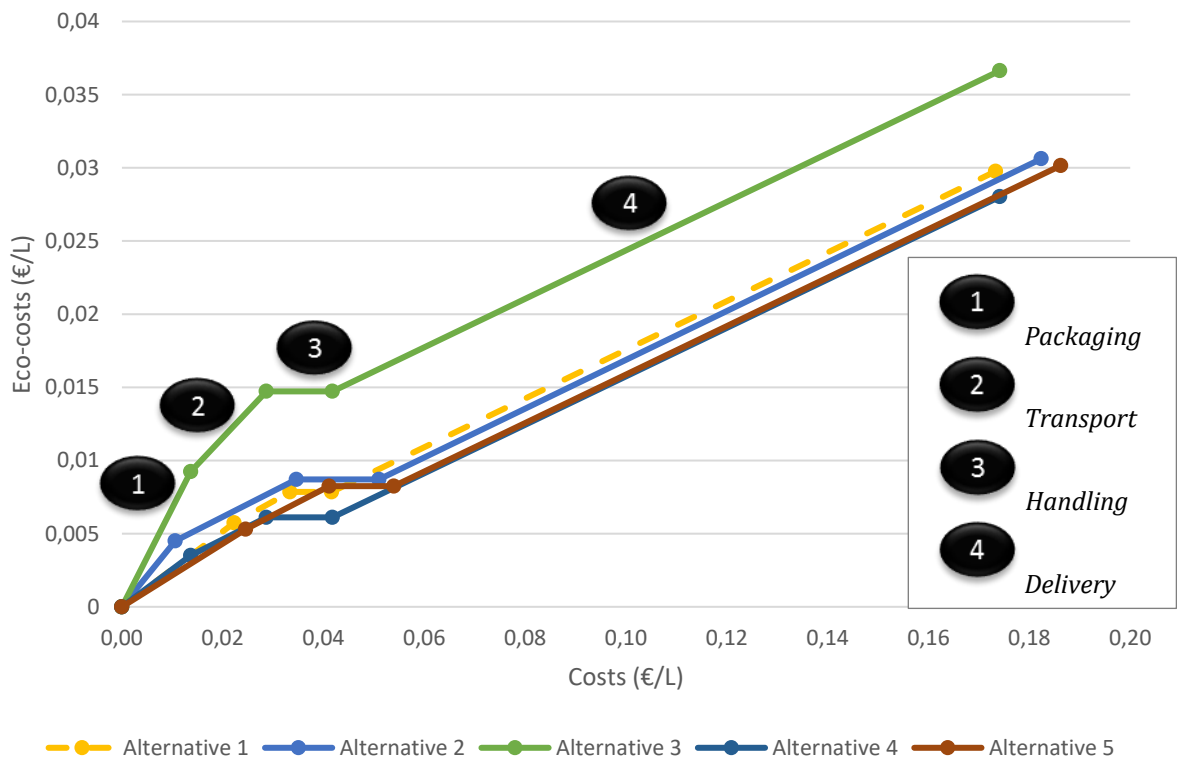


Figure 25. The costs and eco-costs per litre for five transport packaging alternatives

## 5.2 Validation

### 5.2.1 Sensitivity analysis

For every criterion, the weight factor has been changed to 0 to gain insights into the impact of the specific weight factor and criteria to the overall score of the alternative. As can be found in Table 23, alternative 4 remains the alternative with the highest overall score in all the cases that the weight factor of a specific criterion is set to 0.

Table 23. Sum of weighted normalised scores: Validation per criteria weight factor set to 0.

Criteria Weight factor=0	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Food safety	0.6489	0.5544	0.1317	0.7371	0.4179
Ergonomic	0.7139	0.6094	0.2117	0.7671	0.5562
Costs	0.5689	0.5671	0.2817	0.6667	0.4892
Fit on roll container	0.7022	0.6677	0.2700	0.7905	0.5212
Handling fulfilment	0.7322	0.6294	0.2817	0.8288	0.5679
Filling busses	0.7089	0.6661	0.2683	0.7971	0.5412
Space efficient	0.7239	0.6461	0.2650	0.7955	0.5596
Capacity	0.7289	0.6544	0.2767	0.8221	0.5679
Labelling	0.7189	0.6644	0.2667	0.8121	0.5629
Environment	0.4933	0.4557	0.2817	0.5171	0.3270
<b>Normal</b>	<b>0.7489</b>	<b>0.6794</b>	<b>0.2817</b>	<b>0.8371</b>	<b>0.5679</b>

Another analysis which is performed to test the robustness of the results is the comparison of the results without and with weight factor (see Table 24). The order of the highest to lowest overall scores is the same for both situations.

Table 24. Sum of normalised scores without weight factor

	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
No weight factor	7.132	6.657	3.500	7.614	4.023
Percentage of highest score	94%	87%	46%	100%	53%
Normal	0.7489	0.6794	0.2817	0.8371	0.5679
Percentage of highest score	89%	81%	34%	100%	68%
Difference	-4%	-6%	-12%	0%	15%

This sensitivity analysis showed that the results of the MCA are robust related to the weight factors. In paragraph 4.2.3 it has been mentioned that respondent 3 might be left out for the determination of weight factors. However, since this validation showed that the analysis is robust also without influence of weight factors, it is not necessary to change the weight factors.

### 5.2.2 Scenario analysis

To analyse the robustness of the LCA and cost comparison in the future some scenarios have been determined. The scenarios are related to the transportation and delivery since these aspects have shown to have the most influence on the overall eco-costs and costs (see chapter 4).

#### Transportation

The several used transport legs in the analysis have a combined distance of 311 kilometres. In the scenario analysis, this distance is varied. From 50% of this distance to 425% (1320km.) of this distance. The graph of the eco-costs related to the distance (see Figure 26) shows that an increase of distance has more influence on the reusable alternatives than on the cardboard box. Also, this graph shows that from 1320 kilometres on the cardboard box will have lower eco-costs than alternative 4. Within the Netherlands a distance of 1320 km. is not realistic. So, alternative 4 will remain with the lowest eco-costs in every transport scenario. In Appendix J (Figure 48) the comparison of the alternatives related to the variation on alternative 1 can be found.

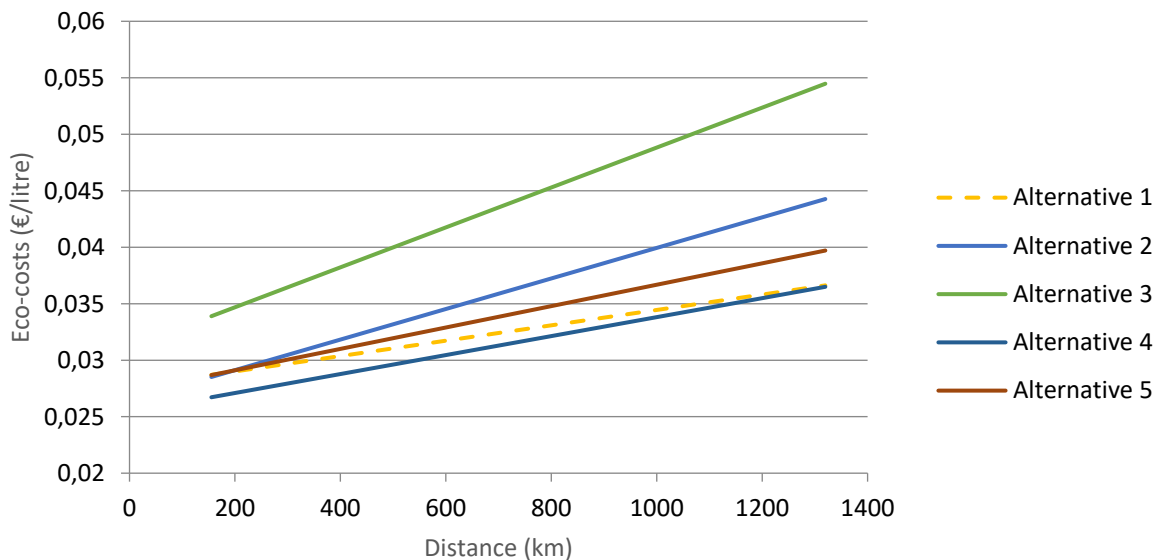


Figure 26. Eco-costs over the total transportation distance future scenarios

Also, looking into the data of the transport distances a low and a high scenario of transport distances can be formed (see Table 25). As can be found in Figure 27 the eco-costs for alternative 4 stay the lowest in every scenario.

Table 25. Historic data transport distance

From-to	Average distance (km)	Low scenario	High scenario
Retailer – Sorting Centre	69.11	32.8	133
Sorting Centre – Depot	70.30	0	104
Depot – Hub	82.09	44	151
Hub- Retailer	89.05	54.2	228.3

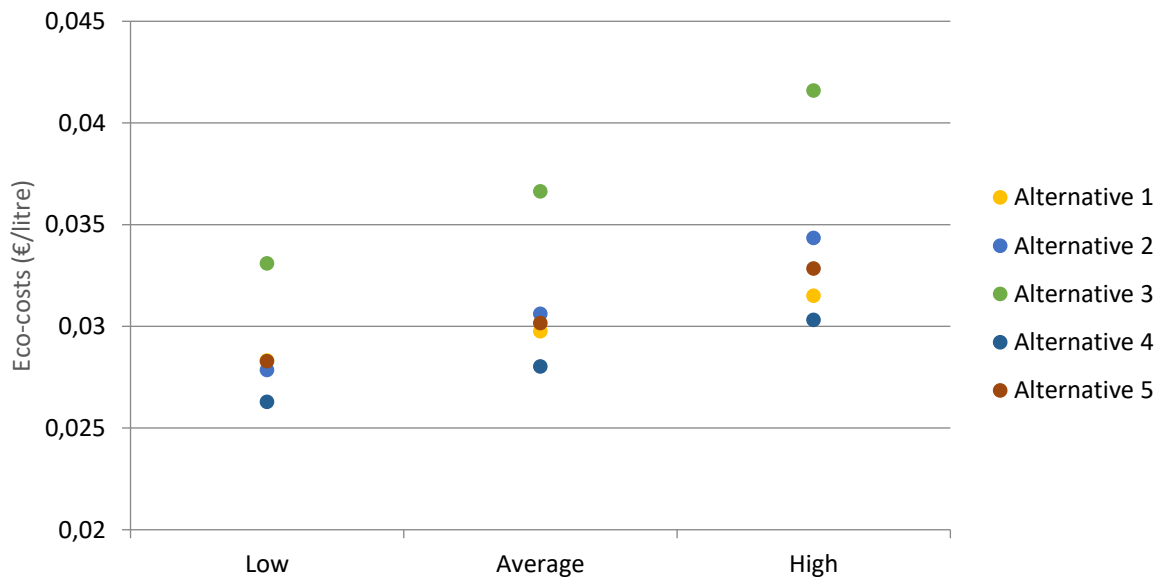


Figure 27. Historic transport distance scenarios and related eco-costs

For costs, the same future and historical scenarios are explored. Figure 28 shows that the cardboard box will remain cheaper than the other alternatives if the total transportation distances are larger than 200 kilometres. Also, the difference in costs between the cardboard box and the reusable trays becomes larger. The reason for this is that the transportation distance has less influence on the total costs if the distance is smaller. The larger the distance, the more influence on the total costs. Since the cardboard box has less return transport this influence becomes higher for longer distances. For the historic scenarios also the cardboard box is cheaper in the 'normal' average and high scenarios, but alternative 4 is cheaper in the low scenario.

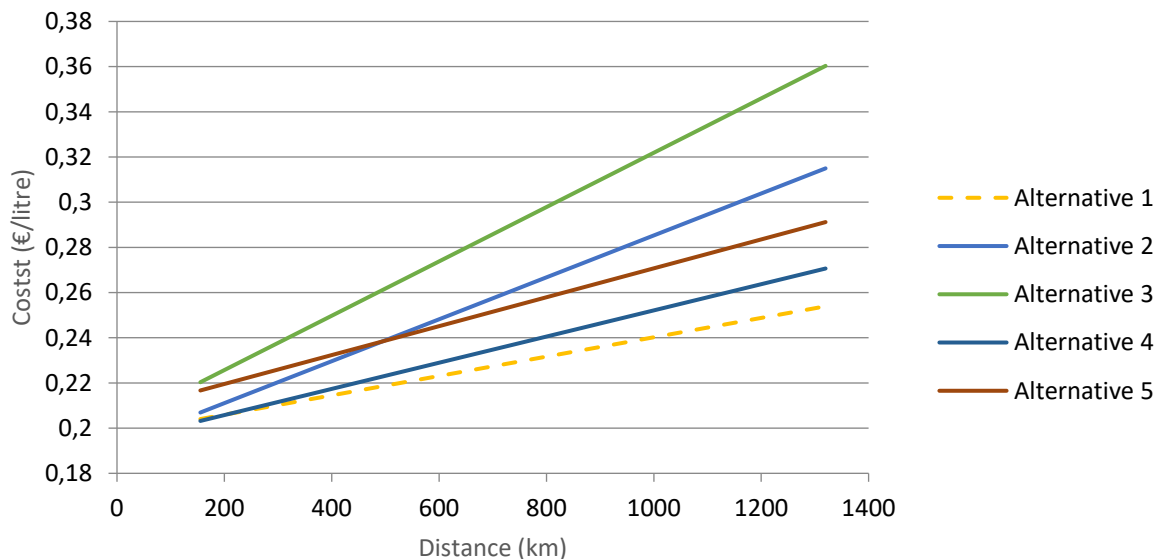


Figure 28. Costs over the total transportation distance future scenarios

## Delivery

The delivery is not only depending on the distance, but also on the amount of stops per route and the amount of boxes per stop. The scenarios based on historical data can be found in Table 26.

Table 26. Historic data delivery aspects

	<i>Average</i>	<i>Low scenario</i>	<i>High scenario</i>
Stops per route	16	7	26
Boxes per stop	1.2	1	7
Time per route (min)	344.5	130	580
Distance per route (km)	190	32	432

The influence of the variation in stops per route can be found in Figure 29. The figures show that the more stops per route, the lower the eco-costs and costs. This seems logical since the impact of one delivery route can be divided by more orders.

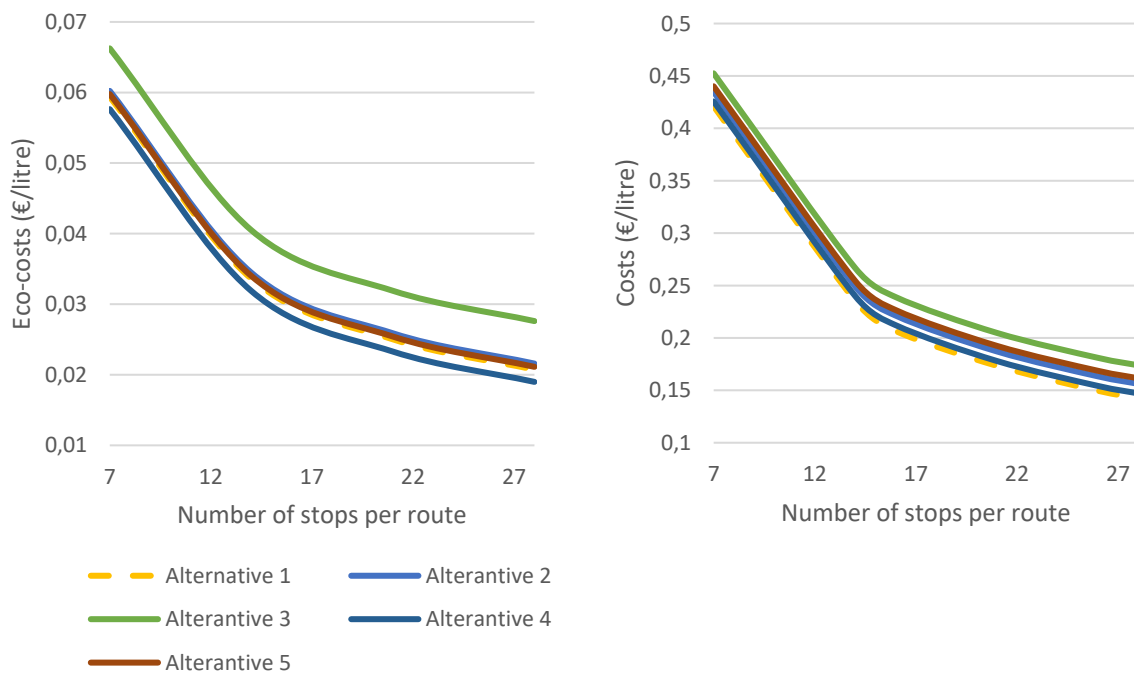


Figure 29. Eco-costs and costs for variations in number of stops per route

After the variation in stops, the number of boxes per stop has been varied. This can be found in Figure 30. Increasing the number of boxes per stops decreases the delivery costs per litre transported groceries.

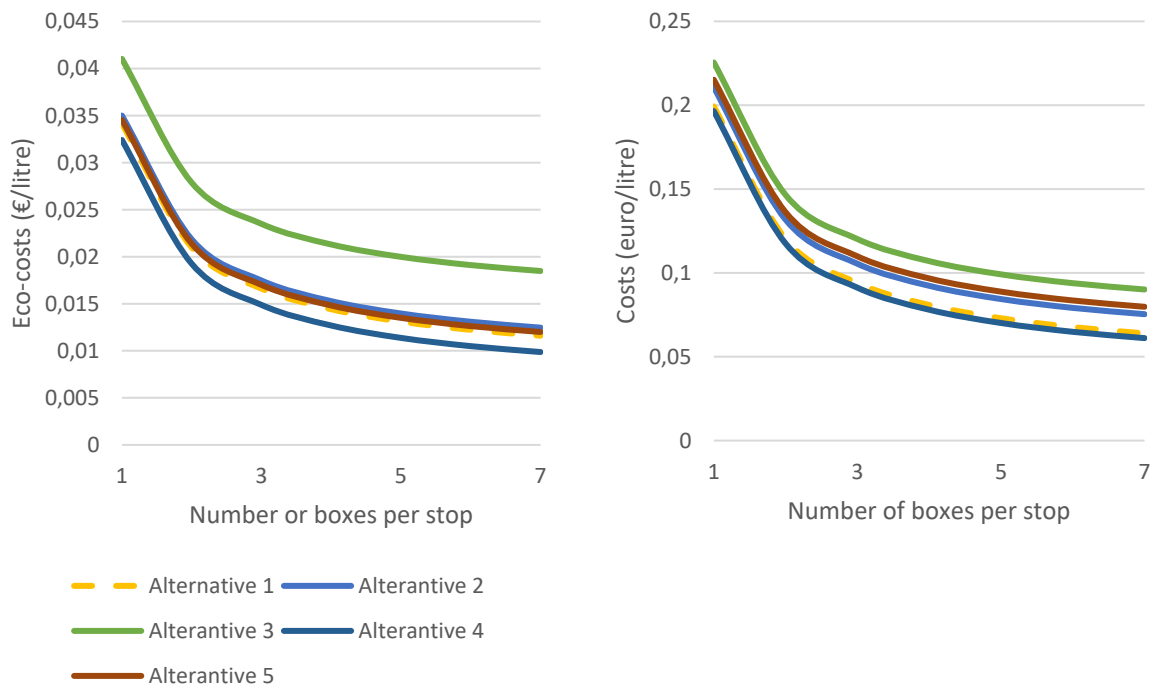


Figure 30. Eco-costs and costs for variations in number of boxes per stop

The variation of delivery distance and time shows the same linear increase of eco-costs and costs for every alternative (Figure 31). So, this variation does not have an influence on the relative differences between the alternatives.

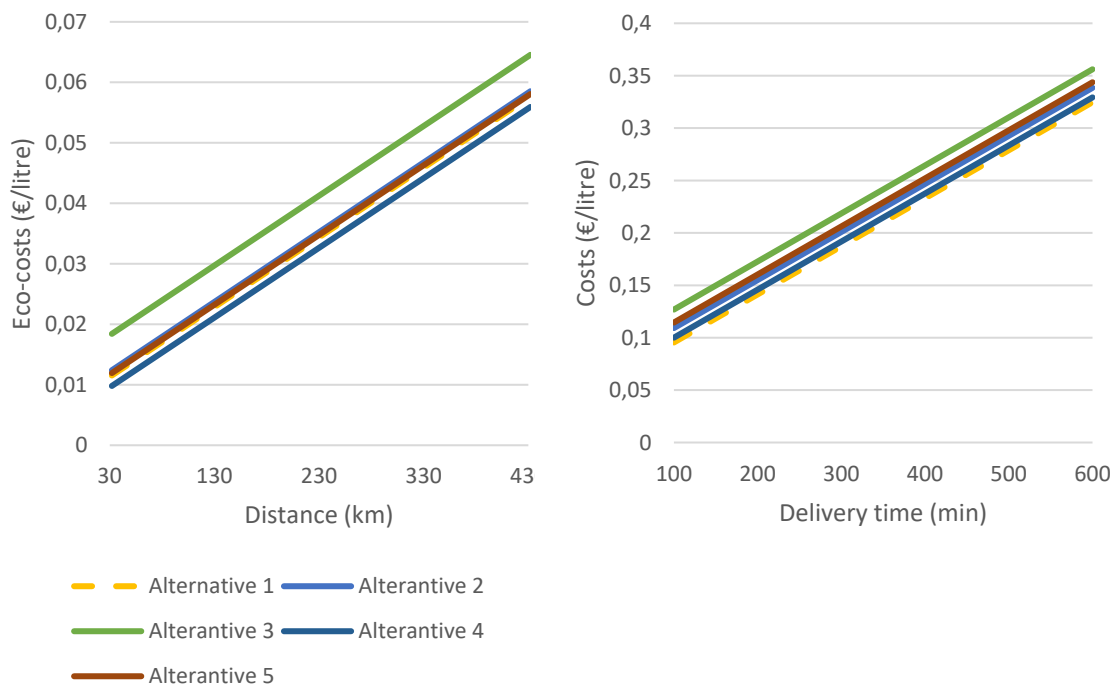


Figure 31. Eco-costs and costs for variations in delivery route distance and time

Next to the scenarios where only one of the factors is varied, also a combination of all the lowest and all the highest factors are combined. The resulting eco-costs and costs can be found in Figure 32.



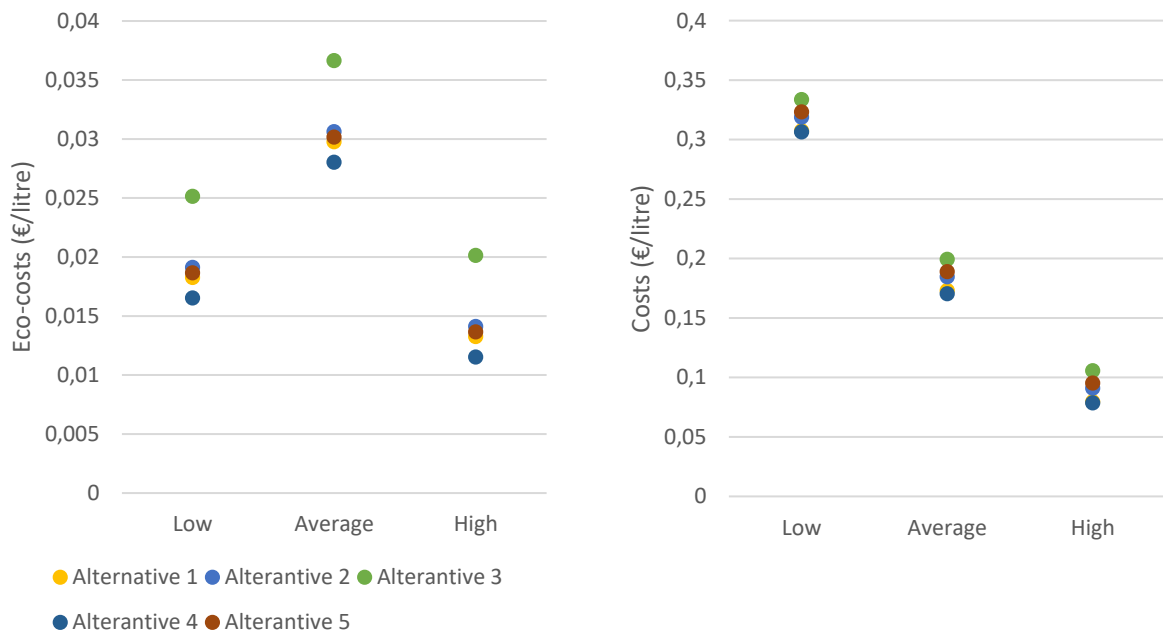


Figure 32. Eco-costs and costs for combination of the number of stops, number of boxes, time and distance scenarios

The above mentioned scenarios are based on historical data of PostNL. PostNL developed also future scenarios for the delivery. These scenarios are shown in Table 27.

Table 27. Future delivery scenarios

	Average	Scenario 1	Scenario 2	Scenario 3
Stops per route	16	44	48	55
Time per route (min)	344.5	398.6	409	403.65
Distance per route (km)	190	159.5	163.39	167.37

The resulting eco-costs and costs of these scenarios are visualised in Figure 33. These scenarios would have a positive effect on both eco-costs and costs.

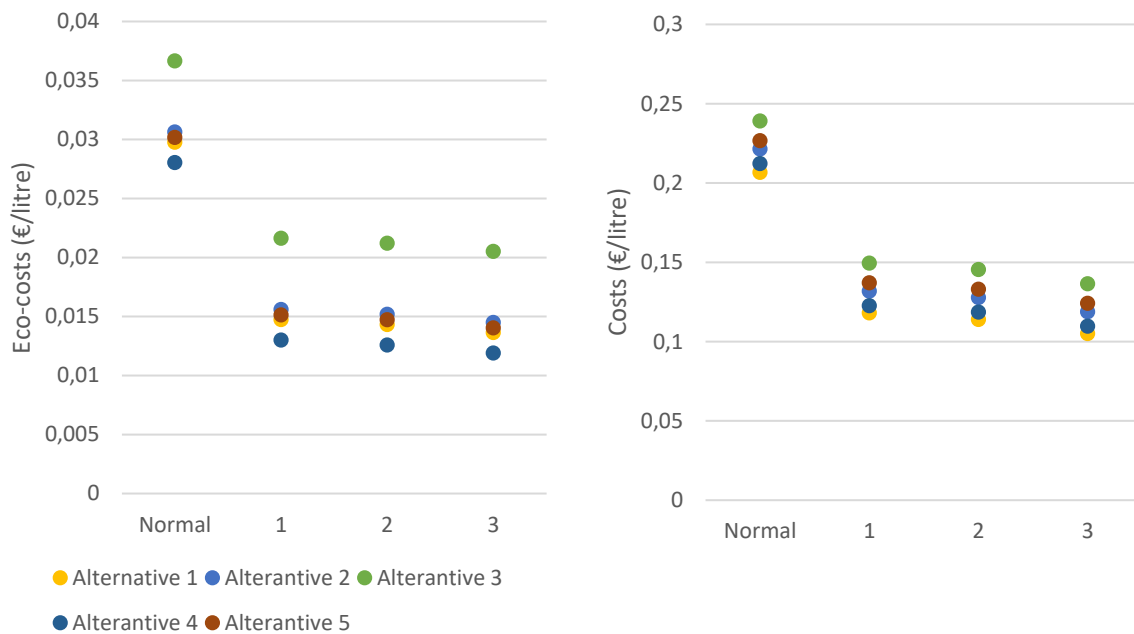


Figure 33. Eco-costs and costs of the combined future scenarios

For all the scenarios, the maximum difference in costs between alternative 4 and alternative 1 is 0.03€/litre. This would change the overall scores. However, even within this maximum change in costs, alternative 4 remains to have the highest overall score. In all the scenarios, the eco-costs remain the lowest for alternative 4. The unlikely event that the eco-costs become equal to alternative 1 have also been analysed. The results are shown in Table 28. Alternative 4 still has the highest overall score. Only a combination of these two extreme events in eco costs and costs will change the overall ranking of alternative 1 and 4 (see Table 28). The probability that this will happen is very small.

Table 28. Sensitivity validation of the scores if maximum difference in costs between alternative 1 and alternative 4.

	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
0.03€ lower costs for alternative 1	0.7489	0.6216	0.2817	0.7494	0.5274
Equal eco-costs for alt. 1 and 4	0.8133	0.6794	0.2817	0.8371	0.5679
Combination	0.8133	0.6216	0.2817	0.7494	0.5274
<b>Normal</b>	<b>0.7489</b>	<b>0.6794</b>	<b>0.2817</b>	<b>0.8371</b>	<b>0.5679</b>

The sensitivity and scenario analysis showed that the analysis is robust. Also, the experiments validated that alternative 4 will be workable in the whole PostNL food supply chain.

### ***5.3 Practical Implications***

The results and validation have shown alternative 4 as the best alternative for the delivery of dry groceries in the current PostNL supply chain. However, this is not necessarily the case for every food delivery supply chain. The developed framework for the assessment of transport packaging alternatives on the criteria should be applied to specific situations to determine the best alternative.

Although alternative 4 is the best alternative of the given set of alternatives, a better alternative is possible. The differences between alternative 1 and 4 showed to be relatively small. Alternative 4 can be improved in several aspects. Looking into the criteria on which this alternative scores relatively low (paragraph 5.1), it becomes clear that the lid on the short side of the tray has a negative impact on the handling during fulfilment. This can be easily improved by changing the lid to the long side of the tray. Also, improvements could be made by changing the dimensions and volume of the tray. However, this would require a total new tray. The costs of this should be compared with the gain in efficiency. Looking into the optimal individual sizes for the several criteria An length of 55 and width of 36 centimetres would be optimal. The internal height of 27 centimetres seems to be already optimal. Applying this to alternative 4 would mean that the volume of the tray will increase with 3L. This would mean lower costs, environmental impact, more efficient use of transport space in the trucks and delivery vans. The score of alternative 4 on the costs could be improved by decreasing the packaging costs below 0.46 euro per cycle. Next to the researched aspects, internal surveys of PostNL to consumers showed the insight that consumers prefer reusable trays over receiving large amounts of cardboard at their homes. Another consideration for preferring reusable trays over cardboard boxes could be that reusable trays can be made 'smart' in order to track and trace the groceries in the future.

The result of this research is a generic framework. The framework can be applied to other cases. The specific numbers as a result of the application of the framework, are case specific. For other cases within PostNL, only small adjustments have to be made. The weight factors can remain the same. Only the alternatives and scores of the alternatives on the criteria might change. For other departments than Food within PostNL, it might be that also some criteria have to be added or removed. However, if the cases are within the Food department, the developed calculation models can be used and only some input variables have to be changed. For other companies, the results might not be applicable. They should address the framework on their specific case. The processes within supply chains differ. The criteria depend on the specifications of the processes. Also, the weight factors depend on the stakeholders of the supply chain. This research shows a relatively high importance of environmental sustainability. Other companies might focus more on the economic sustainability. Although the results of the case study in this research cannot directly be used for other companies, a useful framework applicable to other companies and cases has been developed.

## ***5.4 Discussion***

This research developed a framework to assess transport packaging from a supply chain perspective on sustainability aspects of the triple bottom line. The framework has been applied to the online food industry.

In contrast with the FEFCO report (Vogtländer, 2004), this research shows that plastic reusable trays can be more sustainable than cardboard boxes. This comparison makes clear that it is important to assess every situation individually. In the FEFCO report, the transport of fruit and vegetables from a Dutch greenhouse to a German retail shop in Frankfurt over a distance of 500 kilometres is analysed. The difference with this study is that the return transport has the major impact on the eco-costs in the FEFCO report. However, in this research, there is also some return transport for the cardboard boxes since the roll containers have to be returned. This makes that the impact of the return transport is lower in this research than in the FEFCO report. The impact of the relative short transportation distance within this research outweighs the effect of the material eco-costs of the cardboard box, which makes the reusable tray more sustainable in this research.

It could be discussed whether there also should be looked at the reuse of the cardboard box. Already reusing this box one time would halve the eco-costs impact of the material, which makes the cardboard box more competitive with the reusable tray from the eco-costs point of view. However, it is hard to ensure that the box is clean enough to reuse it. A dedicated process should be needed for this.

The comparison of this research with the FEFCO research shows that the best packaging is case specific. Within this research, the weight factors did not have influence on the ranking of the alternatives. The best alternative was dominant in every situation. However, this does not always have to be the case. So, it is important to determine weight factors. Within this research, only six respondents have answered the questionnaire about the importance of the criteria. To improve the reliability of the weights, more respondents are preferred. Also, within this research, the weight factor for the environmental criteria is relatively high due to the sustainable mindset of the actors. It is expected for other cases that this will be lower.

## 6 Conclusion & Recommendations

This chapter describes the conclusions and recommendations of the research. Answers are given to the main research and sub questions. Finally, recommendations for further research and for PostNL are given.

### 6.1 Conclusions

The main aim of this research was to develop a framework to analyse and gain insights into the negative impacts of transport packaging alternatives for the home delivery of dry groceries.

The main research question was:

*What are sustainable transport packaging solutions for the home delivery of dry groceries and how can their effects be assessed on criteria related to customer wishes, financial efficiency and technical aspects of the logistical system?*

In order to answer this question, multiple sub questions have been constructed as stated in chapter 1. These sub questions are answered individually in the following section. Thereafter, the main research question has been answered.

*What is the current logistical system for the transportation of dry groceries?*

There are several ways in which dry groceries are transported. The bigger supermarkets like Albert Heijn and Jumbo deliver their groceries themselves. Smaller supermarkets use logistics service providers like PostNL. The transportation of (cooled and frozen) groceries can be done by using cooled vans or by using cooling boxes in normal vans. The second way is analysed in this research since the case study is conducted at PostNL, who uses cool boxes. However, this research is about the dry groceries so the differences for the cooled products do not have a high influence. The current system is that the dry groceries are transported from the retailer to the sorting centre at which the orders are sorted to the distribution centre. From the distribution centre, the groceries are delivered to consumers in normal vans. Some retailers use cardboard boxes for the dry groceries, other use the cool box or a tray. All the packaging is transported on roll containers. The cardboard boxes are left behind at the consumers, the other packaging not. After the delivery, the packaging is transported from the distribution centre to the hub at which it is sorted on the retailer to which it will be transported back. Details of the process can be found in Appendix E. The transport packaging alternative for the dry groceries should fit within this system.

*What are the requirements for the transport packaging?*

Research on literature (Chapter 2) showed the three aspects of sustainability; environment, social and economic. This triple bottom line is used as the basis of the requirements for the transport packaging. All the requirements can be categorised to these three aspects.

The requirements originate from wishes of supply chain actors and specifications of the logistical system in which the transport packaging has to operate. The economic sustainability can be divided into costs and logistics performance. Costs is related to the overall costs of the transport packaging during its lifecycle. So, this also includes the transportation, handling and home delivery of the groceries. Logistics performance is the

qualitative performance of the transport packaging in the logistical system. The logistical performance can be divided in sub-sub-requirements, but these requirements are case specific. Important social sustainability requirements to consider are food safety and ergonomics. Within the environmental sustainability aspects as carbon footprint, exotoxicity and resource depletion during the whole life cycle of the packaging are included. The requirements can be divided into constraints and criteria. The constraints are certain boundary values which the alternatives have to meet to be feasible. The criteria can be met to a certain degree.

*What are alternatives for transport packaging solutions for the home delivery of dry groceries?*

Alternatives for transport packaging are formed. Functions for the packaging are established. Inputs for the creation of aspects which could fulfil the functions are specifications of existing packaging. The means are evaluated on constraints. This results in only feasible alternatives. A combination of the resulting means within the different functions formed the alternatives. Only existing alternatives have been considered. Five different groups of feasible existing alternatives have been identified. The alternatives differ in material, size, lid, side walls and the way in which they save space. Namely, one non-reusable cardboard box and four reusable plastic trays. Two of the trays are nestable and two are foldable.

*How to measure the effects of the transport packaging on the criteria?*

A methodology has been developed to assess the effects of transport packaging alternatives on criteria (see Chapter 3). The method is a Multi Criteria Method in which the Best Worst Method is used to determine the weights of the several criteria. In order to determine these weights, a survey has been developed. To score the alternatives on the several criteria three different methods have been used. Life Cycle Analysis has been used to assess the environmental sustainability of the alternatives. A Cost comparison is performed to assess the costs of the transport packaging alternatives. For the other criteria, qualitative assessment based on a developed questionnaire and experiments is conducted. The individual scores per criteria are normalised and combined to determine the overall score per alternative. The combination of these several methods has proven to be a useful framework to compare alternatives and measure the effects of the transport packaging alternatives on the criteria.

*How is the food delivery supply chain affected by changing the transport packaging to the chosen alternative?*

A standardised transport packaging has effects on several aspects of the supply chain. This already starts with the fulfilment of the groceries into the transport packaging. Since every retailer is using another transport packaging at this moment and using different pick carts, the standardised transport packaging will never be perfect for every retailer. However, it is workable for all the current retailers. Also for the other parts of the supply chain, the transport packaging is workable without any adjustments. Although, some efficiencies may be gained if improvements would be made. For example, designing a layout for the arrangements of the trays (in combination with the cool boxes) in the delivery van, since this research showed that the delivery has the highest influence on costs and eco-costs of the life cycle of the transport packaging. The trays can be managed in the same way as the current system for cool boxes (not leaving the boxes behind). However, it is not known if this is the most efficient way.

Also, two specific sub question for PostNL were formulated.

*What is the environment PostNL Food is operating in?*

The market, supply chain and involved stakeholders of the home delivery of food by PostNL are analysed (Chapter 1, Appendix A, B and C). The online food market is a fast-growing market which is expect to grow even more in the near future. Logistics is an important factor to enable this growth. The information about the environment of PostNL Food is mainly used as background information for the rest of the research. The most important actors were identified. These actors are also involved in the research. Next to PostNL as logistics service provider, online retailers are involved in this research as key players. Also, close contact with packaging suppliers has been established. Next to retailers, PostNL has other customers for which it delivers food. However, most of these other companies like food box companies don't deliver enough dry groceries next to their cooled and frozen goods to have a separate transport packaging for the delivery of the dry groceries. The advantage of using PostNL to the deliver the groceries is that a flexible, scalable and reliable logistics network can be used. However, to remain the best food logistics service provider the efficiency in the total supply chain should be improved. Providing a standardised transport packaging solution could contribute to this.

*What is the best sustainable transport packaging alternative for the home delivery of dry groceries by PostNL?*

Five different transport packaging alternatives are analysed and applied to the case study of PostNL (Chapter 4). The results of this analysis (Chapter 5) show that alternative 4 (an 'AH' size, reusable and foldable tray) has the highest score. The differences with alternative 1 (a cardboard box) are relatively small. However, the validation (Paragraph 5.2) of the analysis showed that alternative 4 remains the best alternative in almost every case. Only in a combination of extreme events, alternative 1 is a better alternative than alternative 4. Furthermore, the waste of cardboard is undesired by consumers.

The answer to the main research question is that a useful framework for the assessment of sustainable transport packaging from a supply chain perspective on sustainability aspects of the triple bottom line has been developed. The research has shown that the combination of Multi Criteria Analysis and Life Cycle Assessment is useful for the assessment and comparison of alternatives on aspects of sustainability. This framework could be used for further research on the combination of MCA and LCA techniques. Literature has addressed some combinations of MCA and LCA but never used LCA as input for the MCA considering all three aspects of sustainability. Also, the combination of LCA, MCA and the Best Worst Method as weighting method is new.

## **6.2 Recommendations**

### **6.2.1 Recommendations for further research**

During this research, some aspects for further research have been found.

Delivery:

This research showed the relatively high economic and environmental impact of the delivery compared to other aspects of the life cycle. The delivery could be improved in multiple ways. The analysis showed that increasing the number of stops per route (for the same distance) or decreasing the distance of the route (for the same number of stops) would decrease the economic and environmental impact. To deliver more orders in one route, enough space in the van is needed. Further research can be conducted on improving the costs and environmental impact related to the delivery.

Fulfilment:

The influence of the transport packaging on the fulfilment of the groceries is not analysed in detail in this research. In this research, there is only looked if the transport packaging would be feasible within the fulfilment process. A standardised order picking process may improve the efficiency throughout the whole supply chain. Using standardised picking carts might have the highest influence, since then the same size of transport packaging will be optimal for the cart. Further research is needed in order to determine the optimal picking cart.

### **6.2.2 Recommendations for PostNL**

This research has shown that the alternative with the lowest life cycle costs, is not necessarily the best alternative overall. Alternative 4 gained the highest score. However, the analysis also showed some improvements which could make the performance of this tray even better. Further research by PostNL is needed to investigate whether it is preferred to choose alternative 4 or design a totally new packaging at which the optimal specifications can be applied. In the end, a new tray for which a mould has to be made may be cheaper due to the gained efficiency in the lifecycle of the tray. However, alternative 4 is already used by multiple supermarkets. If these supermarkets want PostNL to deliver their groceries, it would be an advantage for them that the same transport packaging dimensions are used. For the newly designed tray, this would not be the case because these dimensions are slightly different from the dimensions of alternative 4. Also, it should be said that sub optimisations have to avoided and standardised alternatives preferred.

Since the application of the case study to PostNL identified alternative 4 as the best alternative, recommendations for the implementation of alternative 4 are given. Using alternative 4 instead of for example the cool box for the delivery of dry groceries can be very beneficial in terms of costs and eco-costs. For example, if 1200 trays are used instead of 1000 cool boxes, this decreases the costs by ca. €185.00. If next to changing only the packaging also the delivery routes are optimised to alternative 4 this can lead to a decrease in costs of ca. €1225.00. Using 1200 trays instead of 1000 cool boxes per week will lead to a reduction in costs around €64000.00 a year. Also for the eco-costs savings are made by using alternative 4 instead of the cool box. This might be around €15000.00 less eco-costs a year. Details of the calculations can be found in Appendix K. Before a chosen alternative can be implemented some steps need to be made.



### *Production*

The packaging has to be produced by the packaging manufacturer. In consultation with the packaging supplier, it has been decided to produce the lid on the long side of the tray. This is not more expensive but has shown to be more efficient in the handling. To do so, first, a mould must be produced since the lid is not existing yet. The production of the mould sixteen weeks. Before the production of the trays, PostNL should choose whether it is preferred to brand the trays or not. It is possible to vary in colour and logo. It is possible to only brand the lid or the tray itself. Also, embossing is possible next to printing. Embossing has a fixed price, which only has to be paid once, independent of the amount of trays. Printing has a variable price related to the number of trays and a fixed price for the screen. It is cheaper to have black trays, than for example orange trays. The production of the trays including lid is done locally within the Netherlands. This makes it possible that the production time of the trays is only two weeks. After the trays including lid have been produced, the packaging supplier can sell them to PostNL. It is not possible for PostNL to buy the mould and become the owner of it. The reason for this is that the tray is already existing and the packaging supplier has the ownership rights of the tray. So, PostNL has to buy a certain minimum amount of trays, to ensure the profitability of the investment of the mould by the packaging supplier. To know if this minimum number of trays is realistic, an expectation of the needed trays should be known. This is dependent on the expected number of dry grocery orders and the cycle time of the tray.

### *Implementation to retailers*

The cool box is used by the retailers under a leasing contract. The easiest way to implement the trays is to also lease the trays. The currently used packaging of the retailer should be compared with chosen alternative. A tool has been developed for the comparison. The tool shows differences in economic and environmental impact. If both packaging have the same size, the current price agreements can be maintained. For other sizes, the prices should be changed. For the cool box, the retailers are responsible for the cleaning of the boxes. For the trays, also agreements need to be made on this.

### *Implementation to PostNL*

The easiest way to implement the trays within the PostNL processes is to use the same processes for the trays as for the cool box. In this way, the processes don't need to be adapted. This process is described in Appendix E. The cool boxes are customer specific. This means that every cycle the cool box goes back to the same retailer. In order to make the trays customer specific, a label including the code of the trailer is needed on the tray. Since the surface of the tray is not that large if the tray is folded, this should be a smaller label than on the cool box. It is also possible to not make the trays customer specific. However, it should be checked with the food risk expert whether this is allowed by the HACCP regulations. If the trays are not customer specific it is not possible to make the retailers responsible for the cleaning of the trays.

### *Management*

In this research, it is assumed that the tray will be managed the same way as the cool box. However, further research is needed to determine whether another way of managing the trays would be more profitable. Another way of managing would be leaving behind the trays at the consumers and taking the tray back at the next delivery. It would also be possible that the consumer can return the trays at physical locations. If the trays are left behind, a system with deposit is needed to make sure that the trays will be returned. The

management of the trays can also be done by a packaging pooling company from which the trays can be rented. Such pooling company can manage, store and clean the trays. It should be mentioned that if the trays are not returned immediately at the delivery, the trays can make less cycles and so more trays are needed.

This research has been reflected by PostNL. The research has shown to be a useful contribution for the choice of a sustainable transport packaging solution for the delivery of dry groceries. The analyses showed useful insights in the effects of transport packaging. The recommendations will be used for the implementation of the transport packaging. Also, the developed tool will be very helpful to compare the transport packaging with the packaging of the customers and to show the differences to the customer.

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## Appendices

### *Appendix A Interviews*

A list of persons interviewed during this research:

- Manager Food PostNL
- Operations Manager Food PostNL
- Driver Food PostNL
- Financial control and operations PostNL
- Packaging specialist PostNL
- Fleet Manager PostNL
- Sustainability and Innovation PostNL
- Process Manager PostNL
- Food Safety specialist
- Stockit
- Retailer X
- Retailer Y
- Bakery
- Tray Supplier A
- Tray Supplier B
- Tray Supplier C
- Cardboard packaging Supplier

## Interviews with retailers

According to confidentiality reasons, the retailers will not be meant by name.

To get more insight in the preference of retailers according to transport packaging, several retailers are interviewed. Their preferences are different and rely on their current processes.

### **Retailer X**

Function contact person: Sector manager

Date of the interview: 12-04-2017

Duration of interview: 1 hour

This retailer has around 65 physical supermarkets within west and middle of the Netherlands. Their online supermarkets are also available in certain areas within the Netherlands. There are several options for the delivery. The consumers can pick up their delivery at the physical stores. Within the area of the supermarkets, the groceries are delivered by the retailer. Within the other areas, the groceries are delivered by PostNL.

Current process:

- Own delivery:
  - Plastic foldable trays of 52x35x26.5 are used.
  - Max. weight is 15 kg per tray.
  - 40% of the trays is loaded higher than the tray.
  - The trays are left behind at the consumers' houses. The consumer pays a deposit of 4€. The consumer can hand in the tray at the supermarket or at the next delivery.
- Pick-up at the supermarket:
  - This process has the same specifications as the 'own delivery'.
- PostNL delivery:
  - The trays cannot be used as they are, because they are not closed. To solve this problem, a cardboard cover is used. The reason for this is, is that the costs for a plastic lid are extremely high (around 20000 €).
  - The trays are not left behind at the consumers, but the driver takes them back immediately. Because of this, plastic bags are used inside the trays. The driver gives the bags with groceries to the consumers.
  - Also, instead of the trays cardboard boxes are used.

General remarks:

- Other tray sizes do not fit on the pick cart.
- 60-70% of the trays is cleaned per cycle.
- The average of trays/boxes per order is 2.
- There is not a lot of space in the distribution centre to store transport packaging.

Date of the interview: 24-04-2017

Duration of interview: 1 hour

This was a visit to the distribution centre for the online groceries of this retailer. It showed a lot of insights into their current processes. From the delivery of the groceries from the physical distribution centre to the order picking process to the consolidation of the dry groceries to the cooled and frozen groceries onto roll containers.

### **Retailer Y**

Function contact person: business intelligence analyst

Date of the interview: 13-04-2017

Duration interview: 1.5 hour

This retailer has around 70 physical store spread of the whole Netherlands. The focus of this retailer is on biological products. The delivery of the products has two flows. 70% is delivery by the physical stores. The rest is delivered by PostNL.

Current processes:

- Euro pool systems (EPS) trays (24x60x40) are used in most processes of this retailer. However, there are other sizes possible on the pick cart.
- The fulfilment of the dry groceries and the chilled products is not at the same location. This is around 3km from each other. After the fulfilment of the dry groceries, they are transported to the cooled fulfilment centre.
- Frozen goods are not sold online yet.
- For the delivery by PostNL, the dry groceries are first picked in EPS trays then they are transported to the cooled fulfilment centre. There the groceries are moved from the EPS trays into paper bags within the PostNL cool boxes. This is a very inefficient process.

General remarks:

- More chilled products (around 60%) than dry groceries are ordered compared to other online supermarkets.
- The consumers have to order at least groceries for 65€ otherwise, a delivery is not possible. The average consumer order is 75€ at this retailer. This is an average of 2 trays/boxes.
- Plastic bags are not done for this retailer.
- Problems with bottles of glass, big items as toilet paper and for very small items.

This interview also included a visit to the distribution centre for the fulfilment of the groceries.



## ***Appendix B Actor analysis***

This analysis is based on the actor analysis method of Enserink et al. (2010): 'An actor is a social entity, a person or an organisation, able to act on or exert influence on a decision'. Knowing involved actors and their objects is crucial for successful problem-solving.

The most important actors in the food supply chain are: producers of food and transport packaging, wholesalers, retailers, fulfilment parties, logistic service providers, consumers and recyclers. This is described in Appendix C. Other actors are environmentalists, transport companies and public health and safety organisations.

- Logistic service providers
- Online retailers
- Fulfilment parties
- Consumers
- Transport packaging producers
- Food producers
- Wholesalers
- Recyclers
- Environmentalists
- Transport companies (subcontractors)
- Public health and safety organisations

### *Logistic service providers*

Logistic service providers are actors that arrange all the transport from the retailer or fulfilment party to the consumers. The advantage of the use of a logistic service provider is scale and existing reliable networks. Smaller retailers often don't have enough capital or volume to efficiently transport the groceries themselves.

Examples of logistic service providers who are currently active in the food market: Bpost (in Belgium), Leen Menken and PostNL.

### *Online retailers*

Retailers are companies that buy goods from food producers and sell them to consumers. This can be through online channels by online food parties or in-store presentation for traditional retailers. The products can be bought from wholesalers or directly from farmers and other grocery producers. The order picking can be done by the retailers themselves or by a fulfilment party. The transport of the groceries can also be done by the retailer, but another option is by the use of a logistic service provider.

The retailers can be divided into online supermarkets, food boxes and niche parties. Examples of related companies in the Netherlands are:

- Online supermarkets: Albert Heijn, Jumbo, Picnic, Hoogvliet, Plus
- Food boxes: Hello fresh, Marly Spoon, Mathijs Maaltijdbox
- Niche parties: Body&Fit, sameneenkoekopen.nl, Sligro

### *Wholesalers*

Wholesalers buy products directly in large quantities from producers. They sell the products to retailers. The wholesalers don't have a direct connection to the transport packaging

#### *Fulfilment parties*

Fulfilment parties handle the orders of the retailers. So, they put the groceries in the correct box for the consumer. The boxes or other transport packaging has to be easy to handle for the fulfilment parties. This is important for their efficiency.

#### *Consumers*

Consumers are the end users of the products. They buy the final products. The groceries will be delivered to their homes. The consumer has to be satisfied with the home delivery. If the consumer is not satisfied, they will not buy groceries at this retailer anymore.

#### *Transport packaging producers*

The producers of transport packaging can produce the transport packaging for dry groceries.

#### *Food producers*

The producers of food and other groceries sell their products to wholesalers or retailers. The food producers are not directly affected by the transport packaging for the home delivery of dry groceries.

#### *Recyclers*

Recyclers have to recycle transport packaging. It depends on the type of material whether the material can be recycled or not.

#### *Environmentalists*

Transport packaging can be made of different materials. These materials can have a different impact on the environment. Environmentalists would prefer the most sustainable material. The material not only differs in the ease of recycling but also the lifespan of the material.

#### *Transport companies*

The transport can be outsourced by the logistic service providers to subcontractors. The transport packaging has to be easy to handle for the driver and fit efficiently in the trucks.

#### *Public health and safety organisations*

Public health and safety organisations look after food safety and other health issues. Every actor can cause other health dangers. With respect to transport packaging, it is depending on the product what the regulations are.

Table 29. Problem formulations involved actors

<b>Actors</b>	<b>Interests</b>	<b>Desired situation/objectives</b>	<b>Existing or expected situation and gap</b>	<b>Causes</b>	<b>Possible solutions</b>
Logistic service provider	Maximising profit by selling services	Sustainable food network	No sustainable transport packaging	Not enough knowledge about sustainable transport packaging	Develop sustainable transport packaging
Online retailer	Maximising profit by selling products	Low transport price, high service and reliable	Logistics expensive part of the supply chain	Upcoming market	Increase scale and develop improvements in chain
Wholesaler	Maximising profit by selling products	Good income from selling products	Retailers buy directly from producer	Cheaper	Provide additional services
Fulfilment party	Maximising profit by order fulfilment	Good income from order fulfilment	Transport packaging not efficient for process	Cooperation between actors not sufficient	Cooperate in development of packaging
Consumer	Low prices, high quality	Low prices for the home delivery and high service	Prices are too high and service not reliable enough	Logistics expensive part of the supply chain and food needs very high quality	
Transport packaging producers	Maximising profit by selling packaging	Good income from selling packaging			Produce sustainable packaging
Food producers	Maximising profit by selling food	Good income from selling food	Traceability of food safety not enough	Globalisation	Give information about food safety
Recyclers	Maximising profit by recycling of products and more sustainability	Good income from recycling	Not enough use of recyclable packaging	Might be expensive	Make recyclable packaging more attractive
Environmentalists	Fewer pollutions	Good environment	To much waste of	No regulation	Use more sustainable

	and more sustainability	al quality and sustainability	transport packaging and pollution by transportation	and can be expensive	transport packaging and fuel
Transport companies	Maximising profit by transportation	Good income from transporting goods	Transport is not efficient	There is no uniform transport packaging	Use of uniform transport packaging
Public health and safety organisations	High food safety	Good health for people. Safe food transportation	Transport of food not safe enough	Regulations about food safety are not clear	Improve safety by regulation and certification

A power/interest diagram is used to map actor dependencies and the amount of power and interest they have in the realisation of sustainable transport packaging. This can be found in the figure below. The key players who have to be managed closely are: Logistic service providers, retailers and consumers.

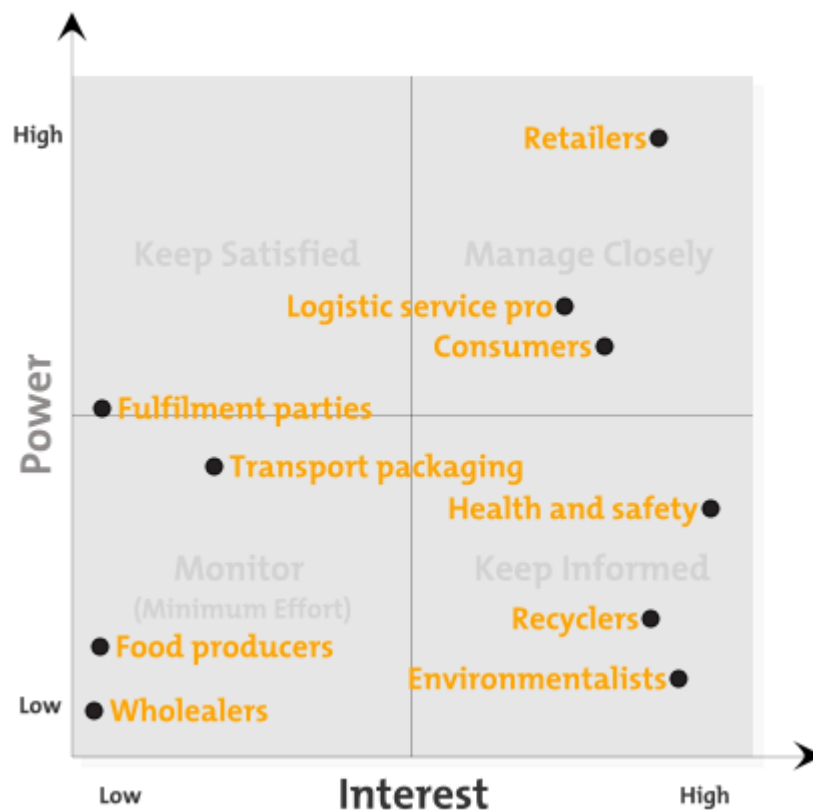


Figure 34. Power/interest grid

## Appendix C Supply chain analysis

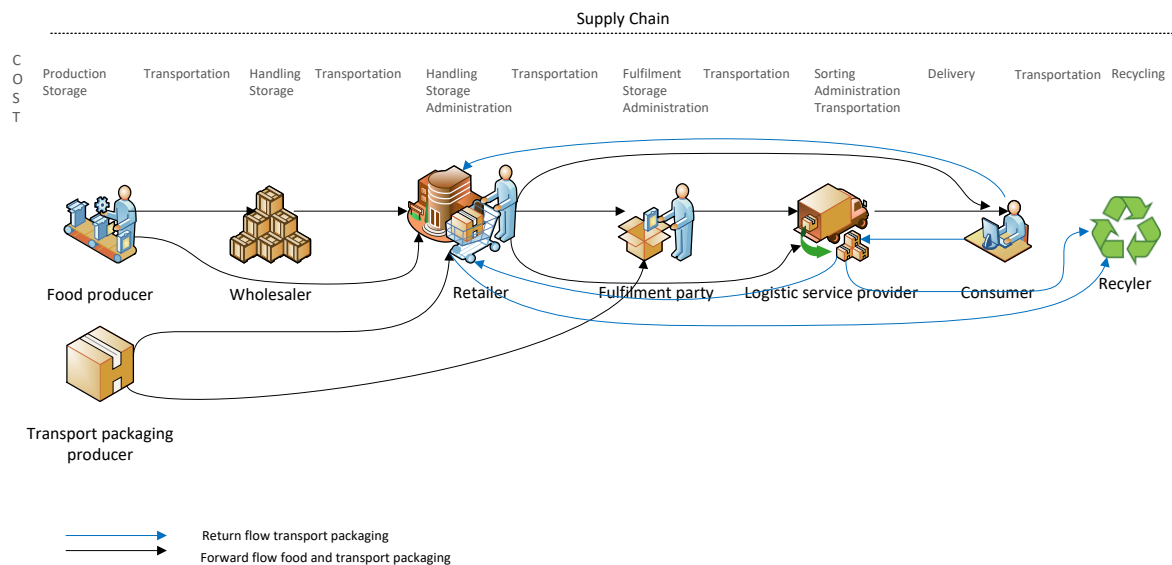


Figure 35. Supply Chain home delivery of food

In the actor analysis, several actors are described. Within the supply chain for the home delivery of food, most of these actors are connected with each other. The supply chain starts with the production of food and the production of transport packaging. The food is sold by the food producer to a wholesaler or directly to a retailer. From the food producer, the products will be transported to the wholesaler or retailer. The wholesaler will sell smaller quantities of the products to the retailer. The retailer sells their products to the consumer. The retailer can fulfil the orders and deliver the products to their consumer themselves or they can use other companies. For the order fulfilment, they can use a fulfilment party. For the home delivery, logistic service providers can be used. After the delivery of the groceries to the consumer, the transport packaging has to be returned. There are several possibilities for this. It depends on the forward flow which one is applicable. It can be directly returned to the retailer. Another option is from the consumer back to the logistic service provider and then to the retailer. At the end of the life time of the transport packaging, it can be recycled by a recycler.

The supply chain includes different cost types:

### Production

The production of food and transport packaging will cost money. This includes variable costs like the use of machines and raw material costs. But there are also investment costs, which will not occur every production. These are investment costs which have to be made if a new product is introduced or if the current production has to be expanded. For example, every different cool box needs a new mould.

### Storage

The storage of goods costs money. This is because, the space the products are stored in costs money. Before goods are sold they will be temporarily stored. The amount of stored goods depends on safety stock levels. The goods can be stored at the producer, wholesaler, retailer and fulfilment party.

### Transportation

Transportation costs are the costs of transporting goods. This includes the costs of the use of transportation modes like trucks. The fuel consumption. Also, this includes the labour costs of the driver. Transportation takes place at several places in the chain.

#### *Administration*

Administration costs are the costs for the control of the orders. It is important to know at each moment where the orders are.

#### *Fulfilment*

Fulfilment costs are the costs of the order fulfilment. This means picking and packing of the products related to the order of the consumer. The fulfilment can be done by the retailer itself or by a fulfilment party.

#### *Sorting*

The packed orders have to be sorted on depot and ride for the home delivery. This sorting is based on the postal code of the consumer. Sorting can be done manually or by the use of a sorting machine.

#### *Delivery*

The delivery includes the costs of the minivan, fuel and the delivery driver. The delivery will be from the location of the retailer or fulfilment party or logistic service provider to the consumer.

#### *Recycling*

Depending on the material the transport packaging is made of it can be recycled. This can gain or cost money.

## Appendix D Competitors analysis

At this moment, there is no standard packaging solution for the home delivery of groceries. Different trays are used by multiple companies. Existing trays are compared on different aspects. This can be found in the Table below. The top five companies in the table are operating within the Netherlands.

Table 30. Comparison of existing trays

	Dimensions (cm)	Side walls	Lid	Foldable	Nestable	Hooks for plastic bags	Weight (kg)
<b>AH</b>	52 x 35 x 26.5	Holes	No	Yes	No	No	
<b>Jumbo</b>	53 x 35 x 28	Holes	No	Yes	No	No	
<b>Picnic</b>		No holes	No	No	No	Yes	
<b>Stockit</b>	60 x 40 x 30	No holes		Yes	No	No	7
<b>Europool</b>	60 x 40 x 24	Holes	No	Yes	No	No	2
<b>Amazonfresh</b>		No holes	Yes	No	Yes	No	
<b>Ocado</b>		Holes	Yes, but loose plate	No	Yes	Yes	
<b>Sainsbury</b>		Holes	No	No	Yes	Yes	
<b>Tesco</b>		Holes	No	No	Yes	No	

As can be found in the table, the trays differ in size, side walls, whether they have a lid, are foldable, are nestable, have hooks to attach plastic bags and weight. Also, as can be seen in the pictures, the shapes are different. Not all the aspects of the comparison are known for every tray.

If packaging will be used inside of the transport packaging it can be preferred to have suspension possibilities (hooks) on the transport packaging. This can make the order picking process easier. However, since PostNL is using paper bags inside the transport packaging instead of plastic bags, suspension possibilities are not considered in this research.



Tray Albert Heijn (AH)<sup>1</sup>



Tray Jumbo<sup>2</sup>



Tray Picnic<sup>3</sup>



Tray Stockit



Tray Euro Pool System (EPS)<sup>4</sup>



Tray AmazonFresh<sup>5</sup>



Tray Ocado<sup>6</sup>



Tray Sainsbury<sup>7</sup>



Tray Tesco<sup>8</sup>

Figure 36. Examples of trays of competitors

<sup>1</sup> <http://vertruffelijk.nl/wp-content/uploads/2016/05/untitled-315.jpg>

<sup>2</sup> [http://www.renault-trucks.nl/media/image/renault-master-jumbo\\_875x447-3.gif](http://www.renault-trucks.nl/media/image/renault-master-jumbo_875x447-3.gif)

<sup>3</sup> [http://foodclicks.nl/sites/default/files/nieuws/foto/Picnic%20dc%20Utrecht%203%20\(Small\).jpg](http://foodclicks.nl/sites/default/files/nieuws/foto/Picnic%20dc%20Utrecht%203%20(Small).jpg)

<sup>4</sup> <https://www.kadenza.nl/wp-content/uploads/2016/03/header-Euro-Pool-System-2.jpeg>

<sup>5</sup> [https://1.bp.blogspot.com/-kiF1kVDIPII/Tf4vU\\_zveI/AAAAAAAAOk4/zAzdHqL\\_dYE/s1600/IMG\\_1821.jpg](https://1.bp.blogspot.com/-kiF1kVDIPII/Tf4vU_zveI/AAAAAAAAOk4/zAzdHqL_dYE/s1600/IMG_1821.jpg)

<sup>6</sup> <http://www.s4rb.com/wp-content/uploads/2016/11/Morrisons-9.jpg>

<sup>7</sup> <http://www.thegiddings.org.uk/blog/wp-content/uploads/2013/07/P7134899.jpg>

<sup>8</sup> <http://i7.alamy.com/zooms/8fbade0992184b609950372d84bbf429/man-unloading-produce-from-tesco-delivery-van-england-uk-f312mp.jpg>



## ***Appendix E Process analysis current food process***

The current process for the delivery of food by PostNL is analysed. This process is described and visualised in IDEF0 diagrams below. The focus of this analysis is on the last mile delivery. IT is left out of scope of this analysis. So, the analysis starts at the moment that the boxes including groceries on roll containers (RC's) are transported from the retailer to the sorting centre of PostNL. This transport is mainly done by the retailer. From the sorting centre, the boxes are transported by truck to one of the five depots from which food is delivered. The current location of the sorting centre is one of these depots as well. At the depots, the boxes are unloaded from the truck and loaded into delivery vans. The drivers of the vans deliver the groceries to the consumers and take back the empty boxes to the depot. In the end boxes on roll containers will be returned to the retailers. Figure 37 shows an A-0 and A-1 decomposition of food delivery. The boxes show activities. The arrows from the left are inputs of an activity and arrows to the right outputs. Arrows from the bottom show resources which are needed for the activity. Arrows on top show the control of the activity. Some of the processes in the A-1 decomposition are further decomposed into the A-2 level. The sorting process is further decomposed and visualised in Figure 38. The delivery of groceries to the consumers is further decomposed and visualised in Figure 39. The return process of the boxes is further decomposed and visualised in Figure 40.

At the sorting centre, the roll containers are set up by employees of the sorting centre in the correct layout for the sorting process. The filled boxes of the retailers are taken from their roll container and put onto the roll container for the right depot and ride. This is done based on the zip codes which belong to a certain depot and the list on which the planned rides are stated. If all the boxes are sorted, the roll containers with sorted boxes are loaded into a truck which will transport the boxes to the depots. This is a manual process, but in the near future, the whole sorting will be done by the sorting machine.

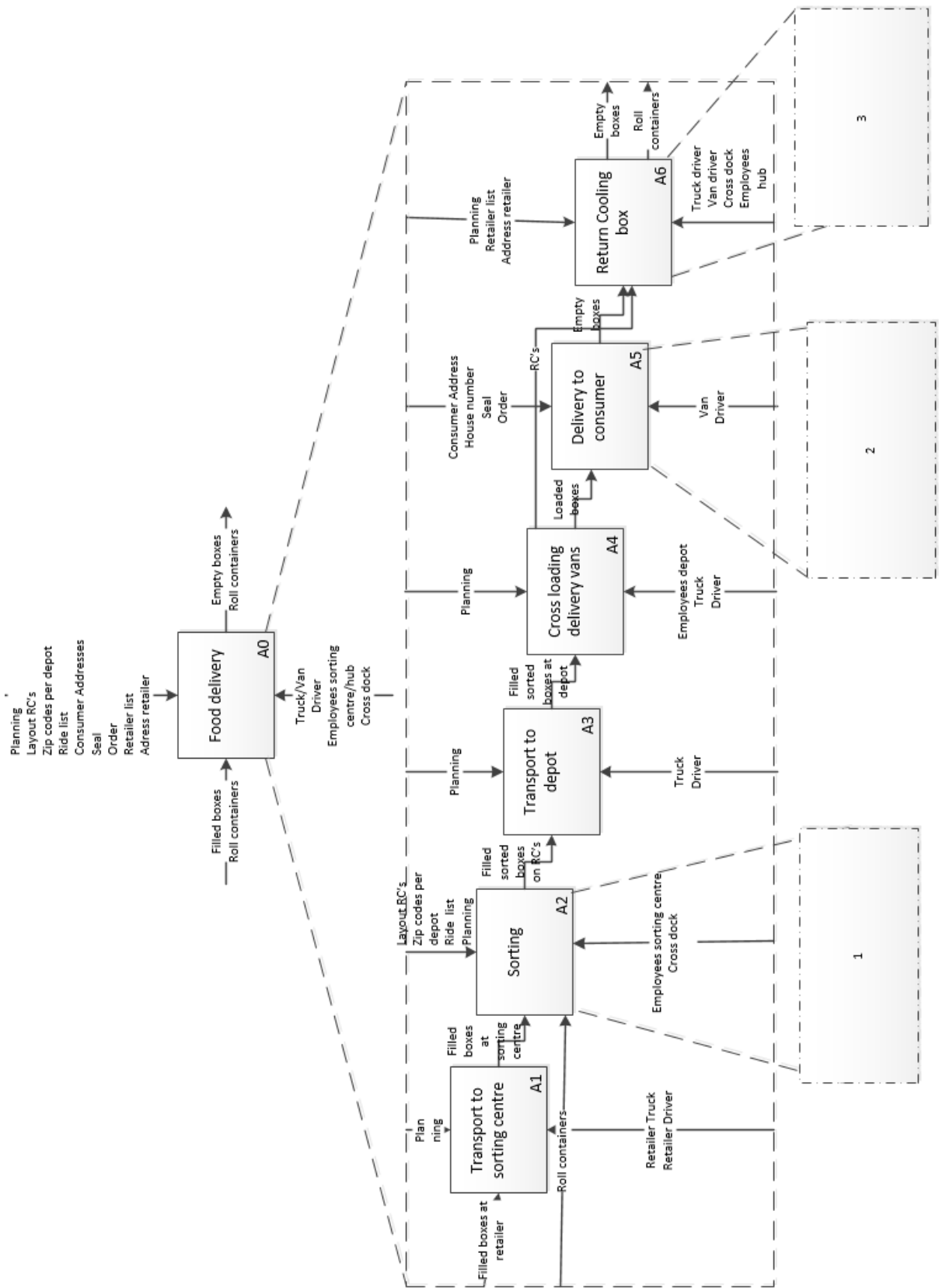


Figure 37. IDEFO Food delivery (A-0 and A-1)

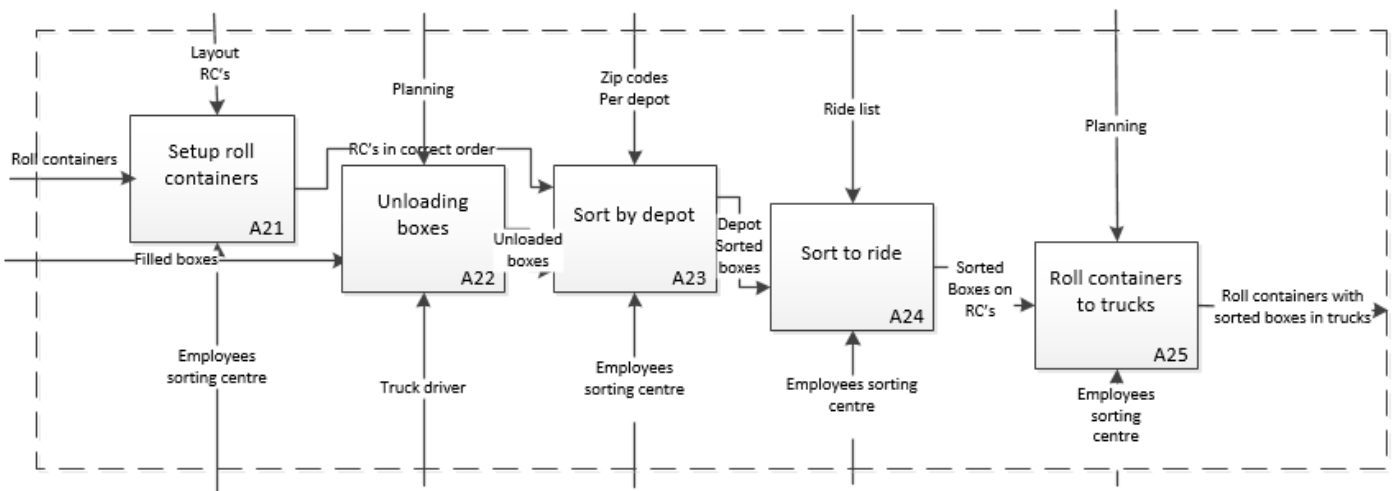


Figure 38. IDEF0 Sub-process: Sorting (A-2)

The delivery has several sub activities. First the van driver has to drive to the house of the consumer. The driver has a list with the addresses of the consumers at which he has to deliver the groceries. After driving to the right address, he takes the right box(es) out of his van and walks to the door to ring the bell of the consumer. If the consumer opens the door, the driver will remove the seal of the box and hands over the bags or cardboard boxes with food. If the consumer is not at home, the driver will ring the bell of the neighbour and deliver the groceries there. If the neighbours are also not at home, the box including groceries will be taken back.

After the delivery ride, the boxes will be returned to the depot by the van driver. At the depot, the boxes are unloaded from the vans onto roll containers and loaded onto the trucks. The trucks transport the boxes to the hub. At the hub, the boxes are sorted on retailer. From the hub, the boxes are returned back to the retailer.

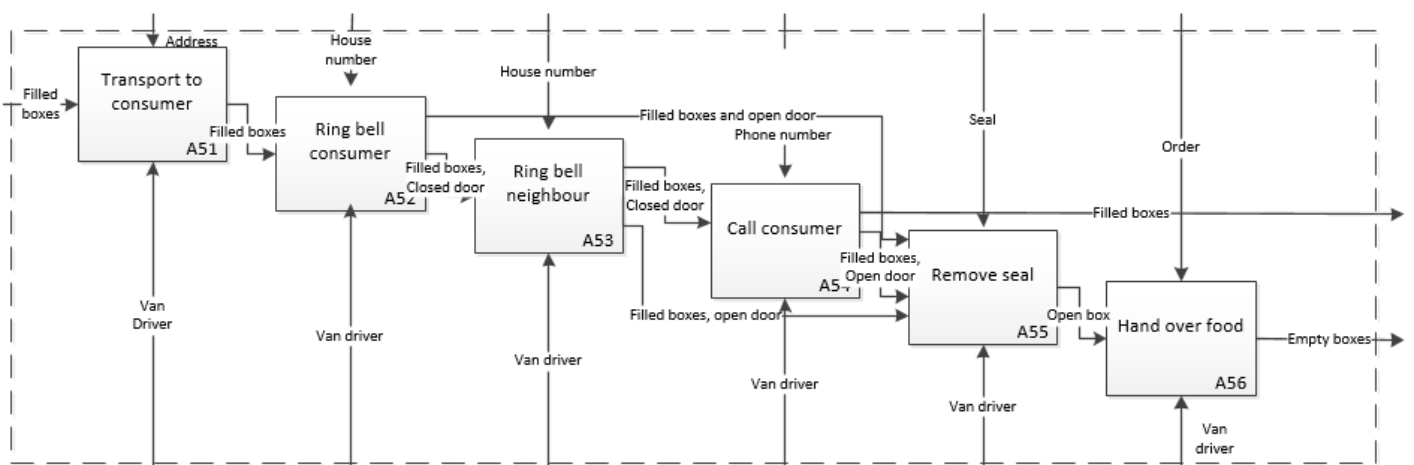


Figure 39. IDEF0 Sub-process: Delivery (A-2)

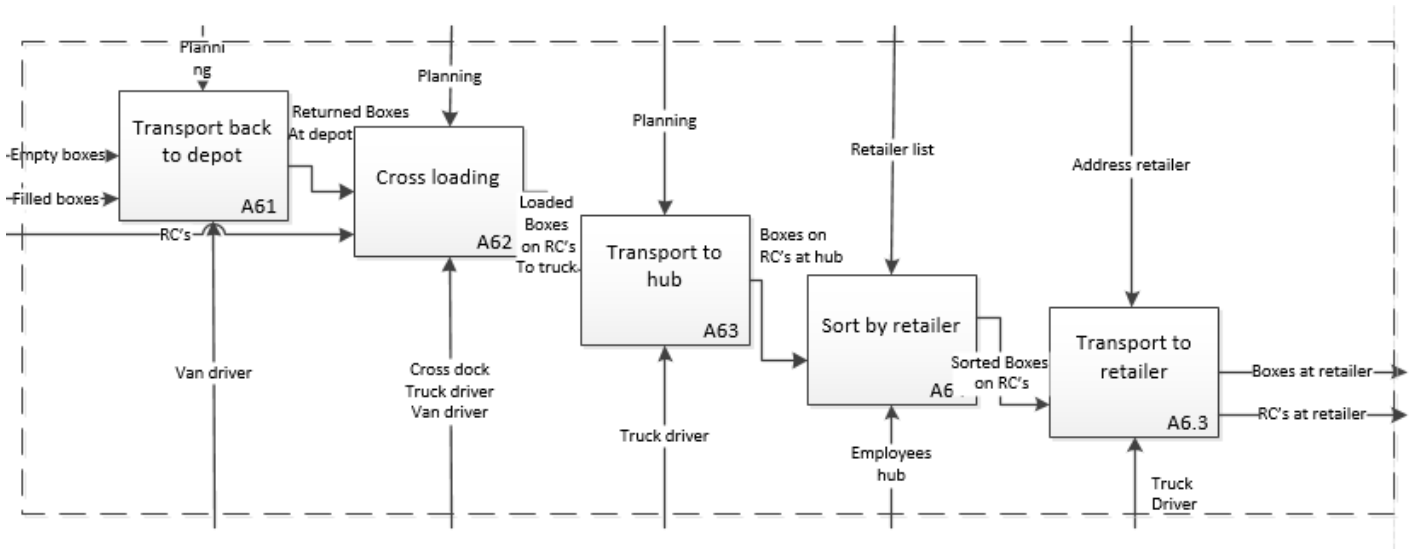


Figure 40. IDEF0 Sub-process: Return (A-2)

The analysis of these processes is used as input for further analyses in this chapter. It is used to better understand the whole process and to identify the process on which transport packaging for dry groceries might have an impact. It also helps to identify which costs are involved in the process.

## Appendix F Questionnaire BWM

### Transport packaging Survey

Please fill in all the grey boxes. Information about the criteria can be found in the other tab.

0. What is your function within your company:

1. There are several factors that are of importance in selecting a transport packaging for the home delivery for dry groceries, which are listed below. In your opinion, what is the MOST important main criterion?

Criteria: MOST important criterion:

*Social*

*Economic*

*Environmental*

2. What is in your opinion the LEAST important criterion?

Criteria: LEAST important criterion:

*Social*

*Economic*

*Environmental*

3. You have selected  as the MOST important criterion.

Select a number between 1 and 9 to indicate the preference of the MOST important criteria over the other criteria. The number 1 shows an equal importance of both criteria. Number 9 means that the MOST important criteria is extremely more important than the other criteria.

	<i>Social</i>	<i>Economic</i>	<i>Environmental</i>
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

4. You have selected  as the LEAST important criterion.

Select a number between 1 and 9 to indicate the preference of the criteria over the LEAST important criterion. The number 1 shows an equal importance of both criteria. Number 9 means that the criteria is extremely more important than the LEAST important criterion.

<input type="text"/>	<input type="text"/>
<i>Social</i>	<input type="text"/>
<i>Economic</i>	<input type="text"/>
<i>Environmental</i>	<input type="text"/>

5. The main criterion 'Social' can be divided into 'Food Safety' and 'Ergonomic'. In your opinion, what is the MOST important and what is the LEAST important social sub criterion?

MOST important sub criterion:

LEAST important sub criterion:

**6. You have selected**  **as the MOST important social sub criterion.**  
**Select a number between 1 and 9 to indicate the preference of the MOST important sub criterion over the other sub criteria.**

	<i>Food Safety</i>	<i>Ergonomic</i>
	<input type="text"/>	<input type="text"/>

**7. The main criterion 'Economic' can be divided into 'Logistic performance' and 'Costs'. In your opinion, what is the MOST important and what is the LEAST important economic sub criterion?**

MOST important sub criterion:

LEAST important sub criterion:

**8. You have**  **selected**  **as the MOST important economic sub criterion.**  
**Select a number between 1 and 9 to indicate the preference of the MOST important sub criterion over the other sub criteria.**

	<i>Logistic performance</i>	<i>Costs</i>
	<input type="text"/>	<input type="text"/>

**9. The sub-criteria 'Logistics performance' can be divided into several sub criteria which are listed below. In your opinion, what is the MOST important logistics performance sub criterion?**

Sub criteria:  MOST important sub criterion:

*Fit on roll container*

*Easy fulfilment*

*Efficient filling buses*

*Space efficient*

*Capacity*

*Labelling*

**10. What is in your opinion the LEAST important logistics performance sub criterion?**

Sub criteria:  LEAST important sub criterion:

*Fit on roll container*

*Handling fulfilment*

*Filling buses*

Space  
Capacity  
Labelling

11. You have selected \_\_\_\_\_ as the MOST important logistics performance sub criterion.

Select a number between 1 and 9 to indicate the preference of the MOST important sub criterion over the other sub criteria. The number 1 shows an equal importance of both criteria. Number 9 means that the MOST important sub criterion is extremely more important than the other criteria.

	<i>Fit on roll container</i>	<i>Handling fulfilment</i>	<i>Filling busses</i>	<i>Space</i>	<i>Capacity</i>	<i>Labelling</i>

12. You have \_\_\_\_\_ selected as the LEAST important logistics performance sub criterion.

Select a number between 1 and 9 to indicate the preference of the sub criteria over the LEAST important sub criterion. The number 1 shows an equal importance of both criteria. Number 9 means that the criterion is extremely more important than the LEAST important sub criterion.

<i>Fit on roll container</i>	
<i>Handling fulfilment</i>	
<i>Filling busses</i>	
<i>Space</i>	
<i>Capacity</i>	
<i>Labelling</i>	

Thankyou for finishing this survey, the information will be treated confidential and fully anonymous.

## Appendix G Detailed results Best Worst Method

Respondent 1: Food administrator PostNL

Respondent 2: Product manager Food PostNL

Respondent 3: Project manager Food PostNL

Respondent 4: Sales Consultant Food PostNL

Respondent 5: Logistic Engineer Food PostNL

Respondent 6: Retailer Y. Note that this is an environmentally oriented retailer (see Appendix A).

Main criteria

Respondent No.	1	2	3	4	5	6	
<b>Criterion:</b>							Avg
<i>Social</i>	0.64	0.22	0.11	0.05	0.22	0.06	0.22
<i>Economic</i>	0.26	0.71	0.76	0.13	0.69	0.23	0.46
<i>Environmental</i>	0.1	0.17	0.13	0.82	0.09	0.68	0.32
<b>Sum</b>	1,0	1,0	1,0	1,0	1,0	1,0	1,0
<b>Consistency indicator</b>	0.14	0.17	0.31	0.34	0.04	0.22	0.20

Social sub criteria

Respondent No.	1	2	3	4	5	6	
<b>Criterion:</b>							Avg
<i>Food Safety</i>	0.86	0.75	0.89	0.33	0.83	0.5	0.69
<i>Ergonomics</i>	0.14	0.25	0.11	0.67	0.17	0.5	0.31
<b>Sum</b>	1,0	1,0	1,0	1,0	1,0	1,0	1,0
<b>Consistency indicator</b>	0	0	0	0	0	0	0

Economic sub criteria

Respondent No.	1	2	3	4	5	6	
<b>Criterion:</b>							Avg
<i>Costs</i>	0.75	0.2	0.11	0.5	0.5	0.5	0.43
<i>Logistics Performance</i>	0.25	0.8	0.89	0.5	0.5	0.5	0.57
<b>Sum</b>	1,0	1,0	1,0	1,0	1,0	1,0	1,0
<b>Consistency indicator</b>	0	0	0	0	0	0	0



Logistics performance sub-sub criteria

Respondent No.	1	2	3	4	5	6	
<b>Criterion:</b>							<b>Avg</b>
<i>Fit on trolley</i>	0.36	0.27	0.10	0.17	0.46	0.14	0.25
<i>Handling fulfilment</i>	0.21	0.27	0.10	0.04	0.03	0.45	0.18
<i>Filling busses</i>	0.14	0.08	0.12	0.38	0.13	0.07	0.15
<i>Space</i>	0.11	0.27	0.52	0.08	0.13	0.05	0.19
<i>Capacity</i>	0.14	0.08	0.10	0.08	0.13	0.14	0.11
<i>Labelling</i>	0.04	0.03	0.05	0.25	0.13	0.14	0.11
<b>Sum</b>	1,0	1,0	1,0	1,0	1,0	1,0	1,0
<b>Consistency indicator</b>	0.07	0.06	0.31	0.11	0.16	0.13	0.14

## ***Appendix H Experiments***

During the assessment of the alternatives, there have been several tests with trays. The purposes of these tests are to explore advantages and disadvantages of the trays specification in the supply chain. The experiments have been performed first at internal PostNL processes. After this, if the trays perform well in the tests they have been tested at the retailers.

PostNL Process:

- Test lids:

How easy is it to handle a tray with a lid?

The goal of this test is to find out whether it is a disadvantage for the handling of trays to have the lid on the short side of the tray instead of the long side. If the lid is on the long side and the trays are standing next to each other at the pick cart, there is a high probability of breaking the lids. Within the PostNL process, the lid will be opened and closed at door of the consumer by the driver. In other PostNL processes, the tray will always be closed.

- Test nestable and foldable in the process:

How easy is it to nest or fold trays in the whole process?

The goal of this test is to identify the ease of handling trays which can be nested or folded. This can be tested during the return flow. The processes between transportation to the sorting centre and the delivery to the consumer are not influenced by the nest or fold aspect of the tray, because the tray is always filled and closed in this process.

- Test size:

What are the desired dimensions of the tray?

The goal of this test is to identify the disadvantages and advantages of different tray sizes. The size can be of importance during the whole supply chain. For the PostNL process, this is of importance for the fit of the trays at the roll containers and the filling of the busses.

- Test stability:

How stable are the trays on the sorter? Do they fall down? Do they shake the products inside the trays a lot?

The goal of this test is to test whether the trays are able to flow over the sorting machine without any damage to the products.

- Test ergonomics:

How easy is the tray to handle for the driver?

So, the packaging has been tested on; if there are no problems if it goes on the sorter, how easy it fits on the roll container in practice, how stable the packaging is if the packaging is stacked and how easy it is to lift/open/close/fold/nest the packaging.

Retailers process:

- Test lids:

How easy is it to move a filled tray at the pick cart if there is a lid in front of the handle?

The goal of this test is to find out whether it is a disadvantage for the handling of trays to have the lid on the short side of the tray instead of the long side. If the lid is on the long side and the trays are standing next to each other at the pick cart, there is a high probability of breaking the lids.

- Test nestable and foldable in the process:

How easy is it to nest or fold trays in the whole process?

The goal of this test is to identify the ease of handling trays which can be nested or folded. This can be tested at the order picking process at the retailers. The retailers have to unfold or take apart the nested boxes and place them on the pick cart before the order picking process can be started.

- Test size:

What are the desired dimensions for the tray?

The goal of this test is to identify the disadvantages and advantages of different tray sizes. The size can be of importance during the whole supply chain. This includes, how do the trays fit on the pick cart and how easy is it to pick the products in the tray with this size.

- Test ergonomics:

How easy is the tray to handle for the order pickers?

So, at the retailers it has been tested how easy it fits on the pick cart, how easy it is to fill the packaging and how the packaging and lid can be handled in the process.

## ***Appendix I Questionnaire scoring qualitative criteria***

### Food Safety

Respondent: Risk specialist Food Safety

How much does the design of this alternative contribute to food safety?

	Very hard	Hard	Hard to medium	Medium	Medium to easy	Easy	Very easy
<i>Alternative 1</i>	1	2	3	4	5	6	7
<i>Alternative 2</i>	1	2	3	4	5	6	7
<i>Alternative 3</i>	1	2	3	4	5	6	7
<i>Alternative 4</i>	1	2	3	4	5	6	7
<i>Alternative 5</i>	1	2	3	4	5	6	7

### Ergonomics

Respondent: Order picker Retailer/driver PostNL

How easy is it to carry the packaging including groceries?

	Very hard	Hard	Hard to medium	Medium	Medium to easy	Easy	Very easy
<i>Alternative 1</i>	1	2	3	4	5	6	7
<i>Alternative 2</i>	1	2	3	4	5	6	7
<i>Alternative 3</i>	1	2	3	4	5	6	7
<i>Alternative 4</i>	1	2	3	4	5	6	7
<i>Alternative 5</i>	1	2	3	4	5	6	7

### Roll container

Respondents: Retailer/Operations PostNL

How does the alternative fit on the roll container?

	Very hard	Hard	Hard to medium	Medium	Medium to easy	Easy	Very easy
<i>Alternative 1</i>	1	2	3	4	5	6	7
<i>Alternative 2</i>	1	2	3	4	5	6	7
<i>Alternative 3</i>	1	2	3	4	5	6	7
<i>Alternative 4</i>	1	2	3	4	5	6	7
<i>Alternative 5</i>	1	2	3	4	5	6	7

### Handling fulfilment

Respondent: Retailer

How easy is it to handle the packaging during the order picking of the groceries into the packaging?

	Very hard	Hard	Hard to medium	Medium	Medium to easy	Easy	Very easy
<i>Alternative 1</i>	1	2	3	4	5	6	7
<i>Alternative 2</i>	1	2	3	4	5	6	7
<i>Alternative 3</i>	1	2	3	4	5	6	7
<i>Alternative 4</i>	1	2	3	4	5	6	7
<i>Alternative 5</i>	1	2	3	4	5	6	7

### Pick cart

Respondent: Order picker

How well does the packaging fit onto the pick cart?

	Very hard	Hard	Hard to medium	Medium	Medium to easy	Easy	Very easy
<i>Alternative 1</i>	1	2	3	4	5	6	7
<i>Alternative 2</i>	1	2	3	4	5	6	7
<i>Alternative 3</i>	1	2	3	4	5	6	7
<i>Alternative 4</i>	1	2	3	4	5	6	7
<i>Alternative 5</i>	1	2	3	4	5	6	7

### Nesting/folding

Respondents: Order picker/driver PostNL

How easy is it to nest or fold the packaging?

	Very hard	Hard	Hard to medium	Medium	Medium to easy	Easy	Very easy
<i>Alternative 1</i>	1	2	3	4	5	6	7
<i>Alternative 2</i>	1	2	3	4	5	6	7
<i>Alternative 3</i>	1	2	3	4	5	6	7
<i>Alternative 4</i>	1	2	3	4	5	6	7
<i>Alternative 5</i>	1	2	3	4	5	6	7

### Lid

Respondent: Order picker

How easy is it to handle the lid of the packaging?

	Very hard	Hard	Hard to medium	Medium	Medium to easy	Easy	Very easy
<i>Alternative 1</i>	1	2	3	4	5	6	7
<i>Alternative 2</i>	1	2	3	4	5	6	7
<i>Alternative 3</i>	1	2	3	4	5	6	7
<i>Alternative 4</i>	1	2	3	4	5	6	7
<i>Alternative 5</i>	1	2	3	4	5	6	7

### Labelling

Respondent: Retailer

How easy is it to stick a label on the packaging and to remove the label?

	Very hard	Hard	Hard to medium	Medium	Medium to easy	Easy	Very easy
<i>Alternative 1</i>	1	2	3	4	5	6	7
<i>Alternative 2</i>	1	2	3	4	5	6	7
<i>Alternative 3</i>	1	2	3	4	5	6	7
<i>Alternative 4</i>	1	2	3	4	5	6	7
<i>Alternative 5</i>	1	2	3	4	5	6	7

### Capacity of the packaging

Respondent: Retailer

How easy do the groceries fit into the packaging?

	Very hard	Hard	Hard to medium	Medium	Medium to easy	Easy	Very easy
<i>Alternative 1</i>	1	2	3	4	5	6	7
<i>Alternative 2</i>	1	2	3	4	5	6	7
<i>Alternative 3</i>	1	2	3	4	5	6	7
<i>Alternative 4</i>	1	2	3	4	5	6	7
<i>Alternative 5</i>	1	2	3	4	5	6	7

Filling of the busses

Respondent: Driver PostNL

How easy is it to stack the packaging next to the cool boxes into the van?

	Very hard	Hard	Hard to medium	Medium	Medium to easy	Easy	Very easy
<i>Alternative 1</i>	1	2	3	4	5	6	7
<i>Alternative 2</i>	1	2	3	4	5	6	7
<i>Alternative 3</i>	1	2	3	4	5	6	7
<i>Alternative 4</i>	1	2	3	4	5	6	7
<i>Alternative 5</i>	1	2	3	4	5	6	7

## Appendix J Detailed Results Multi-criteria analysis

The tables and graphs in this Appendix are related to the analysis in Chapter 4 and results in Chapter 5.

### Scores

Table 31. Overall scores alternatives

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
<b>Criteria</b>					
Food safety	5	6	7	5	7
Ergonomic	4	7	7	7	2
Costs	€ 0.21	€ 0.22	€ 0.24	€ 0.21	€ 0.23
Fit on roll container	5	2	2	5	5
Handling fulfilment	3	7	1	2	1
Filling busses	7	3	3	7	5
Space efficient	4	5	3	6	2
Capacity	5	6	2	4	1
Labelling	7	4	4	6	2
Environment	€ 0.030	€ 0.031	€ 0.037	€ 0.028	€ 0.030

The scores are normalised by the formula:

$$x^{norm} = \begin{cases} \frac{X - \min\{x\}}{\max\{x\} - \min\{x\}}, & \text{if a higher value of } x \text{ is better} \\ 1 - \frac{X - \min\{x\}}{\max\{x\} - \min\{x\}}, & \text{if a lower value of } x \text{ is better} \end{cases}$$

Table 32. Normalised overall scores alternatives

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
<b>Criteria</b>					
Food safety	0.667	0.833	1,000	0.667	1,000
Ergonomic	0.500	1,000	1,000	1,000	0.167
Costs	1,000	0.624	0.000	0.947	0.437
Fit on roll container	0.667	0.167	0.167	0.667	0.667
Handling fulfilment	0.333	1,000	0.000	0.167	0.000
Filling busses	1,000	0.333	0.333	1,000	0.667
Space efficient	0.500	0.667	0.333	0.833	0.167
Capacity	0.667	0.833	0.167	0.500	0.000
Labelling	1,000	0.500	0.500	0.833	0.167
Environment	0.799	0.699	0.000	1,000	0.753



<b>Total</b>	<b>7,132</b>	<b>6,657</b>	<b>3,500</b>	<b>7,614</b>	<b>4,023</b>
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Table 33. Normalised weighted overall scores alternative

<b>Criteria</b>	<b>Weight factor</b>	<b>Alternative 1</b>	<b>Alternative 2</b>	<b>Alternative 3</b>	<b>Alternative 4</b>	<b>Alternative 5</b>
Food safety	0.15	0.100	0.125	0.150	0.100	0.150
Ergonomic	0.07	0.035	0.070	0.070	0.070	0.012
Costs	0.18	0.180	0.112	0.000	0.170	0.079
Fit on roll container	0.07	0.047	0.012	0.012	0.047	0.047
Handling fulfilment	0.05	0.017	0.050	0.000	0.008	0.000
Filling busses	0.04	0.040	0.013	0.013	0.040	0.027
Space efficient	0.05	0.025	0.033	0.017	0.042	0.008
Capacity	0.03	0.020	0.025	0.005	0.015	0.000
Labelling	0.03	0.030	0.015	0.015	0.025	0.005
Environment	0.32	0.256	0.224	0.000	0.320	0.241
<b>Total</b>		<b>0.749</b>	<b>0.679</b>	<b>0.282</b>	<b>0.837</b>	<b>0.568</b>

Scores including several variations for alternative 1

Table 34. Overall scores variations on alternative 1

<b>Criteria</b>	<b>Alternative 1</b>	<b>Alternative 1a</b>	<b>Alternative 1b</b>	<b>Alternative 1c</b>	<b>Alternative 1d</b>
Food safety	5	5	5	5	5
Ergonomic	4	3	3	4	5
Costs	€ 0.21	€ 0.20	€ 0.21	€ 0.21	€ 0.22
Fit on roll container	5	7	7	6	5
Handling fulfilment	3	1	3	3	3
Filling busses	7	3	3	5	7
Space efficient	4	4	4	4	4
Capacity	5	7	7	6	4
Labelling	7	7	7	7	7
Environment	€ 0.030	0.029	0.029	0.030	0.030

Table 35. Normalised weighted scores including variations alternative 1

	<b>Altern ative 1</b>	<b>1a</b>	<b>1b</b>	<b>1c</b>	<b>1d</b>	<b>Altern ative 2</b>	<b>Altern ative 3</b>	<b>Altern ative 4</b>	<b>Altern ative 5</b>
<b>Criteria</b>									
Food safety	0.100	0.100	0.100	0.100	0.100	0.125	0.150	0.100	0.150
Ergonomic	0.035	0.023	0.023	0.035	0.047	0.070	0.070	0.070	0.012
Costs	0.145	0.180	0.172	0.161	0.118	0.091	0.000	0.138	0.064
Fit on roll container	0.047	0.070	0.070	0.058	0.047	0.012	0.012	0.047	0.047
Handling fulfilment	0.017	0.000	0.017	0.017	0.017	0.050	0.000	0.008	0.000
Filling busses	0.040	0.013	0.013	0.027	0.040	0.013	0.013	0.040	0.027
Space efficient	0.025	0.025	0.025	0.025	0.025	0.033	0.017	0.042	0.008
Capacity	0.020	0.030	0.030	0.025	0.015	0.025	0.005	0.015	0.000
Labelling	0.030	0.030	0.030	0.030	0.030	0.015	0.015	0.025	0.005
Environment	0.256	0.273	0.269	0.263	0.241	0.224	0.000	0.320	0.241
<b>Total</b>	<b>0.714</b>	<b>0.744</b>	<b>0.749</b>	<b>0.741</b>	<b>0.679</b>	<b>0.658</b>	<b>0.282</b>	<b>0.804</b>	<b>0.553</b>

Scores including variation on alternative 4

Variation: volume alternative 4 from 45 to 47 litres.

Table 36. Normalised weighted scores including variation on alternative 4

	<b>Alternative 1</b>	<b>Alternative 2</b>	<b>Alternative 3</b>	<b>Alternative 4</b>	<b>4a</b>	<b>Alternative 5</b>
<b>Criteria</b>						
Food safety	0.100	0.125	0.150	0.100	0.100	0.150
Ergonomic	0.035	0.070	0.070	0.070	0.070	0.012
Costs	0.174	0.109	0.000	0.165	0.180	0.076
Fit on roll container	0.047	0.012	0.012	0.047	0.058	0.047
Handling fulfilment	0.017	0.050	0.000	0.008	0.008	0.000
Filling busses	0.040	0.013	0.013	0.040	0.040	0.027
Space efficient	0.025	0.033	0.017	0.042	0.042	0.008
Capacity	0.020	0.025	0.005	0.015	0.015	0.000
Labelling	0.030	0.015	0.015	0.025	0.025	0.005
Environment	0.248	0.217	0.000	0.311	0.320	0.234
<b>Total</b>	<b>0.735</b>	<b>0.669</b>	<b>0.282</b>	<b>0.822</b>	<b>0.858</b>	<b>0.558</b>

### Packaging price

If alternatives have the same size:

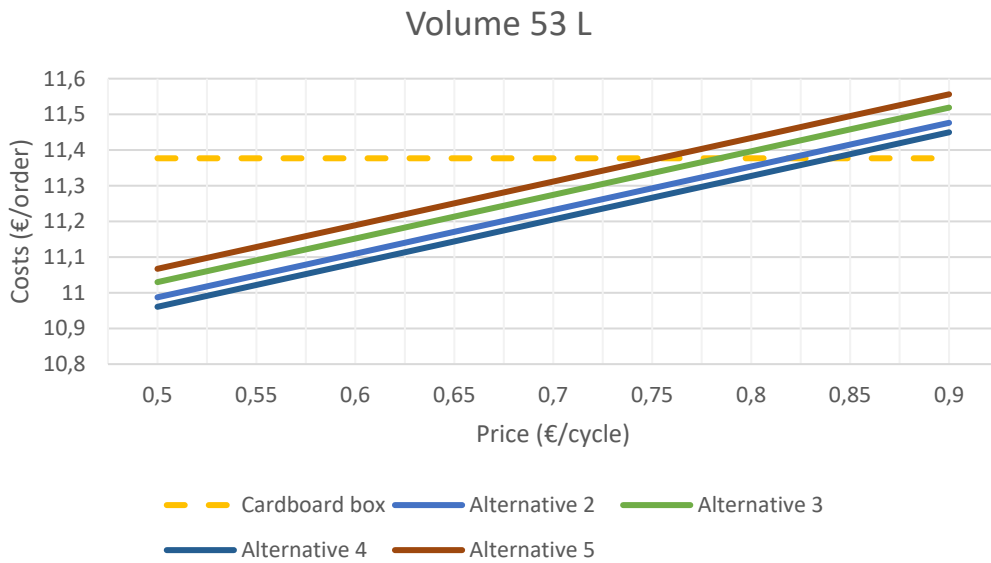


Figure 41. Economic feasible prices for the reusable trays compared with cardboard box of €1.18

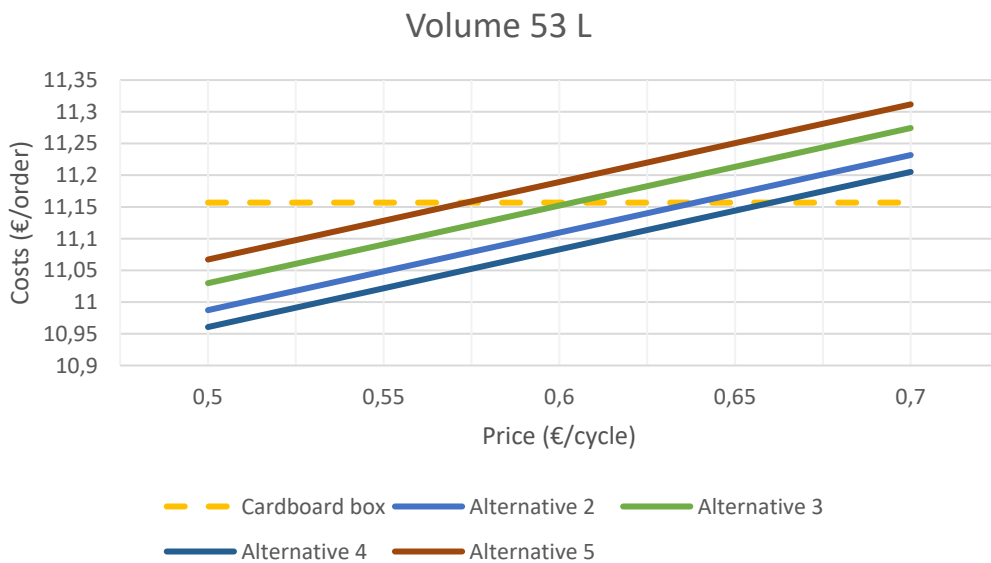


Figure 42. Economic feasible prices for the reusable trays compared with cardboard box of €1.00

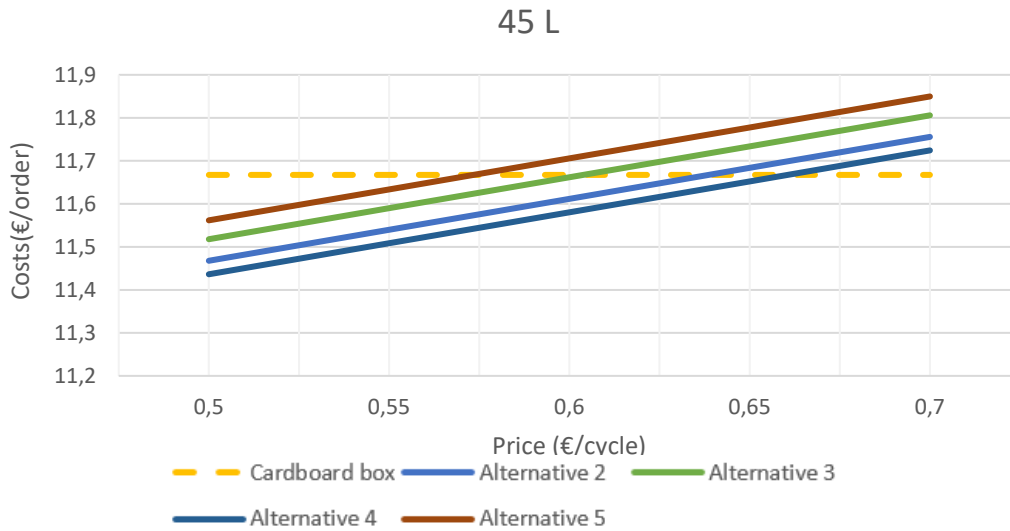


Figure 43. Economic feasible prices for the reusable trays compared with cardboard box 45 litres and a price of €1.00

If the alternatives have different sizes:

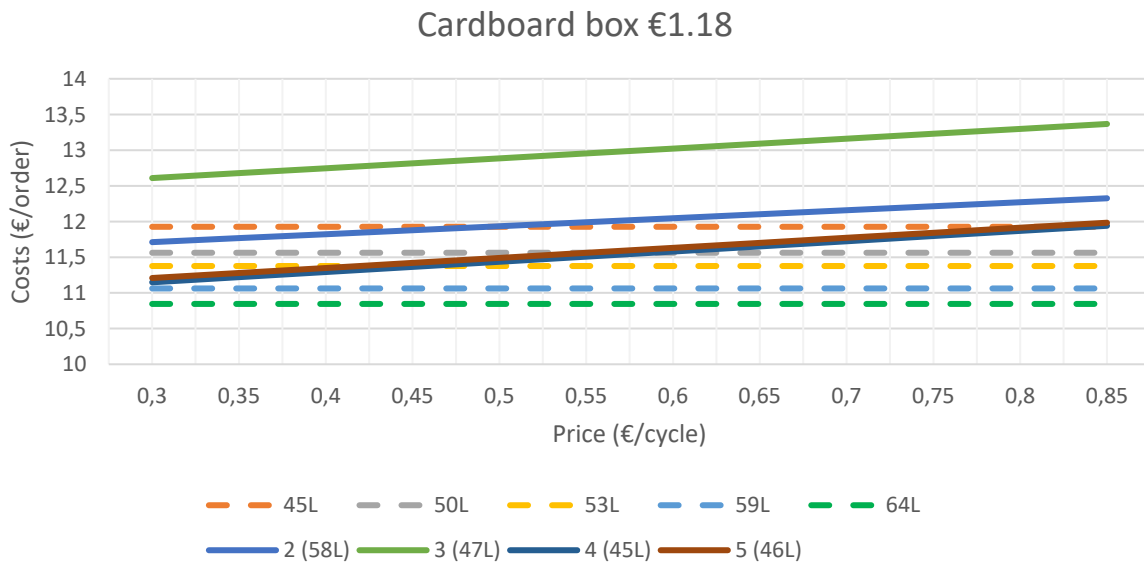


Figure 44. Economically feasible prices for the reusable trays compared to cardboard boxes with different sizes and a price of 1.18€

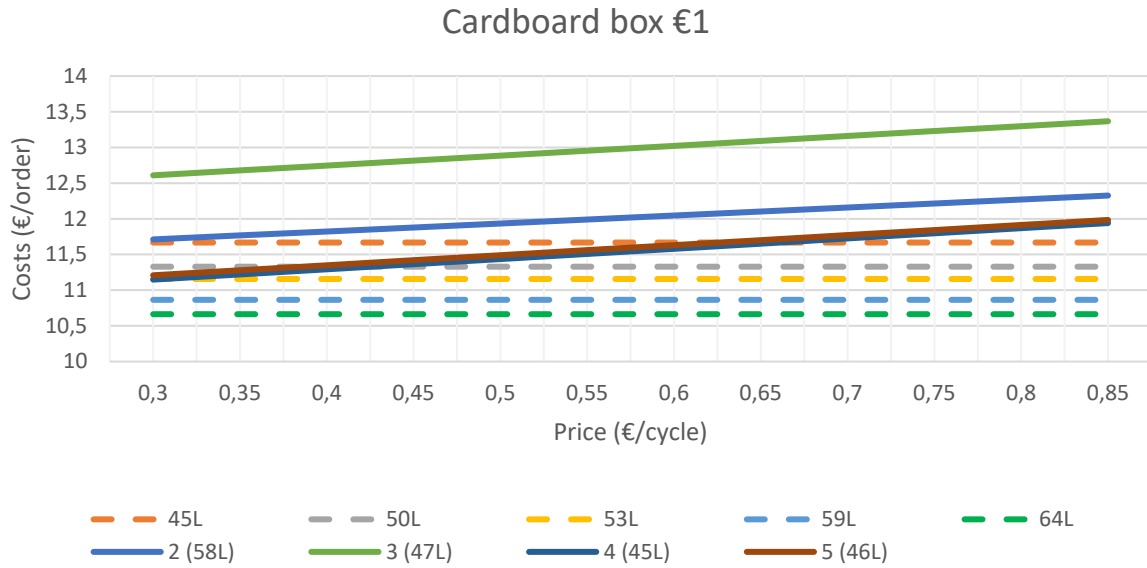


Figure 45. Economically feasible prices for the reusable trays compared to cardboard boxes with different sizes and a price of 1.00€

Variable price box related to volume:

The assumption that the price of cardboard boxes varies with the volume of the box. So, a cardboard box of 45L has a price of 1€, 53L 1.18€ etc.

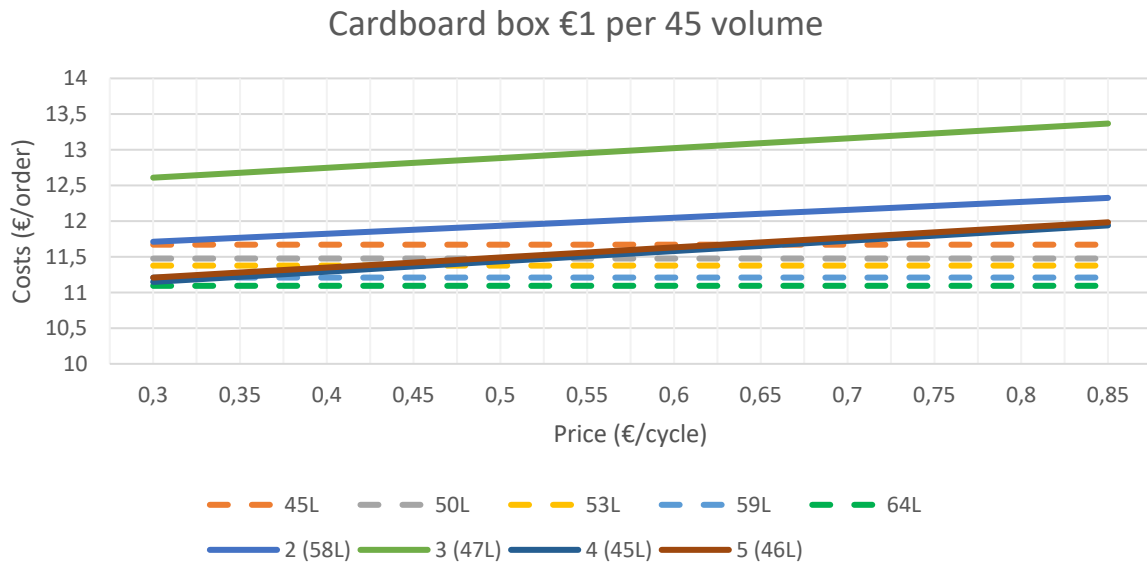


Figure 46. Price of the packaging relative to the overall costs per order including variations in volume of cardboard box

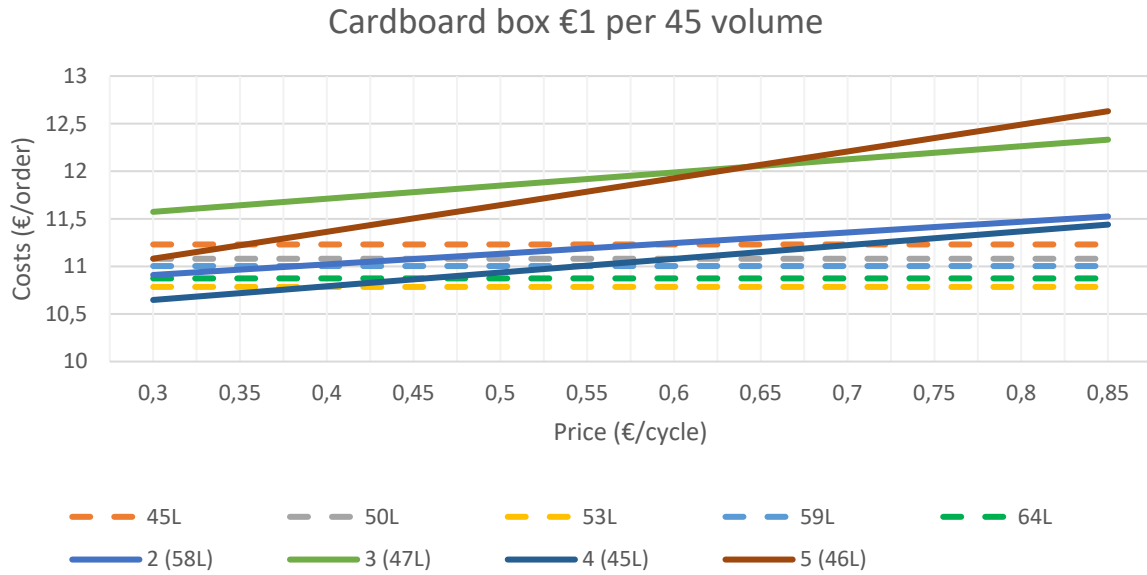


Figure 47. Price of the packaging relative to the overall costs per order including variations in volume of cardboard box if transportation costs to and from retailer is not included

### Recycling

The eco-costs of the alternatives have been compared in a normal situation with end of life, because it is not known what will happen exactly to the packaging after use. However, also a scenario with recycling has been made. For this scenario, it has been assumed that all the packaging has been recycled. The comparison of the end of life situation with the recycling can be found in the table below. Table 37 shows that the reusable trays gain less environmental impact if they are recycled and so become even more attractive.

Table 37. Normal eco-costs (€/litre) of the alternatives and eco-costs of the alternatives recycling included

	<b>ALT. 1</b>	<b>ALT. 2</b>	<b>ALT. 3</b>	<b>ALT. 4</b>	<b>ALT 5.</b>
<b>SCORE</b>	€0.0298	€0.0306	€0.0366	€0.0280	€0.0302
<b>SCORE RECYCLING</b>	€0.0298	€0.0286	€0.0325	€0.0265	€0.0278

### Validation

For every criterion, the weight factor is changed to 0 to gain insights into the impact of the specific weight factor and criteria to the overall score of the alternative. This is done for the normalized values (see

Table 38). Both methods show that alternative 4 remain the best alternative in every scenario. This means that normalisation is robust.

Table 38. Validation per criteria, weight factor=0 (sum of weighted normalised values)

<b>Criteria Weight factor=0</b>	<b>Alternative 1</b>	<b>Alternative 2</b>	<b>Alternative 3</b>	<b>Alternative 4</b>	<b>Alternative 5</b>
Food safety	0.6489	0.5544	0.1317	0.7371	0.4179
Ergonomic	0.7139	0.6094	0.2117	0.7671	0.5562
Costs	0.5689	0.5671	0.2817	0.6667	0.4892
Fit on roll container	0.7022	0.6677	0.2700	0.7905	0.5212
Handling fulfilment	0.7322	0.6294	0.2817	0.8288	0.5679
Filling busses	0.7089	0.6661	0.2683	0.7971	0.5412
Space efficient	0.7239	0.6461	0.2650	0.7955	0.5596
Capacity	0.7289	0.6544	0.2767	0.8221	0.5679
Labelling	0.7189	0.6644	0.2667	0.8121	0.5629
Environment	0.4933	0.4557	0.2817	0.5171	0.3270
<b>Normal</b>	<b>0.7489</b>	<b>0.6794</b>	<b>0.2817</b>	<b>0.8371</b>	<b>0.5679</b>



## Transport scenario

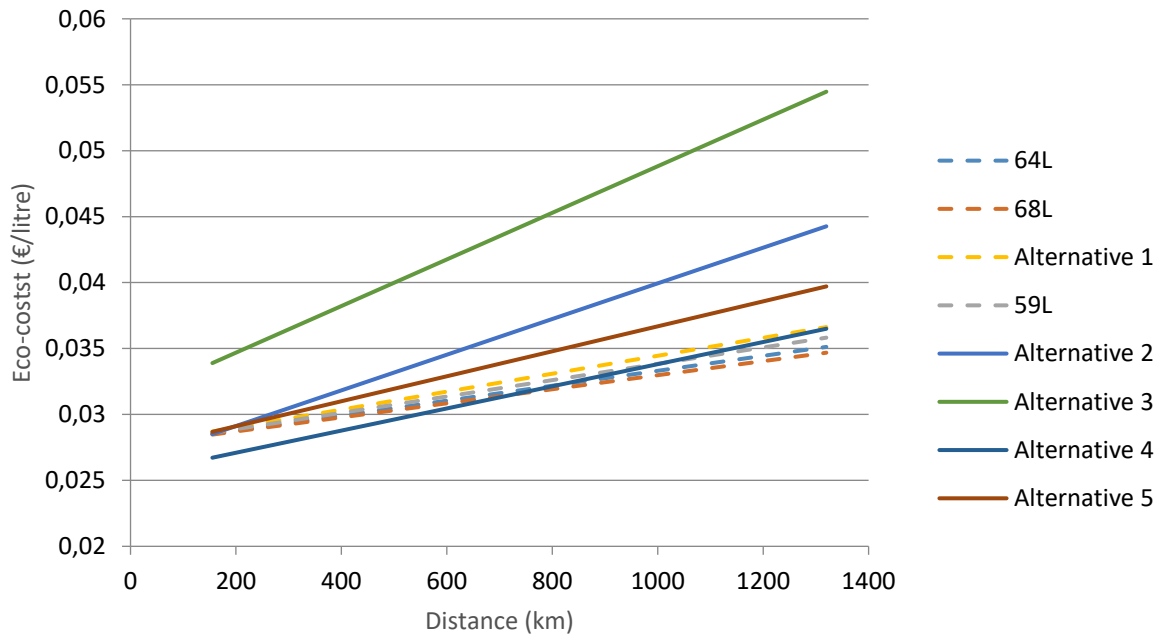


Figure 48. Transport scenario eco-costs to distance including variations alternative 1

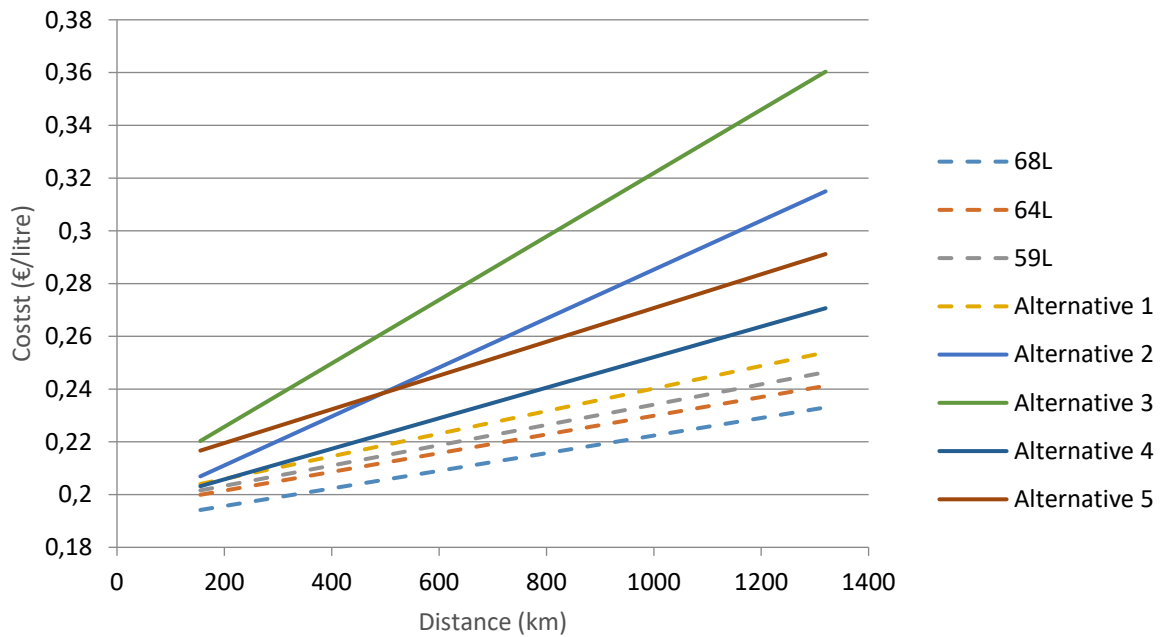


Figure 49. Transport scenario costs to distance including variation alternative 1

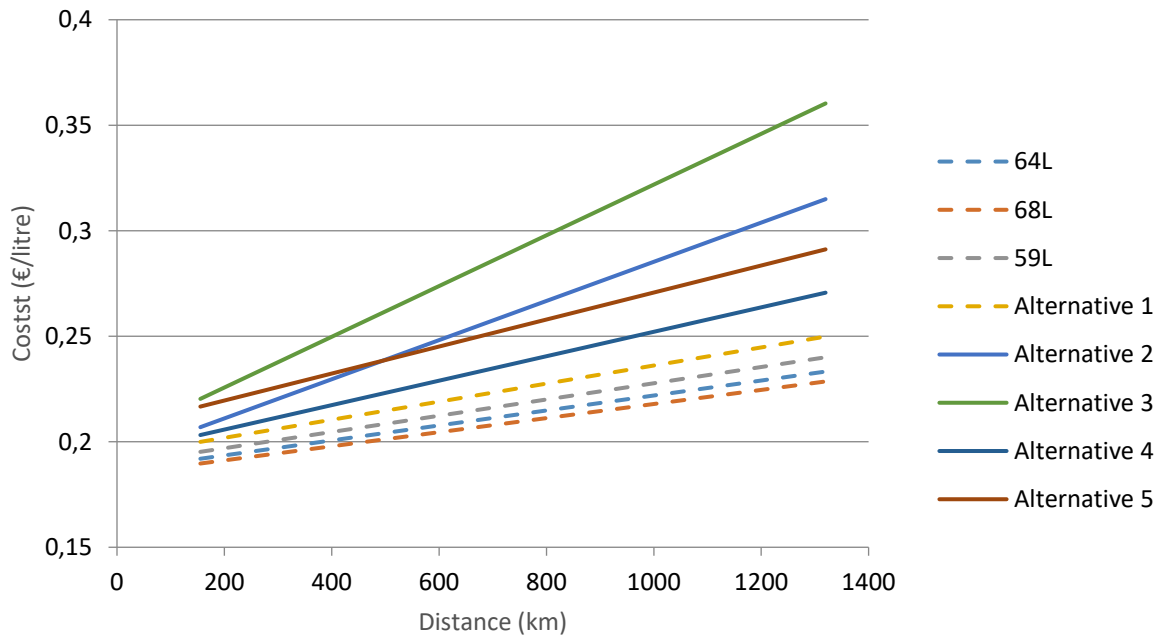


Figure 50. Transport scenario costs to distance including variations alternative 1 if the cardboard box has a fixed price of 1 euro

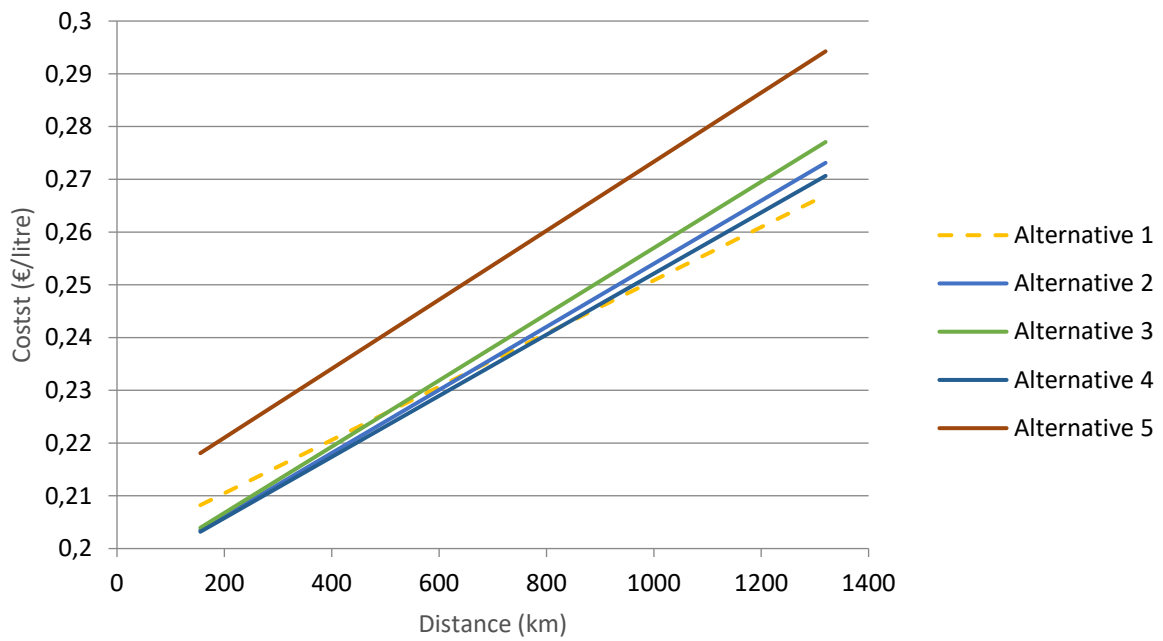


Figure 51. Transport scenario costs to distance if all alternative have the same volume (45L)

## Appendix K Calculations implementation

Alternative 4 and the cool box differ in volume, number of boxes per roll container, space reduction in the return flow and number of boxes that fit in the delivery van. In section 4.4.2 has been shown that three trays fit on one stack in the van. In the van, there are 5 stacks and under the stacks, three trays fit in height. This makes a total of 60 trays. However, even more trays might be possible but this has not been tested so 60 trays will be assumed as the maximum capacity of the van.

Table 39. Differences alternative 4 and cool box

	<i>Cool box</i>	<i>Alternative 4</i>
Volume (L)	54	45
Boxes per RC	10	12
Return transport	100%	20%
Boxes in delivery van	38	60

If the number of boxes per delivery route increases, also the time of the route increases. However, the stops will be closer to each other and the routes more efficient if there are more stops on a route. Taken this into account it is assumed that the delivery time of 38 boxes (32 stops) is the same as for the average time of 344 minutes (19 boxes, 16 stops) used in this research. For the delivery of the trays, it is assumed that the delivery of 60 boxes (50 stops) takes 410 minutes. This is calculated based on the time and number of stops from the future scenarios (see section 5.2.2).

Table 40. Results of differences alternative 4 and cool box

	<i>Cool box</i>	<i>Alternative 4</i>
Boxes	1000	1200
Nr. of RC	100	100
Full return RC	100	20
Transportation costs	€ 1.227,51	€ 809,57
Delivery costs	€ 4.387,37	€ 3.382,25

Next to the transportation and delivery costs, the handling and administration costs for alternative 4 are slightly higher than for the cool box since more boxes are needed. However, these costs are very small. Comparing all the costs, the costs for alternative 4 are €1223.39 cheaper per 1000 boxes than for the cool box. If every week 1000 trays are transported, almost €64000.00 is saved per year.

For the eco-costs, the same calculations have been made. The transportation has €32.60 eco-costs for alternative 4 than the cool box per 1000 boxes. The eco-costs for delivery per 1000 boxes are €253.91 lower. Per year this means that almost €15000.00 eco-costs can be saved by using alternative 4 instead of the cool box for the delivery of dry groceries.

