Exploring the opportunities of reducing the environmental impact of ready meal trays

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Exploratory research on the opportunities and challenges in a food packaging company

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Abstract

As convenience keeps driving the ready meals market, the foreseen rising sales might increase the environmental impact caused by this food category. Strategies for reducing the environmental impact of food products have been identified, some focusing on food packaging and eco-design. However, a gap between the current published guidelines and the requirements considered by food companies has been identified. Moreover, the opportunities and challenges for food packaging companies have only been briefly studied, and a deeper understanding of their role is needed.

This master thesis has been conducted in cooperation with Micvac AB, a ready meal packaging and technology Swedish company. This research aims to identify the opportunities and challenges of reducing the indirect environmental impact of the company through including logistic requirements in their tray design process. This purpose is fulfilled by understanding their current environmental impact in the supply chain, their packaging design process, and the current fill rate performance using interviews, observation, and experiments as primary data collection tools. The information is complemented with a literature review for discussing the findings.

The resulting requirements involve designing the trays based on the dimensions of secondary packaging to improve the fill rate in the packaging system. There is an opportunity of reducing GHG emissions, while the main challenge includes increasing collaboration with retailers, which have the central control of order quantities in Sweden. Consequently, it was highlighted that the improvements in fill rate should go in hand with apportionment requirements by the different actors.

The identified opportunities and challenges give a bigger picture of packaging companies' position when designing more environmentally friendly packaging. The latter pursuing the goal of reducing the negative impact and increasing the value for customers and consumers.

Keywords: Packaging design, Packaging logistics, Transport efficiency, Packaging innovation, Environmental impact reduction, Eco design.

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Uli Nicol·Hosse Pastor

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List of acronyms and abbreviations

CAD	Computed Assisted Design
DC	Distribution Center
FM	Food Manufacturer
FTI	Förpackning & Tidnings Insamlingen
GHG	Greenhouse gases
LCA	Life Cycle Assessment
PDP	Packaging Development Process
RQ	Research question
SRS	Svenska Retursystem

1 Introduction

This section presents the background, research questions, and limitations involved in the Master thesis research project.

1.1 Background

The changing lifestyle of consumers has driven them to increase the importance of the convenience factor when shopping for meals (Chen, 2013). According to Euromonitor International (2021), the world ready meals market had a retail value of 130.439 million USD in 2020, showing an increase of 8.6% compared to the previous year. In Sweden, this sector is forecasted to grow 9% in the following years, of which chilled ready meals are projected to have the strongest growth (Euromonitor International, 2020). Nevertheless, the latter will also increase the environmental impact and the greenhouse gases (GHG) generation, as chilled ready meals have been found to generate more GHG than home-prepared meals (Schmidt Rivera, Espinoza Orias and Azapagic, 2014). At the moment, 26% of the global GHG emissions are accounted to the food sector, from which 18% correspond to the supply chain (Ritchie and Roser, 2020). In order to achieve Europe's 2030 climate ambitions of reducing 55% GHG emissions (European Commission, 2020), the negative environmental impact of these products should be addressed and reduced.

Life Cycle Assessment (LCA) has been used as a tool to evaluate the environmental impact of ready meals in the past years (Berlin and Sund, 2010; Calderón *et al.*, 2010; Schmidt Rivera and Azapagic, 2019). Calderón *et al*. (2010) highlighted that the packaging selection impacts the environmental performance of the meal. Moreover, the authors mentioned that transportation and logistics management could be improved to reduce the negative impact. Schmidt Rivera and Azapagic (2019) also identified distribution as one of the most contributing stages along the supply chain in the UK. In this context, an opportunity to reduce the environmental impact of ready meals by studying the interactions between packaging and the supply chain can be foreseen.

One of the main challenges in sustainable packaging design is to take a holistic perspective and consider the supply chain (Hellström and Olsson, 2016). Zooming in and out helps to analyze the system and the actors independently (Pålsson, 2018). Additionally, considering the different actor's perspectives in the supply chain can help avoid the risk of suboptimization (Svanes *et al.*, 2010). LCAs have been widely used for this purpose, but, as they are time and energy-consuming, practical guidelines and evaluation methodologies have been proposed in line with green packaging design (Svanes *et al.*, 2010; Molina-Besch, 2016; Molina-Besch and Pålsson, 2020).

The indirect environmental impact of ready-meals transportation has not been widely studied, as it is usually overlooked (Pålsson, 2018, p. 44) due to its relatively low contribution in LCA results (Molina-Besch, 2016). The latter is also related to the fact that the indirect environmental impact of packaging seems insufficiently considered in food LCAs as of 2019 (Molina-Besch, Wikström and Williams, 2019). Nevertheless, studies have started to examine the impact of transport efficiency in packaging supply chains (Molina-Besch, 2017). The interest in studying the importance of considering logistic requirements during packaging design has been rising as researchers have identified that they could help reduce the overall environmental impact (Hellström and Nilsson, 2011). In this context, Molina-Besch (2016) presented packaging design guidelines for food products that require refrigerated storage and energy-intensive preparation. The guidelines suggest the minimization of household energy, food waste, and transportation energy. Regarding transportation, fill rate (volume and weight) is a crucial packaging feature that impacts transport utilization, which can positively affects the environment by increasing transport efficiency (Nilsson, Olsson and Wikström, 2011; Lindh *et al.*, 2016).

Additionally, in a study conducted by Molina-Besch and Pålsson (2016), it was identified that food companies in Sweden are aware of the need to maximize the fill rate in the packaging system. The study also identified many opportunities in this topic, including the prospect of redesign for better adapting primary packaging to secondary packaging. This adaptation involves having better compatibility between these two packaging levels. It is well known that including logistic requirements in the design process brings benefits to the food companies (García-Arca, Prado-Prado and Gonzalez-Portela Garrido, 2014; Molina-Besch and Pålsson, 2020), and it has been studied to some extent. However, fewer insights on the opportunities and challenges for food packaging companies in applying this principle are currently available.

A food packaging company and its supply chain can be examined to study this topic further. Micvac® is a ready-meal packaging company with an innovative food processing proposal for elaborating chilled ready meals with extended shelf life (Micvac, 2021). This small Swedish company offers a portfolio of different tray designs sold and distributed to food manufacturing companies, especially in the Nordics. Micvac sells the machinery, the packaging supplies, and gives guidance to the food manufacturer that will buy and implement their technology. It is in Micvac's interest to study the volume and weight efficiency of their main tray models during transportation, as the company strived on reducing, and helping their customers reduce, the environmental impact of their products.

In this context, an opportunity for exploring more about the packaging development process from a food packaging company perspective, is overseen. Based on the literature review presented, it appears to be an opportunity for including logistic requirements in the design process to reduce the indirect environmental impact of chilled ready meals. As a gap between theory and practical industrial application was previously identified (Molina-Besch and Pålsson, 2016), it is important to identify which are the main challenges in this process, and to what extent is this already done by the food packaging company under study. By gathering this information, it is possible to evaluate the best strategies for reducing the negative environmental impact of products in this category.

1.2 Purpose and Research questions

1.2.1 Purpose

The purpose of the thesis is to explore the opportunities and challenges of including logistic requirements in the packaging development process at a packaging company to reduce the indirect environmental impact of chilled ready meals' packaging. Exploring the supply chain enables a complete visualization of the needs, contributing to a holistic identification of the packaging requirements. Therefore, understanding Micvac's supply chain and their current development process is vital for identifying the challenges of including logistics requirements in the process.

1.2.2 Research questions

To accomplish the aim, the following research questions (RQs) must be addressed:

RQ1: How does Micvac's packaging design affects the environmental impact along the supply chain?

RQ2: What requirements are currently considered during the tray design process at Micvac?

RQ3: How can logistic requirements be included in the packaging development process to improve transport efficiency?

1.3 Research delimitation

Due to the time limitation and information availability restrictions, this research focuses on the supply chain of Micvac trays starting from their primary packaging suppliers until the waste handlers only in the Swedish context. The system boundaries include three primary packaging suppliers, a food manufacturer, a retailer (with a distribution center and a retail store), a consumer, two waste handlers, and a transport company. Due to the same restrictions, the supply chain mapping was performed only for the most selling Micvac tray model in Sweden. Additionally, the study does not include an analysis of the secondary and tertiary packaging suppliers, or logistic operations of these packages when they are not in contact with the primary package. The latter because it is out of scope to suggest changes at these packaging levels, and therefore they are considered to stay constant for the purpose of this study.

Moreover, the environmental impact was only quantified in terms of carbon footprint, which misses out other impacted areas (e.g., water use, land use, and fossil-free energy consumption). As Sweden's energy matrix is mainly composed of fossil-free sources (Svenska kraftnät, 2021), the environmental impact of energy production is missed. Additionally, some assumptions were made on the vehicle selections based on the information available through interviews and observation, as there is high variability on this aspect in the real case scenario.

The thesis does not intend to generalize the findings as they will result from a single case study. Nevertheless, it intends to motivate additional research to explore if similar findings are observed in other food packaging companies.

1.4 Structure of the report

The Introduction of the report has presented the background and problems that are addressed in the report. The aim, research questions, and delimitations were introduced to frame the research. The Theoretical Framework is then presented, with highlights in packaging logistics, supply chain, the environmental impact of packaging, and packaging development processes. After grounding the concepts, the Methodology is presented based on secondary and primary research steps that gather qualitative and quantitative data for answering the research questions. The Results are then presented, the supply chain of a selected product is mapped, and the environmental impact estimated. The packaging development process results are presented, followed by the fill rate calculations of the Micvac packaging options. The Discussion section presents the connection between the results and the RQ and comments the results based on literature. The logistic requirements are then discussed, and the opportunities and challenges of the company are analyzed.

Conclusions and Suggestions for future research are presented at the end of the study. Additional material such as detailed information, calculation, and tools can be found in the Appendix section.

2 Theoretical Framework

This section presents the theoretical basis used in the study. It includes definitions and content on Packaging logistics and supply chain; Environmental impact of packaging; and Packaging development process.

2.1 Packaging Logistics and Supply chain

Saghir (2002) proposed a definition for Packaging Logistics as *"The process of planning, implementing and controlling the coordinated Packaging system of preparing goods for safe, secure, efficient and effective handling, transport, distribution, storage, retailing, consumption and recovery, reuse or disposal and related information combined with maximizing consumer value, sales and hence profit."* The mentioned definition is a combination of packaging in a logistics and supply chain context. The latter involves considering the materials and information flow along the supply chain. Hellström and Olsson (2016) also define it as a multidisciplinary field covering the different actors along the supply chain, including packaging design and packaging system analysis.

The interaction between different packaging system levels has been discussed in concerning systems theory by Hellström and Olsson (2016). The authors explain the importance of having a holistic thinking approach to prevent reductionism. These topic has also been discussed by Pålsson (2018), as the holistic approach is necessary to avoid over-specialization in the packaging development process. It is crucial to consider the different actors inside the supply chain and analyze the specific processes that are carried out. The interaction of the different packaging levels and the changes that suffer across the supply chain can be well understood and studied by zooming in and out. Getting the overall picture by zooming out helps understand the system, while zooming in helps to understand the specific conditions in each process, giving great insight for achieving overall improvements.

2.1.1 Packaging system

2.1.1.1 Packaging functions and levels

Packaging has been defined by Paine and Paine (1992) as a coordinated system that strives for safe delivery of the goods to the consumer while minimizing costs. Seven main functions of food packaging were identified by Paine (1981), Robertson (1990), and Livingstone and Sparks (1994). The latter was presented by Hellström and Olsson (2016) as protection, containment, preservation, apportionment, unitization, convenience, and communication of the product.

Protection: The products need to be kept safe and sound from external sources. The package should safeguard it from compression, vibration, gases, odors, and microbiological deterioration. Additionally, it should be able to provide enough protection from climate sources such as temperature and humidity.

Containment: The package should keep the products' content together and secure from the surroundings to be transported and handled.

Preservation: Mainly related to food and perishable goods, the package should preserve the product and keep or prolong its shelf-life.

Apportionment: The package should provide the product in the desired amount to avoid food waste and regulate the appropriate consumption. This also applies for secondary packaging, as it should provide the desired amount of primary packages.

Unitization: This function is related to the material handling aspects, as it makes it possible for the packaging system to be divided into basic building blocks to suit different stakeholders. It relates to the agglomeration of packages to be easily transported or handled along the supply chain.

Convenience: The packaging design should consider the consumer's needs and demands to be user-friendly and convenient to use. This feature involves reducing the effort that a consumer might need to acquire or consume (e.g., resealability, easy to open, easy to cook, easy to use).

Communication: The packaging communicates important regulated information and marketing communication, used as a commercial tool. Different packaging levels might communicate different information for the actors that handle them, including handling instruction.

The packaging system is composed of different packaging levels that interact with each other. According to Paine and Paine (1992), primary packaging refers to the level that holds the basic product that is commercialized. The latter can be grouped in secondary packaging, which allows easy handling of a larger quantity of products at a time. The tertiary packaging level usually refers to transportation packaging, which allows large quantities to be handled and transported along the supply chain. An example can be observed in Figure 1.

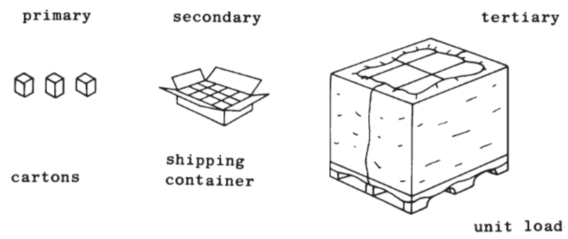


Figure 1. Examples of primary, secondary, and tertiary packaging levels extracted from Paine and Paine (1992) (after E. A. Leonard)

2.1.1.2 Packaging standardization

Pålsson (2018, pp. 21–23) highlights the role of packaging standardization for achieving logistics efficiency, where this term is used for packaging that follow specific design standards. This could help facilitate the unloading and loading activities as handling tools can be easier to adapt for a specific dimension than to a broad array of possibilities. Packaging standardization can also refer to standard packaging material, ergonomic weight restrictions, and recycling guidelines (Pålsson, 2018). Standardization has also been claimed to have known trade-offs, such as decreasing the possible designs that could adapt to consumer requirements. Tertiary packaging is widely standardized for international trade (e.g., Euro Pallet). Some countries have standardized secondary packaging for internal use (e.g., Swedish retailers and the Svenska Retursystem crates), which are adapted for their use in Euro pallets.

2.1.2 Supply chain mapping

In packaging logistics, supply chain mapping has been used as a tool for understanding the different characteristics that might impact the packaging being analyzed. Pålsson (2018) describes it as the first step of the Packaging Performance Methodology and highlights the steps that need to be carried out as the following:

1. Identifying product characteristics and requirements
2. Identifying the actors and activities along the supply chain (as detailed as possible)
3. Describing the packaging system along the supply chain and the changes it suffers
4. Identifying the challenges that the product faces throughout the supply chain

The data for the analysis is collected through interviews and observations, which are used to construct activity maps to picture the system. It is essential to define the boundaries and respect them during the analysis. The boundaries are critical when an environmental impact analysis will be carried out after the supply chain mapping task as they define the “start” and “end” points of the analyzed system.

2.2 Environmental impact of packaging

2.2.1 Types of environmental impact of packaging

The environmental impact caused by packaging can be classified in direct and indirect.

The direct environmental impact involves the production of the packaging material and final disposal (Pålsson, 2018, p. 44). The production of different packaging materials has a mixture of impacts depending on the raw materials used, energy consumption needed, waste generated during production, and technology available (Pongrácz, 2007). On the other hand, it is well known that packaging waste has been causing problems, primarily through littering and solid waste. Four areas have been identified by Pålsson (2018, p. 55) to reduce the direct environmental impact of packaging. The first one focuses on optimizing the packaging material needed to provide product protection, so the overall environmental impact is reduced. The second area focuses on reducing the number of mixed materials used. The third one looks into better use of the energy needed for producing the materials. The fourth area involves avoiding hazardous substances to avoid exposing the consumer to danger, usually regulated by legislation.

As a contrast, product waste, transport, and logistics efficiency are components of the indirect environmental impact of packaging (Pålsson, 2018, p. 44). Product waste, or food waste, has been identified to have a considerable environmental impact in previous LCA analyses (Davis and Sonesson, 2008). Pålsson (2018, pp. 58–59) describes four aspects that should be considered to reduce the waste related to: packaging protection and containment, apportionment, packaging communication capabilities, and the environmental impact of consumer behavior. Regarding packaging impact on logistics and transport efficiency, the author presents three main strategies for reducing their environmental impact. The first strategy involves improving the volume and weight efficiency on all the levels of the packaging system. The measurements are suggested to be combined with truck utilization measurements to understand the overall potential better. Volume and weight efficiencies are vital measurements. As the author explains, these aspects impact energy consumption. The second strategy proposed by the author involves packaging postponement with bulk shipments, where less packaging is used. The final strategy involves using more energy-efficient material handling means, which could be achieved by unitization and modularization. The latter also involved reducing the heating or cooling requirements when possible.

2.2.2 Greenhouse gases and carbon footprint

The most common measure for quantifying the environmental impact are energy consumption and CO_2 emission (Pålsson, 2018, p. 44). Energy consumption includes different energy sources, which can involve or not CO_2 emission. Nevertheless, this information is not always available, and tools have been previously developed focusing on the carbon footprint instead (Pålsson, Finnsgård and Wänström, 2013). The carbon footprint has been defined as *"the amount of greenhouse gases and specifically carbon dioxide emitted by something (such as a person's activities or a product's manufacture and transport) during a given period"* (Merriam-Webster, no date). Moreover, greenhouse gases are referred to the ones that cause heat to be trapped in earth's atmosphere (US EPA, 2021). The United States Environmental Protection Agency (2021) identifies carbon dioxide, methane, nitrous oxide, and fluorinated gases that affect climate change, with individual Global Warming Potentials (GWP). The GWP is based on how long the gas remains in the atmosphere and is the basis for calculating carbon dioxide equivalents (CO_2e), which are used to compare gas emissions (Eurostat, 2017). Greenhouse gas emissions have been suggested as a good indicator for all impact categories by Svanes *et al.* (2010). Nevertheless, LCA analysis is considered a complete analysis.

Four factors have been identified to drive the total CO_2 impact on industrial packaging (Pålsson, 2018, pp. 101–107): Packaging material, transportation, material handling, and waste handling. Packaging material involves the carbon footprint generated by the production processes of the primary packaging and other processes such as storage, handling, cleaning, and repairing that are more related to reusable packaging. Transportation involves product shipping and the different routes that the elements transit in the supply chain. As explained by the author, the transport from the packaging suppliers is also included in this aspect. The environmental impact may depend on the transportation mode used, as well as the load factor and shipping distance. For allocating the emissions of a package, Pålsson (2018, p. 103) suggests considering dividing the transport vehicle emissions by the maximum quantity that hypothetically can be fit in this mode of transport. Material handling entails a deep analysis of the internal operations concerning product manipulation and storage. The author emphasizes acquiring information regarding the energy consumption by the equipment used for handling and the share of the resources consumed during the product's stay in the warehouse. As for the waste-handling factor, the author includes storage, transport, and recycling of waste as important aspects to consider regarding one-way packaging.

2.3 Packaging Development process

During the packaging development process (PDP), three main phases can be identified: Idea generation, Feasibility Assessment, and Consumer Testing (DeMaria, 1999, p. 5). The objective of PDP is to develop packaging for a specific product, considering the specific requirements and the identified packaging concepts (Pålsson, 2018, pp. 139–147). The latter is generated through 1) Information and idea generation, 2) Idea Formulation of a packaging concept, 3) Concept filter and feasibility, and 4) Packaging portfolio generation. The first two steps can be considered part of the Idea generation phase explained by De Maria (1999), which can also be referred to as the Packaging Design process. In this process, different information sources are used to define the requirements for the packaging, which are used to generating the packaging concepts. Further details on this stage are explained in the following sections.

2.3.1 Packaging Design process

Details related to the information and idea generation process presented by Pålsson (2018) are described below. Monitoring market needs systematically and combining them with scientific insights on new materials, technologies, and logistic discoveries are an excellent source of good quality information. Moreover, industry-specific publications, supplier's knowledge, and waste handling facilities could give key insights to get different perspectives during the idea generation process. The information gathered should contain details on the shape, material, technological need, and/or commercial potential, which are later translated into design requirements. During the packaging design process, ideally, the package designer collaborates with the packaging engineer to ensure that the design aligns with the technical and functional aspects (Moskowitz *et al.*, 2009, p. 9).

Important concepts related to the product, production, and customer requirements are presented below. Additional essential requirements include legislative and regulatory requirements, which are not the focus of the research but are assumed to be complied.

2.3.1.1 Product requirements

Product requirements are related to the properties that the packaging should have to maintain the product quality, which is one of the basic functions according to Corner and Paine (2002). This involves getting to know the nature, properties, size, and details of the product and understanding the product/packaging compatibility.

This research focuses on packaging for chilled ready meals. Ready meals have been previously defined as packed meals containing precooked ingredients available at retail stores (Muhamad and Abdul Karim, 2015). Additionally, according to the

European Chilled Foods Federation (ECFF) (2006), chilled foods are defined by their need to be kept under refrigeration temperatures throughout the supply chain to be preserved. The latter can be classified into four different groups: Ready to eat (RTE), ready to cook (RTC), ready to wash (RTW), and ready to reheat (RTRH) (Goodburn and Chilled Food Association, 2008). Consequently, chilled ready meals are a combination of foodstuffs that must be kept under refrigeration conditions to preserve their characteristics and maintain their shelf-life. Conventionally, these products can be preserved for up to 4 days (Muhamad and Abdul Karim, 2015). Nevertheless, pasteurized meals can have longer shelf life depending on the processing time and microbiological factors, extending the time up to six weeks under certain conditions (Tang *et al.*, 2018). There is high variability in the ingredients and recipes used depending on the region and the food manufacturer.

2.3.1.2 Production requirements

Meeting production and packing line requirements was also defined by Corner and Paine (2002) as one of the basic packaging functions. The design should consider the available machines and equipment, especially if it should be adapted to current facilities.

Basic knowledge of microwave pasteurization technology is presented as it is a crucial aspect of the current packaging design. During in-package pasteurization, the package design, dimensions, physical and thermal properties of the food impact the temperature changes during the processing time (Tang *et al.*, 2018). Severe edge heating in food packages could appear if the packaging design contains sharp corners that impact the heating patterns in traditional 2450 MHz multi-mode microwaves. Additionally, Ohlsson and Bengtsson (2001) have previously presented that, to enable the microwave to be transmitted and penetrated by food, only microwave transparent materials (that do not absorb energy to a significant extent) should be used. Moreover, the water and salt content of the meal has an effect on the microwave penetration depth, impacting the cooking time and the flexibility of the packaging design.

Specific recommendations of packaging that will go under microwave process include temperature resistance of at least 120°C and the inclusion of a one-way valve or other mechanisms to allow the steam evaluation during processing (Ohlsson and Bengtsson, 2001, p. 107). Materials usually used include polypropylene (PP), polyethylene terephthalate (APET), and Nylon 6 (PA) (Tang, 2015).

2.3.1.3 User requirements

These requirements are related to the users' desirability explained by Hellström and Olsson (2016, p. 46). The latter include consumer requirements and any needs that a user of the packaging might have along the supply chain, which sometimes are not easy to express. In user-oriented design, identifying latent needs using tools such as interviews, focus groups, surveys, and others is a critical step in the process.

2.3.1.4 Logistic requirements

Logistic requirements involve considering the supplying, packing, material handling, storage, and transport activities in the company and along the supply chain, as identified by Azzi *et al.* (2012). The latter is related to functional requirements, especially for the secondary and tertiary packaging levels. Nevertheless, several authors (e.g., García-Arca *et al*. (2014)) have proposed including logistic requirements in all packaging levels to reduce the indirect environmental impact along the supply chain. Logistic requirements can be grouped into three main areas, storage, material handling, and transport. Storage requirements are related to the warehouse conditions that are available and needed by the product. Material-handling requirements are related to how manual or automatized operations in the supply chain are carried out, mentioned by Svanes *et al*. (2010) as an essential aspect to be considered during packaging design.

2.3.2 Green food packaging design

In the context of sustainable packaging design, the environmental aspect has been more widely studied than the economic and social aspects in the past years (Svanes *et al.*, 2010; Azzi *et al.*, 2012). Green food packaging design focuses on reducing the environmental impact of the food and packaging systems along the supply chain (Grönman *et al.*, 2013). In this context, different guidelines have been developed (Molina-Besch, 2016), as well as evaluation tools (Svanes *et al.*, 2010; Pålsson, Finnsgård and Wänström, 2013; Molina-Besch and Pålsson, 2020).

Hellström and Olsson (2017) have suggested six paths that can be taken for achieving sustainable development using packaging design. The six directions include: fill rate; apportionment; protection; material use; user-friendliness; information and communication.

<u>Fill rate:</u> Increasing the fill rate has the potential to reduce transportation, increase space utilization, and avoid damages across the supply chain. It could refer to volume or weight efficiency and should be considered at all packaging levels and storage spaces.

<u>Apportionment:</u> Optimizing the quantity of product from a supply and demand perspective to reduce product waste and increase profitability. Situational-specific needs can make apportionment considerations difficult to stablish, especially due to large variability and dependency on changing consumer behavior.

<u>Protection:</u> Ensuring product protection will avoid product waste. The required barrier for each specific product should be used to ensure quality throughout the supply chain.

<u>Material use:</u> The adequate amount and type of material should be used to avoid over and underpackaging. The whole packaging system should be considered to ensure an overall optimization.

User-friendliness: Including the user and its interaction with packaging could lead to a reduction of unnecessary product waste resulted from inadequate design. This direction is related to the People pillar, as it also strives to prevent frustration and increase the life quality of the consumer.

Information and communication: Facilitating an effective communication between actors in the supply chain can help reduce wasted time and resources. Improving the information flow is an important aspect for a sustainable system, and should be accompanied by good communication strategies.

The resulting designs can be evaluated in terms of their impact in the three pillars of sustainable development. These pillars include Planet, People, and Profit.

3 Methodology

This section presents the research approach, research design, and the data-gathering techniques applied in the study. Details related to the data collection and analysis of primary and secondary research are presented in detail.

3.1 Research approach

The research was framed as an exploratory case study with qualitative and quantitative data gathering. An exploratory case study has been defined by Yin (2018, pp. 45–46) as an empirical method that can be applied to explore a situation in a real-world context with an in-depth level of study. Different sources of information may be collected for this purpose. The empirical data gathered is later analyzed and discussed within the purpose of the research.

This type of study was chosen because it enables detailed exploration of the current situation of a packaging company facing the challenges of reducing their environmental impact. Case study research has been claimed to be more relevant when in-depth descriptions of phenomena are studied with a holistic perspective (Yin, 2018, pp. 32–35). The study requires detailed knowledge of the specific supply chain and a good understanding of the company's situation. This approach involves mainly primary and complementary secondary research on the current situation of the packaging company and state of art in green packaging design.

3.2 Research design

According to Yin (2018), a research design shows how the data collected is connected to the research question and the conclusions. In this sense, he proposes five main components:

1. Research questions
2. Study proposition
3. Case
4. Logical link of the data to the proposition
5. Criteria for interpreting the findings

In this context, the research purpose and three research questions were formulated in the circumstances of studying opportunities and challenges of including logistic requirements in the packaging development process for reducing the indirect environmental impact of chilled ready meal's packaging.

The study proposition is embedded in the aim, as it reflects on the connection between packaging logistics and the environmental impact of packaging identified by previous research (García-Arca, Prado-Prado and Gonzalez-Portela Garrido, 2014; Molina-Besch, 2017; Molina-Besch and Pålsson, 2020).

The case has been defined and bounded since the beginning of the research, as Micvac AB is a food packaging company whose motivations were aligned to the aim of the study. This case includes the food packaging company and the different actors in the supply chain, starting from the primary packaging suppliers until the waste handlers in a Swedish context.

Regarding the logical link of the data to the proposition, Figure 2 highlights the three main components related to the keywords: indirect environmental impact, logistic requirements, and packaging development process (PDP) from the research purpose. Each of these aspects is addressed by a research question. The strategies used in the study to collect relevant data to answer each question are presented below.

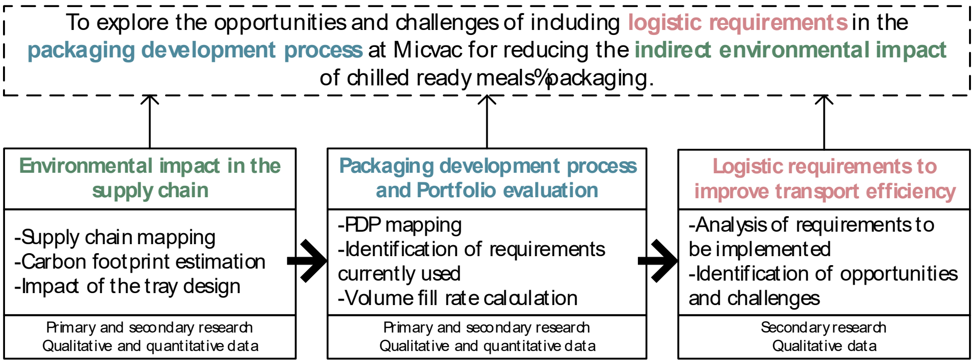


Figure 2. Logical order of the research study

To have a holistic approach to Micvac's situation, the supply chain for a selected product was mapped. Only one tray model was analyzed to gather more in-depth information considering the time constraints for the research. The tray model selected was the "star product" of Micvac in Sweden. A star product has been defined as a product with a high market share and high growth (BCG, 2021), which makes it representative of Micvac's supply chain. Primary research was conducted to gather qualitative data of the different actors and activities involved.

The carbon footprint of the packaging materials, transportation, material handling, and waste handling was calculated along the supply chain. Primary and secondary research was conducted to gather relevant quantitative information for the estimations. The impact of the tray design was discussed based on the results.

The packaging development process at Micvac was mapped to understand the current workflow and activities involved in the process. The requirements currently considered were identified based on interviews. The results were complemented with an evaluation of the current tray portfolio. The volume fill rate was calculated for five tray models in selected secondary packaging currently used by the food industry in Sweden. The results were discussed and compared to available literature from secondary research.

The three main aspects described work together to contribute to the overall purpose. By mapping the Micvac's supply chain and quantifying the environmental impact of the specified factors, it is possible to identify Micvac's role and areas where the company can reduce their environmental impact. This analysis gives insight on the potential impact that improvements in logistic efficiency might have along the actors involved in the chain. This information is later complemented with the practical possibilities that Micvac has of including these requirements in their design process, and the current performance of five selected trays from their portfolio. Finally, the results are critically analyzed and compared to identify the opportunities and challenges that might arise if logistic requirements are to be implemented in the development process from an environmental perspective. The latter is accompanied with practices that could be implemented by the company to improve their current situation and take advantage of the possible opportunities.

The project plan and the outcome for fulfilling the research project are presented in Appendix A.

3.3 Data collection and analysis

Data collection is defined as a systematic process of gathering information that enables the researcher to answer a stated research question (Kabir, 2016). Case study research depends on multiple sources of evidence (Yin, 2018), making mixed data collection a suitable strategy in this research. Non-numerical data, usually illustrative, is referred to as qualitative data, whereas numerical and mathematically computed data is quantitative data (Kabir, 2016). For collecting different types of data, a variety of tools are needed. A summary of the tools applied is presented in Figure 3.

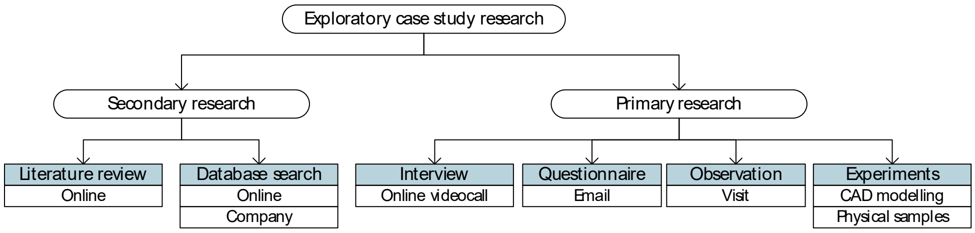


Figure 3. Data collection methods were applied for secondary and primary research with the purpose for which they were used.

Secondary and primary research was conducted for data collection and analysis. Secondary research involves data collection of secondary sources that have already been published or initially collected for a different purpose (Kabir, 2016). A literature review and a database search were conducted under this scheme. Primary research requires first-hand data collection tools from direct sources (Kabir, 2016). This type of research was the primary source of data for achieving the research aim. Qualitative and quantitative data were gathered during the research.

A literature review was conducted before and during the development of the thesis. This tool is defined by Fink (2014) as a survey of relevant publications for a specific area of research interest. It was applied for gaining a better understanding of the current knowledge of green food packaging design, with focus on the inclusion of logistic requirements in this process. Published journal articles were gathered from the library catalog from Lund University and Google searches.

Important terms used for the search are:

- Sustainable/Green/Environmentally friendly food packaging design
- Green packaging logistics
- Packaging design for transport efficiency

The results were used for framing the problem and collecting information regarding best practices in environmentally friendly food packaging design. The abstracts of the papers were read, and the content skimmed to check if logistic requirements were discussed as part of the frameworks presented. After identified the papers that discussed requirements related to storage, transport, or material handling requirements, the publications were thoroughly read. The connections between the data collected from the case study and the literature read were then discussed in the discussion section of the report. Further details on the specific data collection and analysis tools for acquiring knowledge in the three areas presented in Figure 2 are presented in the following chapters.

3.3.1 Environmental impact in the supply chain

3.3.1.1 Supply chain mapping

The supply chain mapping was conducted based on the first step of the *Packaging Performance Methodology* presented by Pålsson (2018, pp. 27–33). Micvac's star product in Sweden, the Flextray Oval, 400 g, was chosen for this analysis. The tools and data collection methods used from the methodology are explained below.

Product characteristic typology identification: This tool helps identify the specific product features that the packaging needs. Pålsson (2018) explains that this step is essential to understand the product's impact on the packaging system. Both should be analyzed in conjunction, mainly when a food packaging is being analyzed (Molina-Besch, 2016). Price, weight, brand, temperature sensitivity, fragility, and type of packaging were the features identified from the studied product.

Map the supply chain: The different actors in the supply chain (one per stage) were identified, and qualitative data was collected related to their processes and activities.

Semi-structured interviews were conducted to gather in-depth information from representatives from the food packaging company, the food manufacturer, and the retailer (Table 1). There were limitations in selecting interviewees, as it depended on the actor's interest in the project and the openability of the person. Semi-structured interviews apply open-end and close-end questions that are usually followed by follow-up inquiries (Adams, 2015). This tool was selected to provide sufficient data within a structure but allow the interviewer to ask for further details on topics that might arise. Additionally, e-mail questionnaires were used to collect information from Micvac's packaging suppliers, waste handlers, and transport providers (Table 2). This tool was suggested by Phellas, Bloch, and Seale (2011) when the questions being addressed need additional time from the subject to collect information before they can answer. The latter was the case, as some questions needed calculations and accurate values for the answers.

Moreover, a structured observation was carried out during a visit to a retail store. For structured observations, the researcher identifies beforehand the specific event that will be studied (Phellas, Bloch and Seale, 2011). In this case, the unloading process was recorded, and the packaging system used was observed. Details on the specific questionnaires, guide questions, and observation protocol are found in Appendix B.

Table 1. Details of the actors with which semi-structured interviews were conducted

Supply chain actor	*Position*	*Years of experience*	*Date*	*Duration*
Valve supplier: Micvac AB	Production & Sourcing manager	16	11/02/21	45 min
	Customer service manager Sales manager for the Nordics	8	11/02/21	45 min
Food manufacturer: Gooh AB - Lantmännen Cerealia	Gooh production department manager	2	26/02/21	1 h
Distribution Center: ICA Sweden	Head of packaging and traceability in the logistics chain	20	02/03/21	1 h

Table 2. Details of the actors that answered email questionnaires for mapping the supply chain

Supply chain actor	*Position*
Tray supplier: Faerch Plast s.r.o.	Team Leader Internal Sales
Film supplier: Scandiflex Plast AB	Inside Sales
Transport provider: Bring Frigo AB	Quality Systems Operational Excellence & Sustainability
Waste handling: Förpackning & Tidnings Insamlingen (FTI)	Business Analyst
Waste handling: Svenskplastatervinning	Development Engineer
Waste handling: Renova	Business area recycling Project manager

Process maps were constructed for each actor in the supply chain based on the information collected by questionnaires, interviews, and observations as suggested by Pålsson (2018, p. 31). The process map activity symbols and colors are explained in Appendix C.

<u>Describe the packaging system throughout the supply chain</u>: The data collected also contained information regarding the packaging system used. The information was analyzed and presented using Stackbuilder software.

3.3.1.2 Carbon footprint calculation

The environmental impact of the packaging was calculated in terms of carbon footprint based on the methodology applied by Pålsson, Finnsgård, and Wänström (2013). Packaging material, transport, material handling, and waste handling are the four factors that the authors present that contribute to carbon dioxide (CO_2) generation in the supply chain of packaging. Information regarding these factors was collected alongside the supply chain mapping activities. This information includes distances, routes, and types of vehicles used, which were systematized in tables presented in Appendix E and F. The functional unit used for the calculations is one 400g Ready-meal tray.

An LCA database search was conducted to gather accurate information for the carbon footprint emission calculation. Ecoinvent Version 3.7.1 (2020) Database was consulted for information related to packaging material production and waste handling. The Network for Transport Measures (NTM, 2021) Database was consulted for accurate vehicle carbon footprint data. The transportation emissions were calculated with CO_2e well-to-wheels emission factor considering weight load factors for each route. The weight load factors were calculated for each vehicle depending on the weight of the cargo of each specific route. Using the NTM Database, these values were used to obtain the CO_2e_{wtw} emissions factor for each case, which were used to calculate the emissions per route. The transport company in charge of carrying the products from the food manufacturer (FM) to the distribution center (DC) provided additional information from their company database to get more accurate values for this specific route. This helped considering the specific case of a temperature-controlled truck of 13 t. Additional details on the calculations are found in Appendix F. The results were put into percentage charts for the interpretation of their relative contribution to the overall GHG emission.

The information from the supply chain and the study on the main factors contributing to the carbon footprint enables an understanding of how the environmental impact is affected by the packaging studied. The reflection obtained from the study helps to understand further and answer RQ1.

3.3.2 Packaging development process and Portfolio evaluation

3.3.2.1 Product development process mapping

The product development process has not been previously documented in the company; therefore, it was essential to collect data from the actors involved. In-depth interviews encourage a more fluid conversation within a specific line of inquiry, which has been considered an essential source in case study research (Yin, 2018). This tool was specifically selected as most of the activities related to product development of trays have been conducted by a single person in the company. Complementary, a semi-structured interview with the Marketing Director was conducted to complement the findings, as a collaboration was identified between the technical and the marketing area. Specific open-end questions were formulated to guide each interview, which is presented in Appendix B. A summary of the interviewees' profiles is presented in Table 3.

Table 3. Interview details for collecting data to map the product development process

Type of interview	*Position*	*Years of experience*	*Date*	*Duration*
In-depth interview	Technical & Support Director	15 years in Micvac	31/03/21	1 h
Semi-structured interview	Marketing Director	2 years in Micvac 25 years overall	08/04/21	30 min

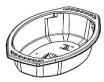
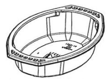
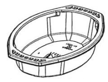
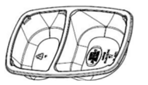
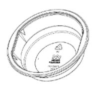
Due to the ongoing COVID-19 pandemic, the interviews were conducted online via Microsoft Teams video call software. This format allows the recording of the interview and the supplementary documents shown for a complete explanation from the interviewees.

The results from both interviews were merged and summarized for analysis. The interviewees revised the summary to allow modification if needed. Current requirements needed for the design process and main challenges expressed by the interviewees were identified for discussion.

3.3.2.2 Fill rate calculation and analysis

Micvac selected tray designs in their portfolio that, from their perspective, are considered the most important to analyze for the Swedish market. The company provided the datasheets and blueprints of the trays for calculating the volume occupied by them. A summary of the most relevant data is provided in Table 4.

Table 4. Micvac trays specifications

	Flextray Oval., 330 g	***Flextray Oval., 400 g***	***Flextray Oval., 600 g***	***Flextray 2-comp Rect., 400 g***	***Flextray Round., 300 g***
Tray sample	***A***	***B***	***C***	***D***	***E***
Weight	20 g	20 g	29 g	27.39 g	13.5 g
Geometry					
length	202 mm	202 mm	203 mm	208 mm	145 mm
width	136 mm	136 mm	137 mm	145 mm	145 mm
height	41 mm	45 mm	60 mm	41 mm	45 mm
Empty Volume*	*When the tray is not under vacuum				
compartment 1.	580 ml	630 ml	820 ml	290 ml	450 ml
compartment 2.				380 ml	
Appearance	 Micvac ®	 Micvac ®	 Micvac ®	 Micvac ®	 Micvac ®

Additional data were collected by direct measurements of processed trays. The term "processed trays" refers to a tray that has been filled with ready-meal content and underwent in-pack pasteurization, causing a compression of the top and bottom areas of the packaging. As the packaging suffers dimensional changes during the process, the data on the datasheets needed to be complemented with information regarding the compressed distance that the sealed trays show. The dimensions were taken from samples bought in a retail store, and the distances were measured with a ruler (± 0.5 mm).

The data collected from the datasheets, blueprints, and direct measurements were used to construct 3D models of the “processed trays”. The CAD (Computer-assisted Design) models were constructed using Solidworks software. The volume occupied by the processed trays was calculated by the software, as it calculates the total volume of the solid constructed.

Once the primary packages were chosen, the secondary packaging in which they are usually transported was selected. Svenska Returnsystem (SRS) is a reusable packaging company owned by The Trade Association for Grocery of Sweden and the Swedish Food & Drinks Retailers Association (Svenska Retursystem, 2021). Their packaging is widely used in Sweden by food manufacturers and retailers, corroborated by the interviewed actors during the supply chain mapping. Three crate models were identified during the supply chain mapping interviews for the ready-meals product category. The selected crate models are presented in Table 5 (2017c, 2017b, 2017a). Additional measurements were performed with a ruler (± 0.5 mm) to collect information on the inner length and width. 3D CAD models were constructed similarly to the ones constructed for the Micvac trays.

Table 5. Svenska Retursystems (SRS) crates specifications

	Half-size 50/80 blue	***Half-size 120 red***	***Full-size 50/80 red***
Crate sample	***X***	***Y***	***Z***
Weight	0.71 kg	0.76 kg	1.21 kg
Geometry			
Outer length	400 mm	400 mm	600 mm
Outer width	300 mm	300 mm	400 mm
Outer height	108 mm	148 mm	106 mm
Inner length	357-388 mm	362-388 mm	552-570 mm
Inner width	253-280 mm	257-280 mm	352-370 mm
Inner heigh	80 mm	120 mm	80 mm
Available volume	7 700 ml	11 600 ml	16 000 ml
Appearance			

Virtual experiments were conducted in Solidworks by assembling the designed pieces to find the best orientation in which the trays can be ordered in the crates. Practical considerations were made as the tested configurations should not involve complex alignment. For this purpose, a simple approach was taken. The logical order is explained in the following steps:

1. The trays were positioned with the top part facing up and the longest side aligned with the longest side of the crate.
2. Additional trays were added in the same position to the crate until no more could be fitted in the same position.
3. If additional space was identified on the edge of the crate, an additional tray, with the top part facing the long or short side of the crate, was attempted to

be added. In some cases, one or two additional trays could be fitted in the crate.

4. The previous steps (1-3) were also performed, starting with a tray positioned with the top part facing up and the longest sides aligned with the sorted side of the crate.
5. The previous steps (1-3) were also performed, starting with a tray positioned with the top part facing the longest and shortest side of the crate.
6. Additional trials were performed with a mixture of tray orientations to explore the possibility of increasing the number of trays that could fit.
7. The configurations were tried with physical samples before concluding on the maximum amount on each combination.

After finishing the experimentation, the configuration with which the largest number of trays could be fitted in a crate was used for calculating the volume fill rate. The following formula was used for the calculation:

$$Volume\ fill\ rate = \frac{Primary\ packaging(\ tray)\ volume\ \times number\ of\ packages\ that\ fit\ in\ 1\ crate}{Crate\ available\ volume} \times 100$$

The obtained fill rates were used for calculating the carbon footprint of each configuration if the pallet were to be transported from the FM to the DC. The details on the type of truck and distance transported were obtained from the results of the supply chain mapping. The calculation process was done based on *3.3.1.2*. The formulas used are presented in Appendix F and G.

This process enables gathering enough information to understand the requirements that are considered in the PDP and the resulting tray solutions of the previous designs. The evaluation of the current portfolio in terms of volume fill rate gives an idea of the performance the trays designed with the current PDP, which will provide insights into improving them further.

3.3.3 Logistic requirements to improve transport efficiency

A review of the empirical results of the previous section was done, which lead to reflection and analysis on results related to transport, storage, and material handling requirements. These requirements were identified based on the needs in the supply chain and their relationship with the primary package design. These were presented in form of summary in the results section of the research. The way the identified requirements were no be included in the packaging design process was analyzed and discussed. Additionally, to exemplify the potential improvement in transport efficiency, a specific combination of tray (Sample A) in crate (Sample Y) was studied and improved by applying the findings related to transport requirements in the chapter. Based on the observations done during the process described in *3.3.2.2.,* the dimensions of the tray were adapted to the dimensions of the crate. A reduction of the width was done based on the height of the crate, which lead to additional changes in design to try to maintain a similar overall volume of the tray. The improvements in transport efficiency were calculated in terms of carbon footprint based on the same calculation applied in *3.3.1.2*. and *3.3.2.2.*

A good analysis, according to Yin (2018, p. 213), relies on establishing a good analytical strategy by the researcher. The general strategy follows the initial theoretical proposition, which relates the inclusion of logistic requirements in the design process to the reduction of the environmental impact. This is one of the general strategies suggested by Yin (2018, p. 216). As part of the strategy, the result's parts were reviewed to identify patterns, insights, and concepts that could give answer to each research questions. The outcome was discussed, which enabled identifying the opportunities and challenges for the food packaging company in introducing logistic requirements in their packaging development process.

3.4 Quality of the research

Yin (2018, p. 78) presented four tests for assessing the quality of a case study research design. The four tests are construct validity, internal validity, external validity, and reliability. As internal validity has been stated to mainly concern for explanatory case studies, the quality of this exploratory research was not assessed by this criterion.

3.4.1 Construct validity

This test focuses on the ability to consider enough measure to predominately take an objective judgement along the data collection process. According to Yin (2018, p. 80) there are three main tactics to increase construct validity. The first one is related to gathering data from multiple sources of evidence, which will help converge different perspectives over the same aspect observed. During the supply chain mapping, the data was collected from one representative from each actor, which could be detrimental for the validity of the study. Nevertheless, as the actors interact between each other in the supply chain, a certain level of convergence was achieved for the connecting points between actors. Moreover, a higher level of construct validity was achieved when collecting data from the PDP at Micvac, as different people that interact in these processes were interviewed. The second tactic involves establishing a chain of evidence, which could be considered imbedded in the analysis of a supply chain, as the data collected from one end of one process is inevitably chained to the data that will be collected at the start of the next process. The third tactic involves letting the informers review the draft report, which was done at some extent. The interviews done were reviewed by the interviewees in the supply chain in most cases, and the final draft of the report was checked by Micvac during the whole process. Consequently, it could be stated that the construct validity of the study is enough to consider the results valid for the purpose of the study.

3.4.2 External validity

External validity is related to the possibility of generalizing results from the case studied, which can be challenging as only one specific case was analyzed. The latter could be somehow overcome considering that different people from the different actors involved in the supply chain were interviewed. As Micvac was the main actor to be analyzed in the study, by gathering information from different actors that interact with this company, the risk of getting biased results is reduced. Nevertheless, as the current COVID-19 pandemic did not allow for data collection through observation at the different stages of the supply chain, the validity is somehow limited to the word and honesty of the interviewees. The external validity of the research might be limited; hence, the author avoids generalizing findings based on the research.

3.4.3 Reliability

According to Yin (2018, p. 82), the reliability aspect of a case study has the objective to assure that any researcher could arrive to the same findings if the procedure is followed as described if the same case is studied. The atter relied on the ability of documenting the procedure used for data collection and analysis, which was previously presented in Section 3.3 with the corresponding Appendix for additional details of the tools and calculation process, where the process was described as deeply as possible. The latter was reviewed by the thesis supervisor, which guided on the process of expanding the explanation of the methodologies used in the research.

4 Results and analysis

The supply chain of a selected Micvac tray is presented in the first chapter followed by the estimation of the carbon footprint of each stage. The second chapter presents the packaging development process at Micvac, and the requirements considered in the process. It also presents the calculated volume fill rate of the current primary packaging portfolio in the secondary packaging crates used in Sweden. The third chapter ends the section with the identified logistic requirements and an example of the possible improvements in the primary packaging design.

4.1 Environmental impact in the supply chain

This chapter presents the supply chain map for Micvac's tray star product, which currently holds the most significant market and growth for Micvac's portfolio in Sweden. The environmental impact is presented in terms of carbon footprint contribution from four main factors (packaging material, transportation, material, and waste handling). The results aim to provide enough information to have a holistic view of the processes that interact with the primary packaging studied. It also gives insight into the improvement opportunities along the supply chain that can be addressed to reduce the environmental impact in terms of GHG emission.

4.1.1 Product characteristics

The selected product (Figure 4) is a chilled ready meal packed in Micvac packaging with in-pack pasteurization technology. It is part of the product portfolio of Gooh AB, a Lantmännen company, one of the most important customers of Micvac trays in Sweden. The product also comes in the most used Micvac tray design in the market: Flextray Oval., 400 g. The latter makes this product the most representative Micvac tray design in the Swedish market. Details on the product features and their impact on the packaging are presented in Table 6.

Figure 4. 400g ready meal composed of meatballs and mashed potatoes (Gooh AB, 2021a).

Table 6. Product features and their impact on packaging

	Specificities	*Impact on packaging*
Price	59 - 65 KR	This convenience good falls into the high-quality product within the ready meals. The packaging is important for preserving the product; therefore, it is possible that the packaging cost is not the main priority.
Weight	400 g	The packaging should hold this weight without breaking.
Brand	gooh!	The brand portrays a high-quality product developed by specialized chefs (Gooh AB, 2021b). The packaging should reflect the quality of the product.
Temperature sensitivity	During processing: up to 100°C Once packed: below 4°C	The material should withstand the different conditions that the product will go during processing and storage steps (Micvac, 2020) with a considerable upper and lower safety margin.
Fragility	Some vitamins in the product might be light sensitive and prone to oxidation.	The packaging must provide enough barrier properties to preserve the nutritional value of the meal.
Industrial or consumer packaging	Consumer packaging	The design of the packaging should contain marketing attributes and comply with the European labeling legislation.

The product's primary packaging consists of a clear polypropylene (CoPP) tray in an oval shape. According to Faerch (2021), the tray manufacturer, the packages are suitable for microwave cooking and can withstand temperature from -21°C until 121°C. The tray is lidded with a plastic laminated film composed of polyamide (PA) and polypropylene (PP) to provide the barrier properties needed to protect the product. A valve, made up of polyvinylchloride (PVC), is added to the film during the process and has no contact with the food product. This valve is vital for letting water vapor get out of the packaging during the pasteurization process. It assures that the package is vacuum sealed when the product is cooled down. These three components make up the primary packaging for the ready meal (Figure 5). As the label material and design vary greatly depending on the food manufacturer, it was not included as part of the scope of the study.

a) b) c)

Figure 5. The main component of the primary packaging studied a) CoPP tray, b) PA/PP lidding film, and c) PVC valve

4.1.2 Overview of the supply chain

The supply chain analyzed includes the primary packaging suppliers, the food manufacturer, the retailer's distribution center, the retail store, the consumer, and the waste handling actors. The overall structure is depicted in Figure 6. It is essential to highlight that the diagram shows the materials flow inside the supply chain and not the information flow, as Micvac manages the assortments of all the primary packaging components to the food manufacturer.

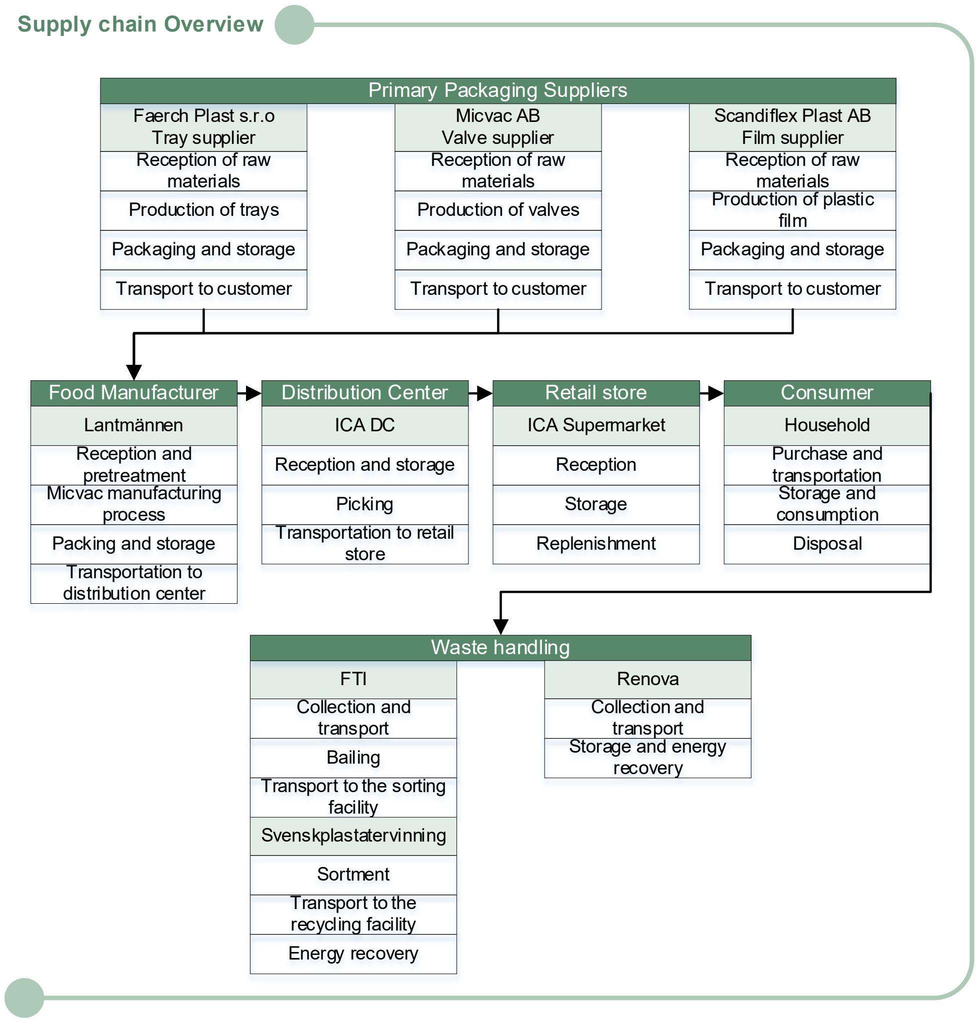


Figure 6. Supply chain overview

The activities and processes carried out by each actor are described and discussed in the following sections.

4.1.2.1 The primary packaging suppliers

The primary packaging is composed of a plastic CoPP tray, a plastic multilayered PA/PP film, and a plastic valve manufactured by Faerch A/S, Scandiflex Plast AB., and Micvac AB, respectively. The characteristics of the packaging system used for distributing each component to the food manufacturer (referred now as FM) are described in Table 7; additional details can be found in Appendix D.

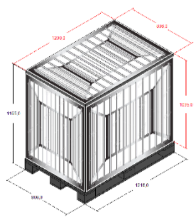
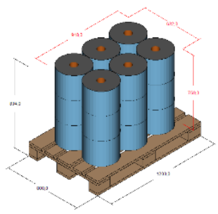
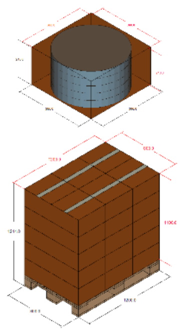
The CoPP trays are manufactured by Faerch, a strong international player in the Czech Republic. The Oval trays for 400g of product are packed in a steel cage with the characteristics specified in Table 7Table 7. The tray is manufactured by a thermoforming process. Heated PP sheets are positioned over molds where vacuum is generated to make the sheet take the shape of the container. The formed shapes are then cut, mechanically piled up, and manually packed. The steel crates are later mechanically covered in plastic wrap and loaded with forklifts to be transported. The means of transportation may differ based on the quantity ordered by the FM. The shipment can be transported to the FM by road or by a combination of road and ferry. The decision of the transport mode depends on the availability of transport in the market from the freight providers. Details on the approximated routes considered for this project are found in Appendix E.

Scandiflex Plast manufactures the multilayered plastic film in Landskrona, Sweden. The film is produced by a lamination, printing, and slitting process. The reels are later put into wooden pallets and wrapped in plastic. The pallets are later packed into Rigid trucks <= 7.5 t for their transportation to the FM. Due to weight constraints, a maximum of 20 pallets holding 18 reels each can be currently fit in the truck, leaving the upper part of the truck partially empty.

Micvac manufactures the valves at Mölndal, Sweden. The packaging details can be found in Table 7.The reels produced are packed manually in cartons and then loaded into pallets. Each layer in the pallet holds six boxes, and the company usually ships three layers or less, based on the client's order (540 000 valves per shipping). The pallet is later transferred to the loading area, and the transport company oversees the loading process. In this case, DHL services are used for the transportation of the valves to Gooh AB Facilities. Micvac only ships a maximum of one pallet per order, which are shipped based on the food manufacturer's orders. The truck from the transport provider is usually filled with other articles transported along the route, which is usually referred as co-distribution.

The packaging material supplier's selection is handled by Micvac, which gives the company freedom to choose and change supplier if necessary. At the moment, the company holds long-lasting relationships with the current supplier. Nevertheless, they oversee looking for additional options to have a safety net and less reliance on only one supplier

Table 7. Packaging characteristics of the packaging suppliers

Supplier	*Faerch A/S*	*Scandiflex Plast AB*	*Micvac AB*
Packaging component they supply	CoPP Oval tray 400g	Multilayered plastic film	Valves
Component Weight	1 tray Approx. 19.95 g	1 reel Approx. 18 580 g	1 reel Approx. 3 820 g
Primary Packaging	Plastic bag	-	Corrugated cardboard box C-flute Weight: 400 g 400x400x220 mm*
Transport Packaging	Steel Cage + Pallet Weight: 52 kg 1216x806x1165 mm* With plastic wrap	Wooden Euro Pallet 1200 x 800 x 144 mm Weight: 25 kg With plastic wrap	Wooden Euro Pallet 1200 x 800 x 144 mm Weight: 25 kg With plastic wrap
Truck size characteristics	Truck with trailer 34-40t	Rigid truck 7.5-12t	Rigid truck 7.5-12t
Components in a Primary Packaging	3712 trays	-	5 reels = 30 000 valves
Primary Packages in a Tertiary Packaging (max)	1 steel cage	18 reels lidding material for 88 615 trays	5 levels of 6 boxes 30 boxes in total
			
Tertiary packages in a Truck (max)	66 pallets Due to max. volume	20 pallets Due to max. weight	18 pallets Due to max. volume
Components in a full Truck	244 992 trays	360 reels for lidding 1 722 308 trays approx.	2 700 reels for 16 200 000 trays approx.

* Outer dimensions

4.1.2.2 Food manufacturer

The FM receives the three primary packaging materials in their production center at Järna, Sweden. The manufacturing process is done according to the Micvac method; details of the operations can be observed in Figure 7. It is important to highlight that Micvac also provides the machinery for preparing the packaging material and sealing the product, as it is part Micvac's business to provide all the equipment needed for the in-pack pasteurization process. They also provide the microwave cooking oven; therefore, the company has knowledge of the dimensions and processing capacity. The packed ready meal is manually loaded into modular, reusable SRS crates (half-size 120 red and half-size 50/80 blue) and SRS Euro pallets. Half-size 120 red SRS crates were considered for the analysis. The manual handling allows more flexibility in the configuration used inside the crate, as it does not depend on a packing machine. The latter also demands that the secondary packaging used must be ergonomic and provide handles for easy handling, which the SRS crates offer. The pallets are later transported to the Retailer's Distribution Center (DC) by a transportation company. The manufacturer must already cool the product with some degrees colder (2 to 4°C) to ensure that the cold chain is not lost during the loading and unloading processes.

The transport is done by Bring Frigo transportation company, which is entitled to choose the appropriate temperature-controlled vehicle for the sensitive cargo. The company's typical distribution unit can hold 18 pallets with a max capacity of 13 tons. Their fleet also contains a typical linehaul that can hold up to 51 pallets. Bring Frigo uses Euro classed 4 or higher vehicles and uses ammonia NH_3 as refrigerant in the warehouses and terminals, which is claimed to have a global warming potential (GWP) of 0 (Pavkovic, 2013).

4.1.2.3 Distribution Center

ICA's central warehouse in Kungälv works as a distribution center for their retail stores in Gothenburg. The activities carried out in the DC can be observed in Figure 8. An electric forklift carries out the unloading process. Information about the delivery is collected by scanning the pallets, which might contain the information in EDI (Electronic data interchange) format or not. The pallets are then transported to buffer shelves or to pick places. It is essential to highlight that a change in packaging is made when a pickup order is placed by a retail store, and that mixed roll containers are built according to the order. The products in the roll containers are organized according to the store's assortment to optimize the replenishment process. Thus, a modular packaging system is preferred to ensure a good fit between the secondary and tertiary packaging. At Kungälv, where some processes are still manual, the handles on the SRS crates help during loading activities.

ICA works with different transport providers for the distribution of goods across Sweden. As an example of the type of trucks used for this purpose, a Mercedes-benz

A Ctros 2018 truck was observed to be used during a visit to a retail store in Gothenburg. The type of vehicle is chosen based on the distance and type of retail store that will be replenished.

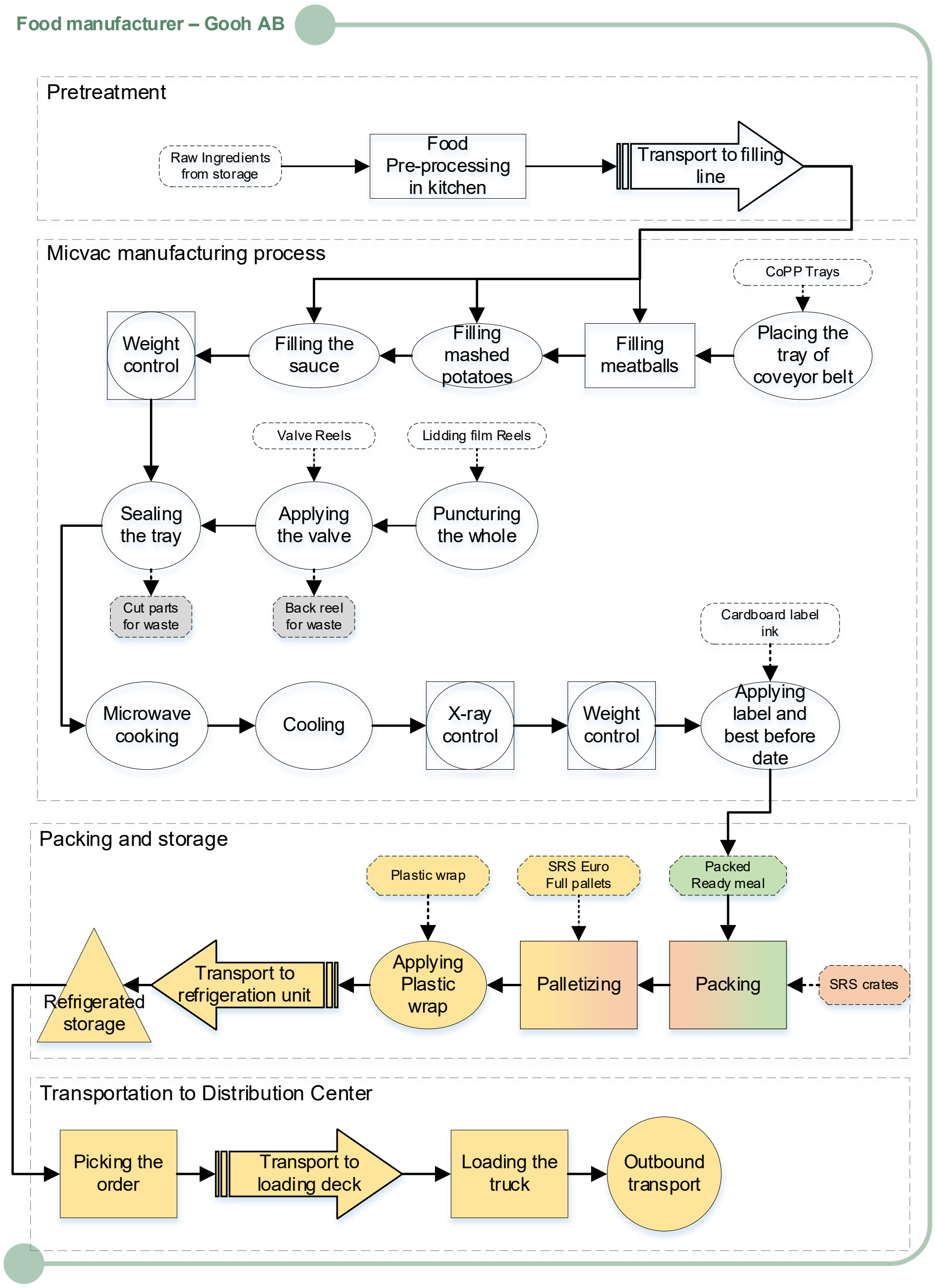


Figure 7. Food manufacturer activity map

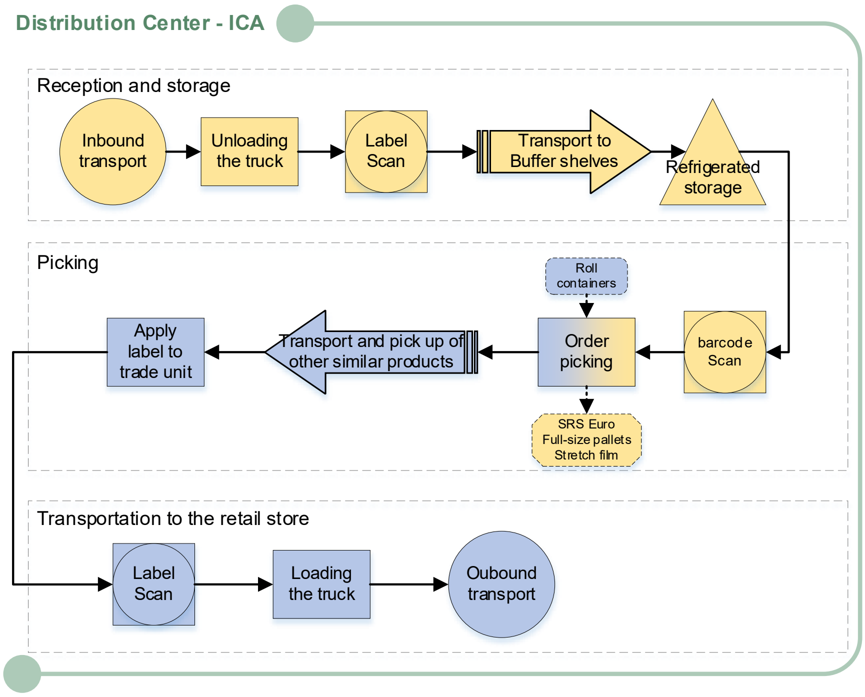


Figure 8. Distribution Center activity map

4.1.2.4 Retail store

There are four different concepts of ICA retail stores across Sweden. For this study, the observations were made at ICA Supermarket, at Brunnsbo in Gothenburg. This store concept focuses on having a wide assortment of everyday meals. The operations for unloading and storing the products were done manually; details can be observed in Figure 9.

The ready meals are delivered to the retail store five times per week based on the amount ordered by the store and the weekly promotions established by ICA's central office. Once the roll cages and SRS crates are emptied, they are stored and handed to the transport officer that delivers the products. ICA's central office predefines the number of ready meals than can be ordered by the supermarket based on the number of packed products in the crates. For example, it was identified that a minimum order of nine products or multiples of nine (or six in other recipes) is the only amount that can be ordered for this product. This is because the central warehouse does not change the quantities of products in the crates. The latter has implications in the overall supply chain, as ICA determines the number of products that should go in the crate based on the smallest retail store where the item is being sold at in Sweden. The quantities are also subject to change based on the sales projections and the increase of orders from the retail stores to the warehouse, which could show the complex dynamics involved in this relationship.

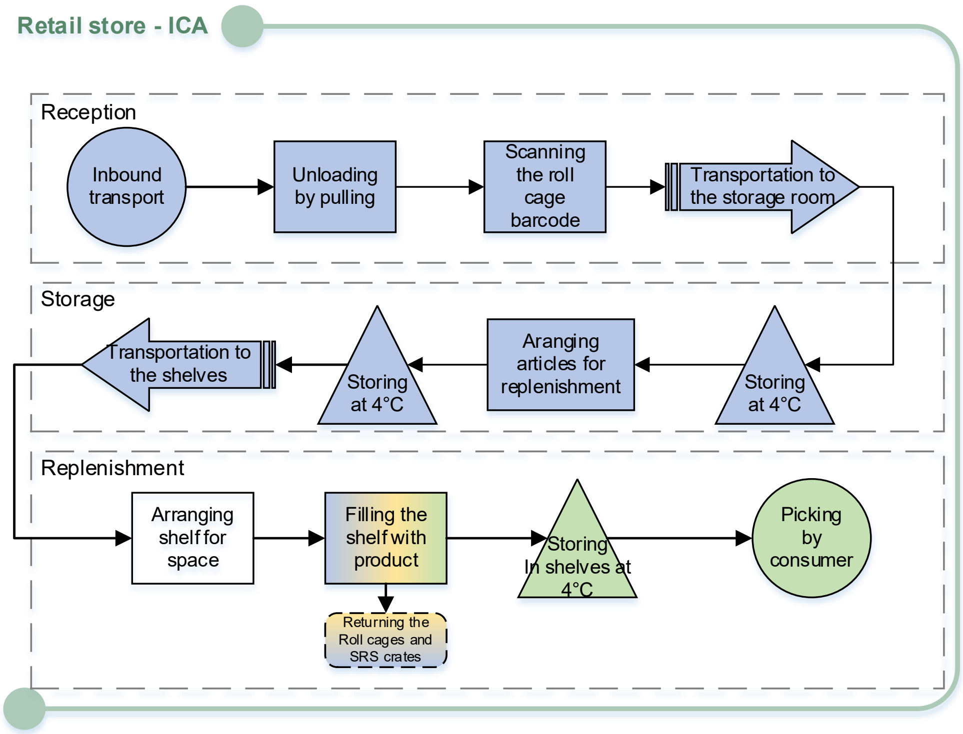


Figure 9. The retail store activity map

4.1.2.5 Consumer

Considering that the e-commerce share in this sector is still low (4.8%) (HUI Research, 2020), it is accurate to consider that most of the purchases are made in-store. The consumers get the ready meal from the retail store and transports it to their home by car, walking, or public transportation(Sonesson *et al.*, 2005). Assuming the consumer will follow the storage instructions, the ready meal is stored at refrigeration temperature until reheated using a microwave oven. Once the meal is consumed, the package might be sorted for recycling or discarded as waste. The activity map is presented in Figure 10.

4.1.2.6 Waste handling

According to ordinance SFS: 2018:1462 on extended producer responsibility for the packaging, the actor that fills the packaging has the responsibility for its correct disposal. The packaging waste generated after the consumption of the product is either sorted for recycling or disposed for energy recovery. This decision depends on consumer's behavior, but companies should encourage consumers for correct disposal of the articles. The waste handling companies considered for this study were FTI (the packaging sorting for recycling company) and the residual waste handler (Renova).

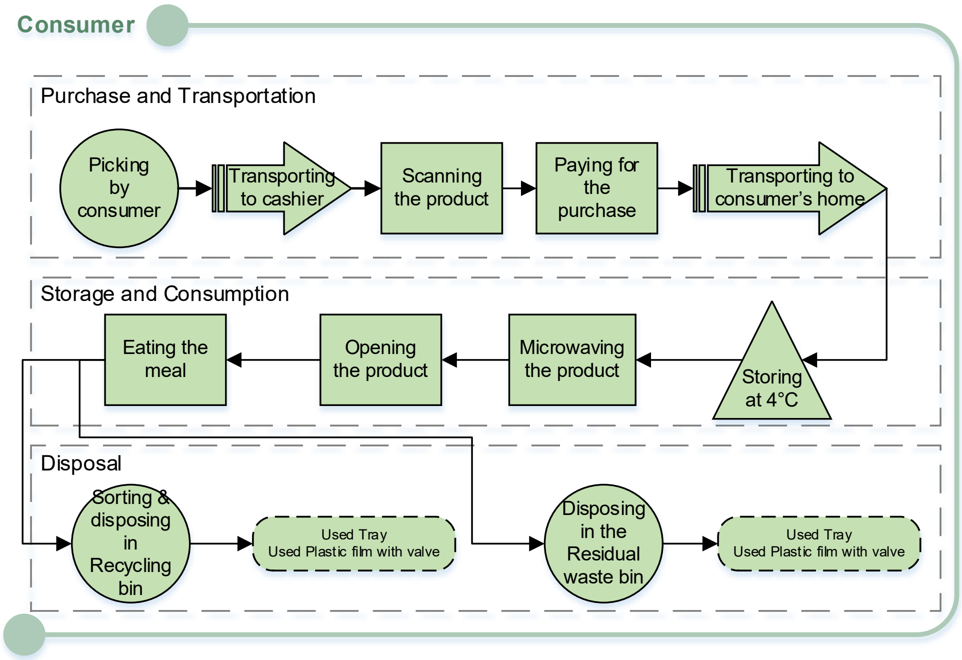


Figure 10. Consumer activity map

4.1.2.6.1 Förpackning & Tidnings Insamlingen (FTI)

FTI collects the plastic packaging from recycling stations and compresses them to plastic bales. The latter is later transported to the sorting station managed by Svensk plaståtervinning (Swedish Plastic Recycling) in Motala. The specific activities that the two actors carry out are presented in Figure 11. The process mapping will not cover the specific activities carried out by each plastic recycling company, as the project's scope is up until the plastic is sorted for mechanical recycling. Only mono materials can be sorted with the current technology at Motala. As the material identification uses photometric scanners, there are design requirements that the packaging must comply with to be fully sorted for recycling. Not only technological but also economic constraints exist in the recycling process, which has an impact on the materials that can be sorted and sold to recyclers.

4.1.2.6.2 Renova

Renova is a waste handling and treatment company that operates in western Sweden own by 11 municipalities. The company collects the residual waste from households and transports them to their facilities, where the waste is burned for energy recovery. The overall simplified operations are depicted in Figure 12.

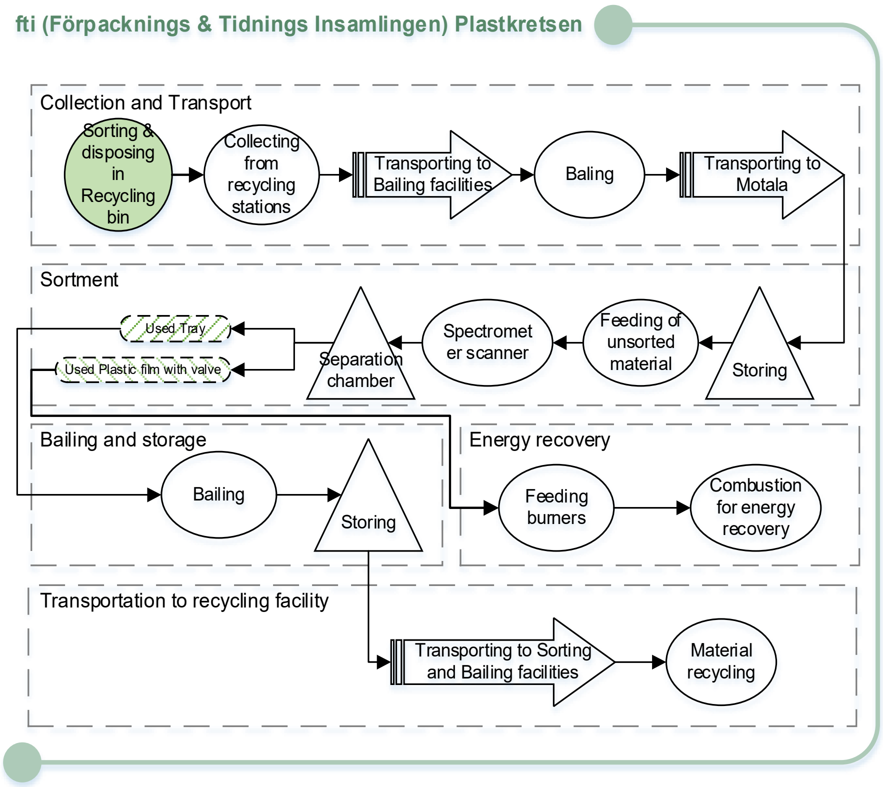


Figure 11. FTI (Packaging recycling company) activity map

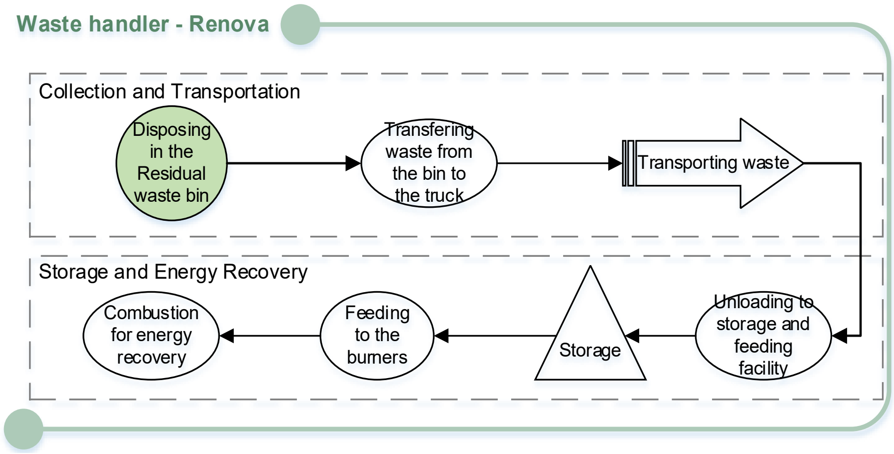


Figure 12. Renova activity map

4.1.3 Packaging system characteristics

The changes that packaging system suffers along the supply chain are presented in Figure 13. Details on the packaging P1, S1, T1, and T2 characteristics are presented in Appendix D.

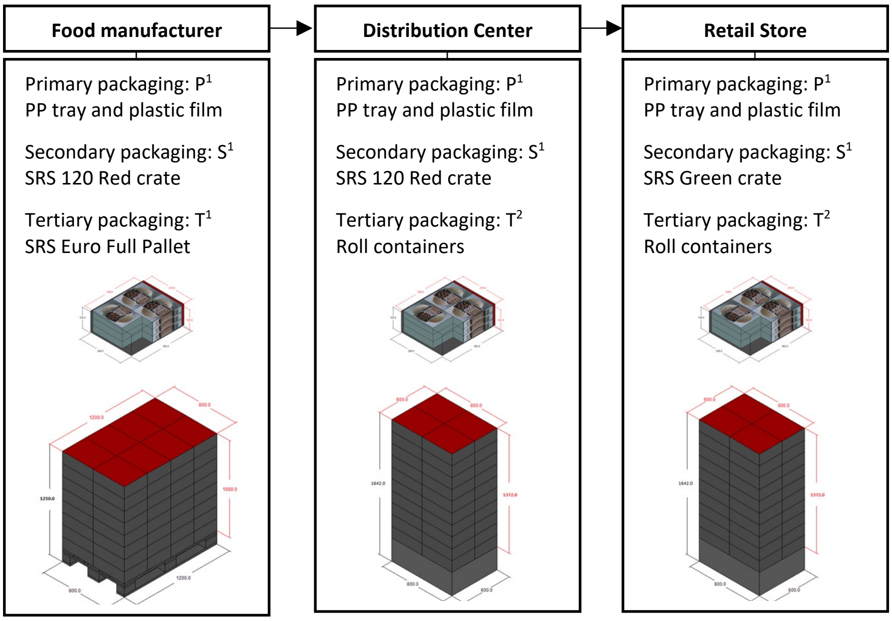


Figure 13. Packaging system description with Stackbuilder recreations

4.1.4 Factors that contribute to carbon footprint

4.1.4.1 Packaging material

The carbon footprint of the packaging material depends on the materials used. As previously mentioned, the components of the ready meal packaging involve the CoPP tray, the multilayered PA/PP plastic film, and the PVC valve. The tray production is carried out in the Czech Republic, where fossil fuel-based energy accounts for 71% of the energy supply (International Energy Agency, 2020). Nevertheless, Faerch (2010) claims their energy supply is purely non-fossil fuel-based, and therefore the transformation process does not have considerable amounts of carbon footprint emissions. On the other hand, the film and valve are manufactured in Sweden, where the electric matrix is mainly non-fossil fuel-based (90%)(Svenska kraftnät, 2021). Therefore, the carbon footprint of their transformation process will not be considered for this analysis. Consequently, only the processes involved in the pellet production are considered, as they represent the biggest GHG emissions. The processes considered for each material production are presented in Table 8.

Table 8. Processes considered for the carbon footprint calculation in the packaging material manufacturing.

Packaging material	Process considered
Polypropylene (PP)	Polypropylene production, granulate
	Ethylene production, average
	Propylene production
Polyamide (PA)	Nylon 6 production
Polyvinyl chloride (PVC)	Polyvinylchloride production, suspension polymerization
	Vinyl chloride production
	Ethylene production, average
	Chlorine production, gaseous

4.1.4.2 Transport

The transportation between the actors of the supply chain is mainly done through fossil fuel-based vehicles. The details on the approximate distances, type of vehicle used, and data used for calculating the GHG emissions per product unit are presented in Appendix E. It is essential to highlight that the transport companies are the ones that choose the vehicles based on the sender's shipment requirements. Therefore, there can be variability on this aspect based on availability. Volume and weight truck capacities were used for the analysis, and it was found that only the transport of the lidding film was constrained by weight, while the other maximum capacities were constrained by volume. The volume constrains influences the weight load factor, and therefore on the carbon footprint. The truck type and the distance transported also influences the overall GHG emissions.

Previous studies have found that consumer transport can be considerably high compared to truck transport for ready meals (Davis and Sonesson, 2008; Berlin and Sund, 2010). Nevertheless, consumer transport was not considered for this calculation as it highly depends on consumer behavior (shopping frequency, amount of food purchased per visit, and mode of transport) (Sonesson *et al.*, 2005), and similar studies have already taken this approach (Molina-Besch, 2017).

4.1.4.3 Material handling

The equipment used for handling the packaging material and the product is manual or automatic in some cases, as depicted by the flow diagrams from Figure 7 to Figure 12. The latter relies on electric power to work, and therefore the carbon footprint of its consumption is estimated to be very low in a Swedish context. No data was provided by the distribution center or retail store regarding the warehouse handling activities that may involve operations that involve GHG emissions. As material handling mainly relies on non-fossil fuel sources, their contribution for this analysis is considered 0%. The activities have an environmental impact that cannot be measured using this indicator as energy consumption is not reflected by GHG emissions in Sweden.

4.1.4.4 Waste handling

The waste handling factor was only considered for the primary packaging components and not for the supply chain's secondary and tertiary packaging levels. These two levels were excluded of the analysis as they are fixed variables in the Swedish context, and it is not in the study's scope propose changes in these levels. Additionally, in the European context, it can be assumed that the materials of the packaging levels not included are usually widely reused and recycled (Molina-Besch and Pålsson, 2020) and might have a lower impact compared to the waste generated from the primary package.

The waste handling process has two main actors: Renova and FTI. From Renova's side, the CO_2 generations come only from the plastic packaging combustion, as transportation to their facilities is done through electric vehicles. Regarding recycling, the process analyzed includes the collection and sorting processes. Swedish Plastic Recycling mentioned that the biggest carbon footprint in this sector is due to transportation of the material and mechanical recycling. Nevertheless, these processes are only partially considered for the present analysis as the scope is defined up until the sorting process, including the transport from the collection point to the sorting station.

According to the summary presented by Naturvårdsverket of the report *Kartläggning av plastflöden i Sverige* (2019), only 49% percent of the plastic packaging is separated by the user and collected for recycling. This number matches the information provided by the Swedish Plastic Recycling, as they claim that 45-50% is collected as separated plastic packaging. Based on the data gathered from Swedish Plastic Recycling representatives, the estimated recycling rates for CoPP clear trays are between 22% and 36%. The previous values consider that the packaging is 100% designed for recycling, that the yield in the sorting process varies from 80% to 90%, and that the recycling process has a yield between 60% to 80%. As for the lidding film and the valve, they are not currently recycled. Thus, they are used for energy recovery by incineration.

4.1.5 CO_2e generation in the supply chain

The carbon footprint of the four factors has a total of 149.34 g CO_2e per tray. The calculations performed for each factor are presented in Appendix F. It is important to put this value in context with the approximate carbon footprint of a meal to have a complete picture of the magnitude. According to a large food manufacturer of ready meals in the Nordics, an average ready meal of 400 g has a carbon footprint of 1104.35 g CO_2e. A similar value was also obtained using an LCA Database for the calculation, which is available in Appendix F. This means that the meal content represents 88% of the carbon footprint, while 12% is caused by the packaging material, waste handling, and transport (Figure 14).

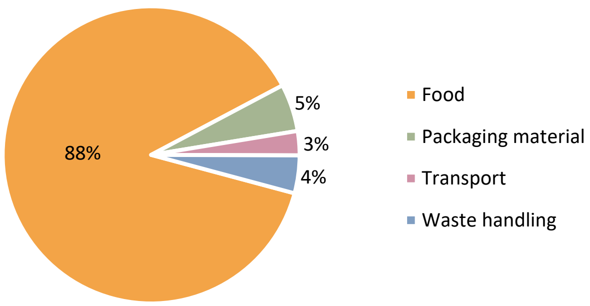


Figure 14. Carbon dioxide emission per origin for a 400 g ready meal

The results showed that avoiding food waste should be a priority, as the carbon footprint of the food content is considerably higher than the other factors. LCA analyses on ready meals have also identified that food ingredients have the highest environmental load in a cradle to grave analysis (Calderón *et al.*, 2010). This is aligned with the findings from Molina-Besch (2016), where it is suggested to prioritize food waste reduction during green food packaging development for energy-intensive meals. Once this first protective requirement is fulfilled, the focus on reducing the impact of the packaging material, waste handling, and transport should be addressed and not neglected.

The carbon footprint contribution by factor in each stage of the supply chain is depicted in Figure 15. According to the results, packaging material production is the process in the supply chain with the highest impact, similarly as observed in previous research (Davis and Sonesson, 2008). This factor is followed by waste handling, as the incineration of the packaging has a relatively high contribution due to the low recycling rates. Transportation contributes 22% of the CO_2e in this analysis.

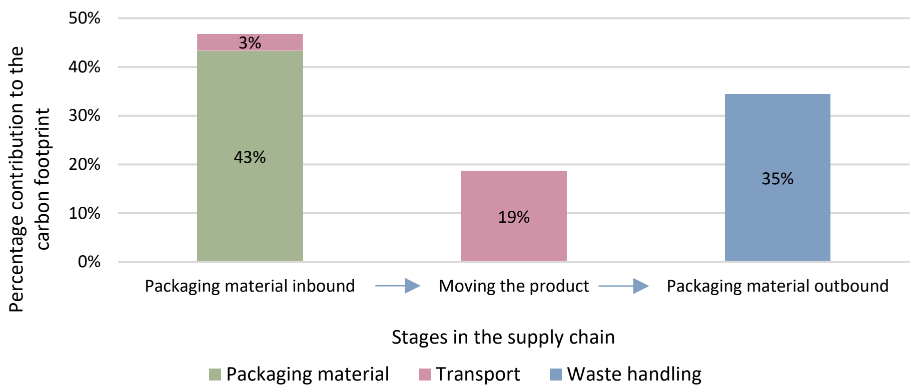


Figure 15. Carbon dioxide emission per actor for one Gooh ready meal.

As the research wants to explore the opportunities to reduce the environmental impact by including logistic requirements in the packaging design process, a deeper analysis of the transportation factor was conducted. A breakdown of the sources of GHG emissions for this factor is depicted for analysis in Figure 16. The results show that most GHG (82%) is generated during transportation from the FM to the DC. This value is mainly influenced by the weight allocated for each product and the distance from the FM to the DC. Firstly, the product's weight at this step includes the food content and the packaging material that is being transported, meaning that a higher portion of the GHG emission from the truck is allocated to the analyzed product. Additionally, the long shipping distance (450 km) and the transport mode (temperature-controlled truck) also increase the transport emissions. The second major emissions occur when the trays are transported from the supplier to the FM. In this case, the distance in this route is three times larger than from the FM to the DC, but the weight of the shipment is lighter, and a higher fill rate due to the nestable trays in the steel crates is achieved. The latter reduces the impact allocated per tray transported, as the carbon footprint was calculated based on weight load factor. The three other routes analyzed present low emissions compared to the other analyzes. However, this should be analyzed carefully, as the retail store chosen for the analysis was relatively close to the DC, which might not be the store in northern Sweden. The secondary packaging on this route is the same as the one used from the FM to the DC; therefore, an improvement in the fill rate could reduce the environmental impact on the last two transportation routes. This route might be the ones with the highest potential to either increase or decrease the overall impact for the Swedish case.

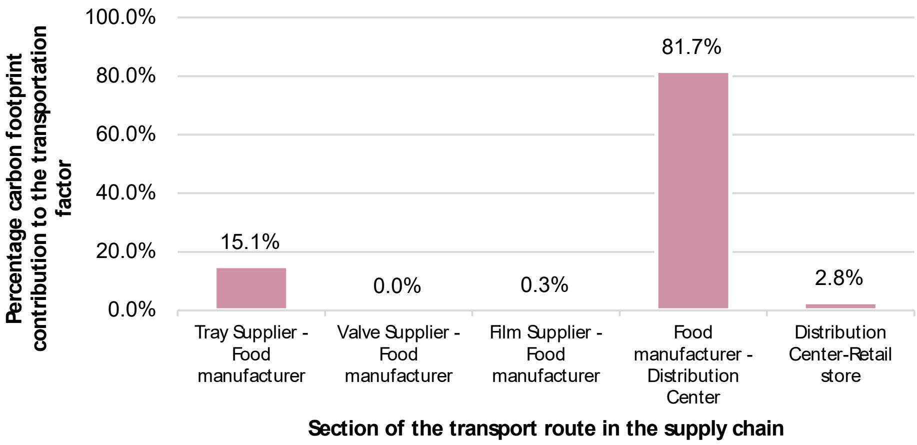


Figure 16. Breakdown of the sources of carbon footprint emissions that are part of the transportation factor.

4.1.6 Main remarks of the section

- Micvac has control over the packaging material supplier's selection. The tray dimensions determine the quantity that the reusable steel cages can transport from the supplier to the food manufacturer. At the same time, the designs might not have an impact on the dimensions of the lidding film and valve reels if the dimensions are kept under their current width.
- The primary packages are manually packed to reusable crates and piled up in pallets at the food manufacturer stage. The tray dimensions determine the maximum number of trays that can fit. Nevertheless, the retail's distribution center has requirements on the amount the crates should contain based on the smallest store format. The latter limits the control the food manufacturer has on increasing the fill rate of the secondary packages.
- Transport companies oversee choosing the transport mode based on the customer's need and internal availability, limiting the actor's control for the service. However, this could have a positive effect as transport companies can help avoid air being transported by planning and allocating co-distribution when needed.
- The manufacturing process of the primary packaging materials has the highest contribution to the carbon footprint. Even though the tray material is designed for recycling, the current rates show that waste handling is the second biggest contributor to GHG emissions. 22% of the overall estimation can be assigned to transport activities, from which the route from the FM to the DC has the highest emissions (81.7%). There is an opportunity to improve the tray/crate's fill rate used for the ready meals category, which could reduce the environmental impact.

4.2 The packaging development process and portfolio evaluation

4.2.1 Innovation funnel framework at Micvac

An innovation funnel framework is used to structure the innovation and development projects at Micvac (Figure 17).

The first step gathers internal and external sources for improving or generating new packaging and technology projects. Innovation projects that have been prioritized in the past have been technology-centered but involved benefits for the customers (e.g., reducing energy consumption). As for packaging development, the ideas were based on potential customer requests and requirements. According to the Marketing Director, the company is trying to shift the focus from a technology-centered to a customer-centered innovation with active participation on proposals based on market trends. The sales and technology department usually gathered these requirements during meetings with potential customers.

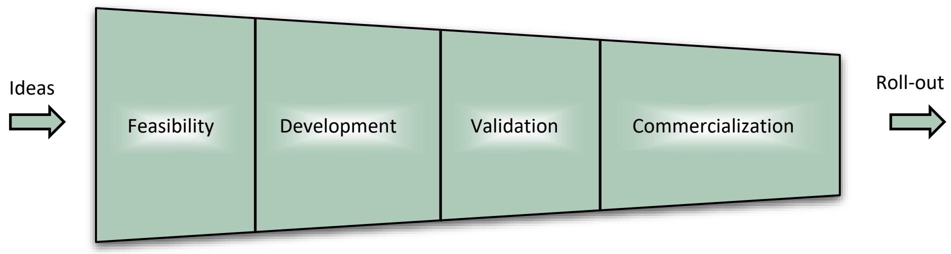


Figure 17. Innovation funnel model process at Micvac

The ideas generated pass through a feasibility evaluation regarding the technological and commercial aspects. The latter also includes an evaluation of the ideas that comply with legal and safety requirements. Production requirements are also considered in this step, as the packaging design should allow in-pack microwave pasteurization. In the tray designs, a preliminary concept and calculations are made by Micvac, which are further developed in collaboration with the tray supplier. Potential designs are generated using Computer Assisted Design (CAD) models, which are later reviewed by the technical team at Micvac. Feedback is generated during this iterative development process until a hand-made sample is presented for validation. The validation process involves production trials using the newly designed tray with a mock food product. This step is carried out at Micvac facilities, and special attention is put to the heat transfer behavior changes with the new packaging design in the ready meal. The sales, marketing, and technical support team later carry the commercialization and roll-out phase.

4.2.2 Requirements currently used during the product development process

As the tray development process is mainly project-based, the requirements mainly depend on the customer's ability to communicate their needs and the technology available. The following requirements were identified to be considered based on the Marketing and Technical & Support Directors:

- Customer requirements: The requirements are mainly related to the packaging's physical appearance and the weight capacity according to the customer's request (food manufacturer).
- Product requirements: The packaging should be made of food-grade materials with oxygen and moisture barrier properties. The meal's recipe also impacts the tray design, as the ingredients' properties and dimensions determine the heat transfer behavior during the cooking process.

- Production requirements: The packaging design should allow penetration of the microwaves and avoid sharp corners to prevent burned spots during the pasteurization process. The height should be minimized to allow the product to be cooked by the microwave radiation and to reduce the areas that would have to be reached by heat conduction. It should also fit into the current microwave oven tunnels used during the production process and have the possibility to be stacked vertically on the feeding line. Adaptation to current sleeving machines can also be a production requirement asked by the customer.

Due to the increasing environmental concern of customers and consumers of plastic packaging, an additional requirement for recyclable material has been recently included. It is expected that the customers start inquiring more on the environmental impact of the packaging, as tighter regulations are foreseen to be applied soon.

Customers sometimes ask for additional requirements related to logistics. For example, a customer asked for a reduced tray size because the current one could not fit the maximum available space on a retail store's shelf in Norway. As the company supplies customers around the globe, market-specific requirements could sometimes be requested. Nevertheless, Micvac is now keeping the focus on the European market.

4.2.3 Constrains identified during the product development process

The frequency at which new tray models are developed and put on the market is currently low. As the company is in a growth phase, the Marketing Director expects an increase in the demand for new packaging sizes and models. On average, one new tray has been fully developed every two years since the company started. The main constrain in this process is the significant investment needed for molds for new tray designs. There can be two situations in this matter. The first one involves the production of a new mold for a novel tray design. The second one involves the adaption of a current tray model from the supplier's catalog. The adaptation is made with an insert to the current mold, which adds the flexible bottom to allow the tray to be used for Micvac in-pack microwave pasteurization process. The investment needs to be absorbed by the customer, limiting the available customers who are willing to invest in a new tray design. The additional investment could be between 15 000 to 50 000 Euros, without considering the customer's initial investment in machinery. The latter is combined with the fact that customers want to start producing small volumes, which might not be attractive enough to invest in a new mold. The company considers this aspect the main reason only around half to one-third of the trays designed reach the market.

In the previous years, the packaging company has only had access to information about the final consumer through their customers (food manufacturer). Therefore, the knowledge acquired about the consumer was limited. Consequently, little effort has been put into designing based on consumer needs and requirements in the previous years. During the technical trials, the only usability tests conducted concerned the easy-to-open quality of the trays. Nevertheless, the company has recently conducted consumer research to better understand the ready-meal category, with no specific focus on the packaging level.

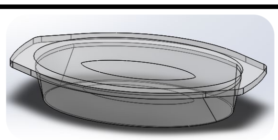
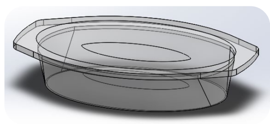
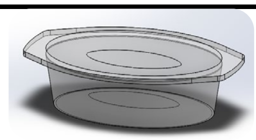
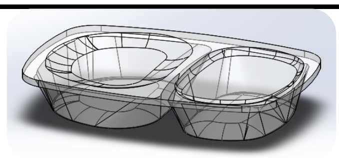
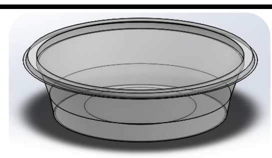
The innovation projects have been stopped since the Covid-19 pandemic in 2020. Nevertheless, the company strives to continue with them once the global situation improves.

4.2.4 Product portfolio's Fill rate calculation

4.2.4.1 Primary packaging characterization

The CAD models were created for the five trays presented in the Methodology section. These models consider the reductions in volume that the packaging suffers after the ready meal's pasteurization. The CAD models and the volume that each tray occupies are presented in Table 9. General features on the shape and design can be observed. Trays A, B, and C have similar designs with slight differences in their height. Tray D is a two-compartment model that allows division between ingredients, while tray E shows a circular design for smaller volumes.

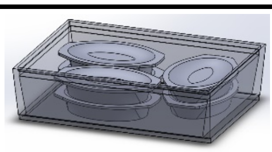
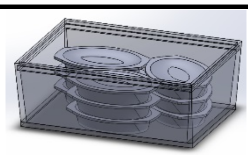
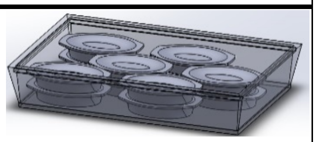
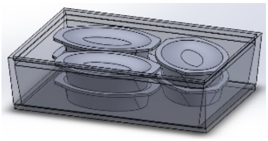
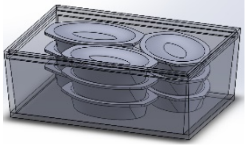
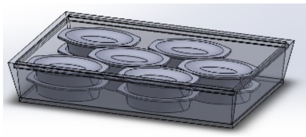
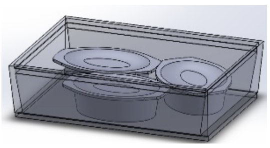
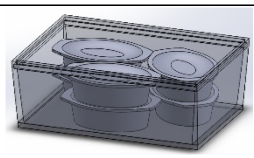
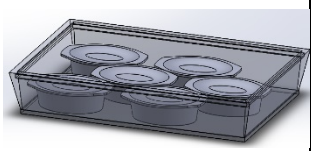
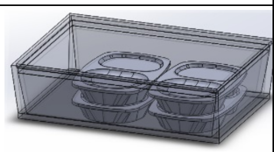
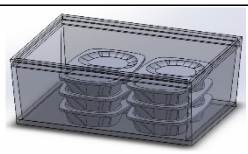
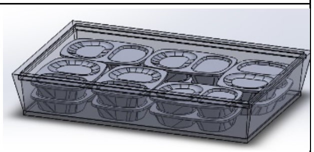
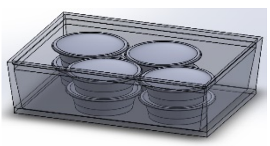
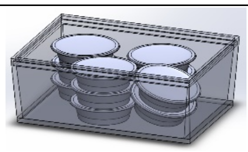
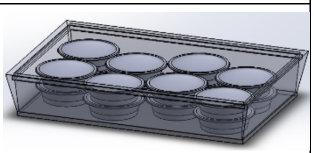
Table 9. The volume of the trays after processed

Tray	*A*	*B*	*C*
CAD model			
Volume	421 ml	479 ml	673 ml
Tray	*D*		*E*
CAD model			
Volume	508 ml		325 ml

4.2.4.2 Volume fill rate calculation

The volume fill rate was calculated for all the combinations between the tray samples (A to E) and the SRS crates studied (X to Z). The results on the maximum number of trays that can be accommodated in each combination are presented in Table 10, as well as the configuration on each case and the calculated volume fill rate. Crates X and Y have similar dimensions with the main difference in height. Crates X and Z show similar height, but crate Z is twice as long than crates X and Y.

Table 10. Volume fill rate in each Tray/Crate combination

	Crate models		
Tray	***X***	***Y***	***Z***
A	 6 trays Volume fill rate: 33%	 9 trays Volume fill rate: 33%	 12 trays Volume fill rate: 32%
B	 6 trays Volume fill rate: 37%	 9 trays Volume fill rate: 37%	 12 trays Volume fill rate: 36%
C	 3 trays Volume fill rate: 26%	 6 trays Volume fill rate: 35%	 6 trays Volume fill rate: 25%
D	 4 trays Volume fill rate: 26%	 6 trays Volume fill rate: 26%	 12 trays Volume fill rate: 38%
E	 8 trays Volume fill rate: 34%	 11 trays Volume fill rate: 31%	 16 trays Volume fill rate: 33%

The volume fill rate values vary from 25% to 38%. As the crates are part of a modular system, they are designed to have a 100% fill rate at the pallet level. Therefore, these fill rates may also represent the efficiency of the overall packaging system. In a sample of ready meals in the Swedish market, fill rates of 18% and 29% were observed for a two-compartment box and a pasta box respectively (Details on Appendix H).

The main challenges in increasing the volume fill rate of the Micvac tray could rely on the geometry of the packages. To exemplify this, a close-up model of tray sample B (Flextray Oval 400g) enclosed in a rectangular prism can be observed in Figure 18. The green volume corresponds to the packed product, which is 44% of the enclosed volume. The red volumes (top and bottom void volume due to vacuum shape) correspond to 13% of the prism volume. The latter leaves a 44% of void volume that is related to the empty space under the rims and handles of the packaging.

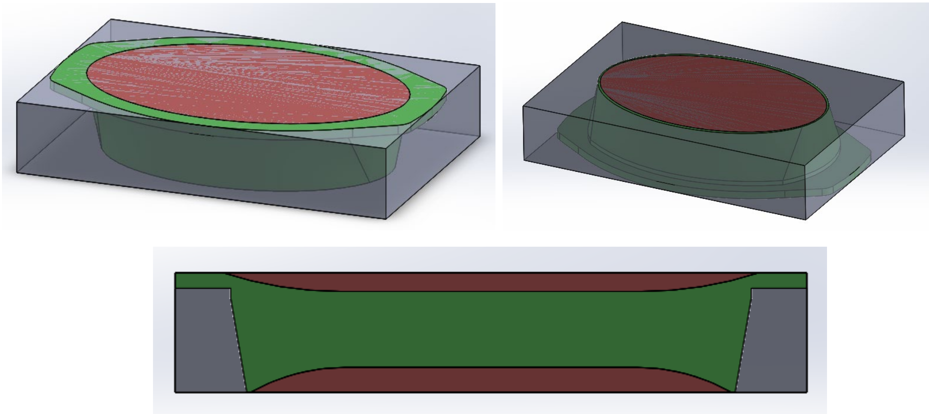


Figure 18. Tray sample B with sectionized volumes

4.2.4.3 Relationship between volume fill rate and carbon footprint

It is essential to consider that weight also impacts the carbon footprint caused during the meal's transportation, which is related to the volume fill rate and the number of packages that can be transported in a pallet. An estimation of the CO_2e emission per gram of meal transported in the different configurations was calculated and plotted in relation to each case's volume fill rate in Figure 19. The details on the distance and type of vehicle considered for the calculations are presented in Appendix F. A correlation factor of -0.86 was calculated between these two factors, which presumably show the negative correlation between the volume fill rate and the carbon footprint of the meal. This result is interesting to analyze, as the graph shows that improvements in the fill rate in any tray model (indifferently from its capacity) might imply a reduction of the carbon footprint caused per gram of meal transported. Even small increases in the fill rate (5%) might reduce 10 g CO_2e per kilogram of meal transported. More analysis is needed to validate the accurate values. Nevertheless, the company has an opportunity to reduce the indirect environmental impact by increasing the fill rate (even for a small percentage). The order size and the truck's capacity for transporting the shipment could limit the opportunity of reducing the carbon footprint indifferently for small or large companies(Molina-Besch, 2017).

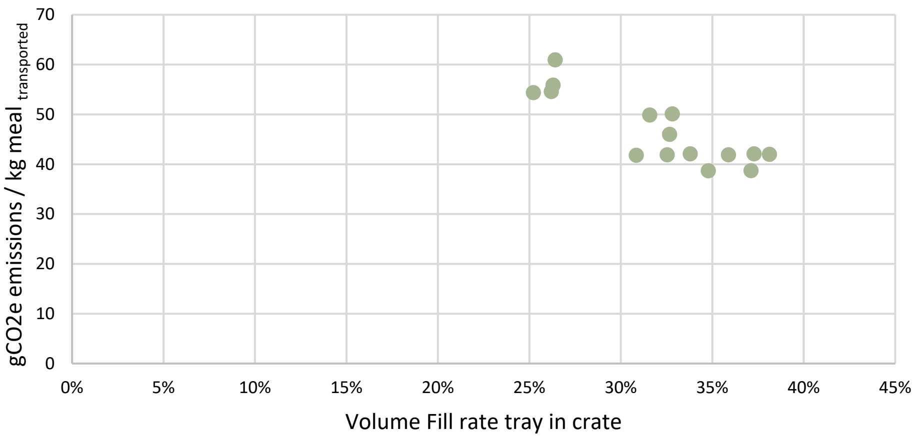


Figure 19. Scatter plot of CO_2e emission during transportation per kilogram of meal vs. Volume fill rate of the combinations studied

4.2.5 Main remarks of the section

- The requirements that Micvac currently considers during the tray design process include production, product, and customer requirements. There is an intention to include environmental requirements due to consumers' requests, a consequence of the increasing awareness.
- The main constraints on getting new trays models into the market are financial, as small customers cannot invest in new molds. However, there is a potential for designing based on consumer needs.
- The current fill rates of the Micvac portfolio vary from 25-38%. There are opportunities for increasing the fill rate of the current Micvac trays. As an example, it was shown that for sample B there is a 44% of the void space that could be avoided if changes in the handles are made.
- Increasing the volume fill rate shows that lower GHG emission per kilogram of meal transported can be achieved. Even small increases have an overall impact. There is an opportunity of reducing the environmental impact if the fill rates of the current packages are increased.

4.3 Analysis of logistic requirements that could help reduce the environmental impact

The inclusion of logistic requirements strives to consider needs related to transport efficiency, storage, and material handling. The research focuses on including requirements that could help improve the transport efficiency of the package. Nevertheless, implications of considering storage and material handling requirements are also included in the analysis. The following sections present the results of the analysis based on the empirical data collected in the previous sections. It also includes an example of how these requirements can be included to redesign one of the sample packaging systems analyzed in 4.2.4.

4.3.1 Transport requirements

After packaging material and waste handling, transportation has been identified as a contributor to the carbon footprint generated in the supply chain. In this context, it has also been found that the fill rate of the packaging system has an overall effect on the emissions per tray. To increase the fill rate in the system, the dimensions of the current crates used as secondary packaging should be considered in the design process for the primary packaging. This will enable a higher fill rate of the current system when the order size matches the quantities in each crate. Additionally, the inbound transportation of the packaging material can be reduced if the distance is decreased, which implies considering tray suppliers in Sweden. These requirements might not be included in the design itself but should be included in the supplier's selection to reduce the environmental impact. As the current supplier uses reusable steel cages for shipping the trays from a long-distance location, it is possible that recyclable transport packaging might have a lower environmental impact, as observed in previous research (Pålsson, Finnsgård and Wänström, 2013). Further analysis is needed to fully evaluate different transport packages, which are not in the scope of the research.

4.3.2 Storage requirements

The storage requirements are related to the warehouses used along the supply chain and might not significantly impact the tray design. The tray is stored in two conditions: with and without food content, where the most energy-intensive period occurs under refrigerated conditions at the FM, DC, Retail store, and consumer refrigerator. However, the primary package only interacts with the consumer refrigerator, and secondary and tertiary packages are the ones that need to be adapted to the warehouses in the other parts of the supply chain. The latter has a modular design; therefore, it is expected that the shelving zones are designed to fit the containers. General guidelines for warehouses state that the size of shelving zones must depend on the type of product, type of cargo units, and additional aspects (Zajac, 2016). Moreover, specific guidelines for packaging have been design by suppliers and retailers in Sweden to ensure that the packaging designs are adapted to storage areas (ECR Sweden 2018). Finally, as there is significant variability in refrigerator designs, it might be challenging and not much beneficial to include these requirements in the tray design process.

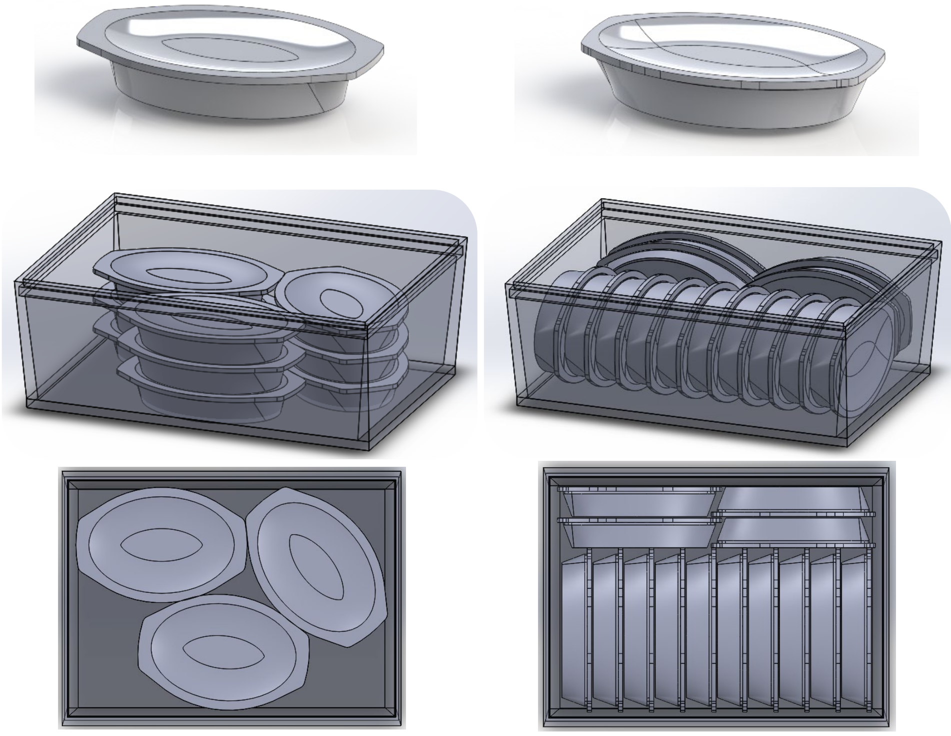
4.3.3 Material handling requirements

Regarding material handling requirements, a similar scenario is identified, as the secondary and tertiary packages are the ones that interact the most along the supply chain and are already adapted to the transport vehicles used. Nevertheless, the primary packaging does interact with the packing personnel in the FM during manual packing, which gives flexibility to the possible configurations that the trays could have in the crates. This aspect could be considered when choosing the best arrangement. Additionally, as the consumer handles the packaging during preparation and consumption of the product, it would be interesting to look at the consumer needs related to the design that could improve the handling of the package while it is hot. This aspect might be more related to user-friendliness than material handling; therefore, no specific requirements are suggested.

4.3.4 Example considering transport requirements

As an example of the potential improvement that applying logistic requirements could bring for Micvac, a specific case was analyzed. Tray sample A in crate size Y was studied, which correspond to an oval tray design for 330 grams of ready meal in one of the most used SRS crates in the market (Half-size 120 red crate). The transport requirements taken into consideration are the crate dimensions, as the crate is used as transport packaging for the studied trays. The results from *4.2.4.2*. were used for the analysis as tray Sample A corresponds to the same design as Sample B (in Figure 18) with a diminution in height.

Based on the crate dimensions, it was identified that the reduction of the tray width will allow the trays to be stacked horizontally instead of vertically (as depicted in Figure 20). Additionally, the length of the tray was kept, but the handles were reduced by expanding the inner volume of the tray in this direction. These changes allowed fourteen trays to fit in the crate, resulting in a volume fill rate of 47%, compared to a previous nine trays with fill rate of 33%. Additionally, the weight load factor in the truck is also increased from 64% to 88%, increasing the number of trays per pallet from 576 to 876. This improvement also allows reducing the carbon footprint per gram of meal transported from 15.17 gCO_2e to 10.25 gCO_2e for a 320 g meal if the same distance and transport mode used for the calculations in section 4.2.4.3. are utilized. These results can also be presented as a reduction from 0.046 gCO_2e/g meal to 0.034 gCO_2e/g meal, which also shows a reduction of the GHG emissions per gram of meal transported. The trade-off in this preliminary study relies in the reduction of the volume that a tray could hold. This was estimated to be approximately 10 g less that the original tray. Further tests should also be performed to check if the proposed changes do not affect the tray performance during the cooking process.



a) **b)**

Figure 20. a) Before and b) After tray design if logistic requirements are included in the design process

4.3.5 Main remarks of the section

- Including transport requirements when designing the trays might increase the fill rate and reduce the indirect environmental impact. This involves considering the crate size when developing new trays in the Swedish market. The latter is related to the unitization and apportionment function of packaging, as the practical impact would depend on these aspects. Additional improvements can be made if suppliers located in a shorter distance are chosen.
- Storage and material handling requirements do not seem to significantly impact the tray design from a logistics perspective, as the primary interaction occurs with the secondary and tertiary packages. Improvement opportunities can be identified in the consumption phase, which would

involve further studies in consumer research and user-friendliness of the product.

- A draft design shows a potential of including transport requirements in the design process to increase volume fill rate, truck weight load factor, and reduce the carbon footprint per gram of meal transported.

5 Discussion

The section discusses the results of the previous stages and analyses how the logistics requirements can be added to the packaging development process to reduce then environmental impact in the supply chain. The opportunities and challenges in the process are summarized and critically discussed.

5.1 Environmental impact along the supply chain

RQ1 looks to understand how the Micvac tray design affects the environmental impact of the packaging along the supply chain. Packaging design involves not only the form, but also the material that is used for the package. Based on the results obtained, there are three main aspects identified that determine how the tray design might impact the GHG emissions:

1. Maximum possible fill rate in the packaging system due to form characteristics
2. Possible miss match between the maximum number of primary packages that could fit in a secondary package compared to the retailer's order size.
3. Packaging material

The first two aspects are directly related to the transport impact along the supply chain, while the third one refers to the environmental impact caused by the production and incineration of the packaging material. Sanyé-Mengual *et al.* (2014) found similar results when they analyzed meat trays, as they found that focusing on design and packaging materials could have positive results on reducing the environmental impact of the packaging. Moreover, the aspects identified are also related to the different directions presented by Hellström and Olsson (2017) for sustainable packaging design, addressing 1) Fill rate problems, as well as 2) Apportionment aspects and 3) Material Use. The three identifies aspects are further discussed in the following sections.

5.1.1 Primary package form's impact in fill rate

The primary packaging design has an impact of the fill rate on the different packaging levels. Even though the product has a 100% fill rate in the primary package, it was observed that values of 25-38% were calculated in the secondary packaging level. The package was analyzed to further understand which components (tray, lidding film, and valve) have the highest impact on the fill rate, leading to higher carbon footprint of the packaging system.

The shape defined for the primary packaging impacts its component's environmental impact in different proportions. Results have shown that the impact for transporting the lidding film reels and valve reels is relatively low compared to the tray's impact in the supply chain. It is challenging to compare this aspect with results in literature, as researchers usually group the impacts of each packaging component in the results (e.g., Schmidt Rivera *et al.* (2014)). If the whole supply chain is considered, the impact of the tray design is observed in a larger section, as it determines the fill rates when the packed product is transported.

The possible constrains for increasing the fill rates of the packaging system analyzed (primary packaging in secondary packaging) to 100% could include details related to production requirements and design decisions. Figure 21 can help visualize the analysis using the combination of tray Sample B in crate Sample Y presented in Results section *4.2.4.2*. If all the areas of the crate were supposed to be filled, the packages should have a prism shape to be able to occupy all the void space (green area in Figure 21). Moreover, as the width of the create increases with height, the ideal prisms should also change in size to fully cover all the areas. This is not possible as all the packages should be the same size, and a design with sharp corners will provoke flaws during the cooking process leading to a burned product. Additionally, as the tray should have handles to carry the product while still hot, they also create empty area under them, which also limits the maximum fill rate that could be achieved. Nevertheless, there are some strategies that could be used to increase the fill rate, which were used in section 4.3.4., which include changing the direction of the piled crates and put every other package in a different direction to avoid overlapping of the handles.

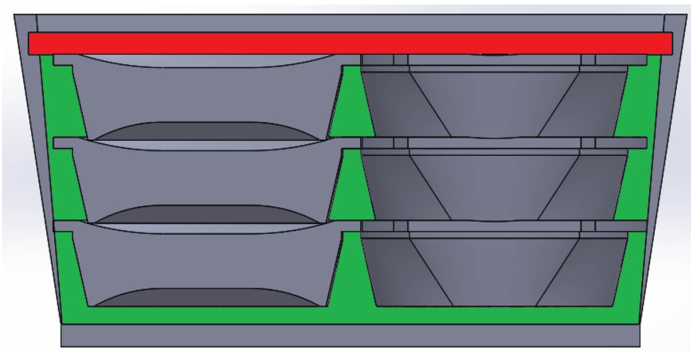


Figure 21. Cross section cut (middle of the crate) of tray Sample B in a crate Sample Y where the green area shows the void space, and the red line shows the maximum height to allow stacking.

The fill rate results of the trays in the crates (25-38%) can be compared to other food products' packaging systems from published literature. García-Arca, Prado-Prado, and Gonzalez-Portela (2014) presented a case where a packaging re-design achieved an improvement from 44% to 49% volume fill rate for food products in a supermarket chain in Spain, which resulted in the reduction of GHG emission and saving for the company. In a case presented by Hellström and Olsson (2017, pp. 132–139), values of around 45% volume fill rate were observed from elliptical ice cream containers in boxes. Putting the Micvac trays into context, they appear to be performing better than some ready meal trays on the Swedish market (18% and 29%), but worse than some food products published on literature. However, this result must be taken with care, as it is possible that other packaging options are performing better in other aspects not studied in the scope of the research.

The secondary and tertiary packaging levels were not a specific focus of the study. However, they form part of the packaging system, and their characteristics impact the overall fill rate and transport efficiency. It was observed that co-distribution is a strategy applied by actors in the supply chain, such as Micvac and Scandiflex AB, to deliver small orders to the food manufacturer. Co-distribution is a good strategy for transport optimization used for small delivery size shipments (Molina-Besch, 2017), especially when standardized packaging is used. Additionally, it was observed that the transportation is done by specialized transport companies, which decide the truck size to be used based on the needs of several customers across Europe. This could bring benefits, as previous research (Hosseini and Shirani, 2011) show possibilities of improving the fill rate when the transport companies implement capacity planning strategies.

The use of EUR pallets enables the reduction of wasted space in a truck level. As explained by Pålsson (2018, pp. 21–22), packaging standardization can help increase cubic utilization at a truck level. Therefore, designing modular secondary packaging to fit EUR pallets can assure high fill rate levels if trucks are also standardized. Consequently, if SRS crates are already designed to fit EUR pallets and transport companies currently use transportation with certain level of standardization, designing primary packaging to fit the secondary packaging is of crucial importance to complete the packaging system design.

The Micvac tray design affects the maximum fill rate that could be achieved by the packaging system in the supply chain. The height, handles, and oval shape of the different design generate empty space in the secondary crates. Adapting the packaging for transport efficiency was previously proposed by several authors (e.g., Grönman *et al.*(2013)) in their frameworks of sustainable food packaging design. The opportunities identified in the results are aligned with the expectations discussed in literature for including additional requirements in the design process.

5.1.2 Apportionment and fill rate

Molina-Besch (2017) has highlighted the importance of matching the order size with the transport and packaging capacity, which impacts the load factor and ultimately the indirect environmental impact caused by transportation. If the order size per crate is lower than the maximum number of packages that could be fitted, this will lead to a low fill rate despite of the efforts during the packaging design process. One actor in the supply chain was observed to drive the order size, impacting the packaging fill rate in the transport route with the highest emissions, the retailer. This actor has control over the quantities that each crate must contain when delivered to the DC and the retail stores. These requirements are based on the purchasing behavior of consumers at the stores, which are the ones that demand the products. If a product is available in the smallest store format of the retailer, the number of packages per crate should be matched to their needs, therefore the retailer will ask for relatively small quantities per crate. If a product is available only on the bigger store formats, there is a possibility to use bigger crates as the store have bigger order sizes. As Gooh AB ready meals are available in small store formats, the retailer requires at the moment only six or nine packages per crate depending on if the specific recipe is highly demanded by consumers. Store can only order multiples of this values, as there are no repacking processes in the warehouse at this packaging level.

Optimizing packaging apportionment based on consumer needs was presented by Nilsson, Olsson and Wikström (2011) as part of a framework for sustainable goods flow. The authors evaluated the pros and cons of optimizing the packaging apportionment for the actors in the flow of goods, where less waste of product was highlighted as an environmental benefit for the retailer. In this context, it is logical that the retailer put constrains on the maximum number of primary packages per crate, as they strive to avoid food waste at a store level. Results have shown that the food content accounts for 88% of the GHG emissions per tray in the supply chain analysis. Therefore, it makes sense to prioritize avoiding food waste in this matter, with a possible trade-off of having more empty space in a crate. According to Molina-Besch (2016) prioritization guidelines for green packaging design, avoiding food waste should be the priority over the other guidelines for products where food production accounts for a large proportion of the overall environmental impact. Some trade-off that apportionment prioritization might bring, according to Hellström and Olsson (2017, pp. 153–154) include an increase on social consequences due to additional manual handling as the number of packages to handle are higher than in bulk-shipping. However, in the case analyzed, the reason behind fixing the order size based on the smaller store intends to reduce the material handling work in the DC, as no repacking is needed after the reception stage.

As there is a wide portfolio of modular crates that could be used, it is still possible to design taking into consideration both aspects: good apportionment and fill rate. Unitization is related to this aspect, as modular packaging helps the retailer, who handles a wide range of product, improve the overall fill rate during transportation. It was found in the results that mixed roll containers are used to transport the ready meals to the retail stores, which improves the fill rate at this point of the supply chain. Unitization and apportionment are related with fill rate in this level, as these two determine the real fill rate of the distribution trucks. The communication of these needs from the retailer to packaging designers, and not only to the food manufacturer, could help improve and lower the environmental impact of the packages.

5.1.3 Packaging material

Based on the percentage contribution to the carbon footprint of the factors analyzed in the study, the focus should be on prioritizing alternatives for the packaging material and packaging waste. However, the protection capacity of the packaging should not be compromised, or else the environmental impact of the food waste generated could surpass the potential reductions of the packaging's direct environmental impact. The latter is aligned to the Prioritization guidelines proposed by Molina-Besch (2016). Minimizing food waste of complete meals is a priority, where aspects such as apportionment and packaging shape could have an impact. Regarding waste handling, the high values in Micvac's analysis are related to the consumer's low values of plastic sorting. This could be overcome by improving the communication with the consumer and the recycling companies, so the materials used are suitable for the recycling processes available. The latter has not been widely studied yet, but literature presents a great opportunity of including this collaboration as part of the packaging development process (de Koeijer, Wever and Henseler, 2017).

5.1.4 Additional observations

The current configuration of the lidding film reels in the pallets seems to be not the most efficient. The pallet area can hold up to 8 reels instead of 6 currently used. If changes are made in the packaging system, the pallet could hold more reels, which also increases the weight. This could lead to fewer pallets but the same number of reels being transported, leaving more free volume in the shipping area. The potential implications of a change in the pallet configuration involve less warehouse space for storing the reels and less pallets to handle, similarly to the findings discussed in case studies published by Hellström and Olsson (2017, pp. 125–131). However, this was discussed with the packaging supplier company, and it might seem that this configuration could have problems as it needs to be carefully aligned to avoid overhanging.

5.2 Packaging design at Micvac

RQ2 strives to identify the requirements that are currently considered during the process of designing new tray models at Micvac. Three main requirements were identified:

1. Production requirements
2. Product requirements
3. Customer requirements

Production requirements are related to the core business of Micvac AB, as the functionality aspect during the in-pack pasteurization process is key for safety and quality reasons. Designing a packaging that would go through a microwave pasteurization process involves specific requirements that have an impact on the tray design. The design process at Micvac considers the same packaging requirements presented by Ohlsson and Bengtsson (2001, pp. 106–109). The authors highlight that the material should withstand temperature stability up to 120°C, which the packaging material complied. It also asks for microwave transparency, which the materials have, and fat and moisture stability, which the datasheets claim to comply. Additionally, the authors mention that form stability in handling, geometry, and ease of opening are important requirements for packaging that go under microwave heating. Going back to Micvac's packaging design process, one of the main constrains they found during the design process is to design shapes without sharp corners to avoid burns in the cooking process. This is related to the geometry aspect mentioned by Ohlsson and Bengtsson (2001, pp. 106–109), and is are the main considerations that the packaging designer should take. Prioritization on the functionality of the packaging during the design process was identified as the main reason the current packaged have an oval-round shape. A trade-off of this design is related to the empty space in the crates, that was mentioned in section 5.1.1.

Product requirements can vary greatly, as Micvac customers (food manufacturers) produce a wide range of products and recipes in the same tray design. The requirements considered in this case are not restrictive, as the tray should be able to work for different products. Nevertheless, some guidelines for microwavable products presented in literature (George and Burnett, 1991; Olsson and Larsson, 2009) mention that it is important to have a collaboration between the food manufacturer and the packaging designer during the food development process. Micvac guides the clients to improve their recipes to make them "microwavable" so the tray design and the recipe could create synergies and enable the product to be suitable for the process.

Olsson and Larsson (2009) discuss that product developers tend to mainly focus on functionality aspects, ignoring the potential value-adding elements that could be achieved with a more innovative perspective. The authors mention that the latter could result in a more environmentally friendly product, which highlight the benefits of considering the package shape as part of the consumer experience. Even though this appears to not have direct connection with logistic requirements, in fact every change that is done in that packaging design have repercussions for all the actors that handle the product. The observations discussed by the researchers are seen in Micvac's case, as the consumer perspective was not part of the design process in the previous years. Their technological focus is reflected on the requirements that they considered during the design process. The company is gradually including these additional requirements, which is related to the suggested guides by Olsson and Larsson (2009). Additionally, the authors also mention that packaging optimization for reducing the environmental impact should not only focus on material reduction, as the product quality should not be sacrificed for this sake. Consumer requirements should be critically assessed, as their perception of what is environmentally friendly not always have a life cycle perspective. As Micvac is starting to include consumer requirements more seriously, it is important for the company to pay attention to the suggestions in literature and critically assess results obtained in consumer research.

In general, the requirements considered by Micvac during the packaging process are insufficient for creating a food packaging design that strives to reduce tits environmental impact. Grönman *et al.* (2013) proponed a framework for sustainable food packaging design, where they includes an evaluation of the packaging materials to ensure they are not only safe for the user, but also to the environment. Micvac could include these requirements when assessing different materials during the packaging design process. Grönman *et al.* (2013) also proposes to make preliminary trials to check the compatibility of the different levels of the packaging system. This test is related to logistic requirements, as the compatibility between levels will also determine the fill rate that could eventually be achieved in the system. García-Arca *et al.* (2014) has shown that considering logistic need in the supply chain can have environmental and economic benefits for different actors in the supply chain.

Additionally, simplified environmental assessment tools were presented by Molina-Besch and Pålsson (2020), which suggest to do a final evaluation on four main aspects: Packaging material, Transport efficiency, Packaging end-of-life, and influence on food waste. This tool could also be applied by Micvac on posterior steps to help on the selection of designs that are more likely to reduce their environmental impact.

5.3 Inclusion of logistic requirements in the packaging design process at Micvac

RQ3 looks to understand how logistic requirements can be included in the current packaging design process at Micvac, with the desire to improve transport efficiency. Based on the results presented in section 4.3. the logistic requirements that could be prioritized to be included in the design process correspond to transport requirements due to their potential to reduce the current carbon footprint based on the GHG emission calculations presented.

Focusing on logistic, the presented requirements have been previously suggested to be part of the design process by different authors either as an evaluation tool or as a requirement for environmentally friendly packaging (Svanes *et al.*, 2010; Azzi *et al.*, 2012; Grönman *et al.*, 2013; García-Arca, Prado-Prado and Gonzalez-Portela Garrido, 2014; Molina-Besch and Pålsson, 2016; Hellström and Olsson, 2017; Molina-Besch and Pålsson, 2020). The integration of the requirements is crucial for pursuing environmentally friendly packaging and reducing the indirect environmental impact that is not involved in the production or end-of-life of packaging material. Inbound transport distance, mode, and load efficiency have been identified as crucial evaluation points by Molina-Besch and Pålsson (2020), as well as outbound transport weight and volume efficiency. Therefore, the criteria for selecting packaging suppliers should be included as part of the evaluation in strive for more transport-efficient packaging. In this way, the environmental aspect of the primary packaging could be considered, and the negative impact addressed.

It is suggested for Micvac to take a leadership position in the supply chain by focusing on packaging logistics. The latter can have not only environmental benefits but also cost benefits for different actors in the supply chain, as shown in the case studies from a Spanish retailer (García-Arca, Prado-Prado and Gonzalez-Portela Garrido, 2014), Swedish retailer IKEA(Hellström and Nilsson, 2011), and manufacturers such as Volvo (Pålsson, Finnsgård and Wänström, 2013). Collaboration between parties is an essential aspect of this analysis; without an information-sharing focus, there is little opportunity of reducing the environmental impact of the operations. In this case, valuable information regarding the specific packaging systems that Micvac customers and retailers use gave important insight to design based on transport needs.

Translating the results and discussion into a practical approach for Micvac, a simplified line of action is summarized here. When the company starts a tray design project (either based on identified trends or customer requirements) apart from gathering information about the production and product requirements, they should think about the transport packaging that will be used for their design. This is done during the "idea generation phase", which is conducted when they get insights from customers and other sources. Taking the Swedish market as an example, once the customer describes the type of product that should be contained and the characteristics of the microwave oven they use, it is essential for Micvac to get to know if the customer will be using SRS crates for transportation or an alternative to this. As SRS crates are used by the big retailers in Sweden, it would be a safe choice to consider these dimensions in case the customer does not have this information at the moment. With these preliminary characteristics and dimensions, it is possible to either search for similar design in Faerch's catalog, or design one from scratch. Once the sample is done, production tests should be conducted with the product that will be packed, as well as usability tests with consumers. These tests are performed during the "feasibility assessment" phase, that is present in the Micvac development process. Based on the results a new proposal might be developed and tested before the final roll-out. In case changes in the packaging material are proposed, additional research should be done with the waste handlers to ensure that there is a system for disposing the new material that is not worse than the current PP trays. This is country specific and should be taken with care and tested properly.

5.4 Opportunities and challenges

Different opportunities and challenges were identified for including logistic requirements in the tray development process at Micvac. An analysis of the implications in other areas of the supply chain were also discussed when appropriate. As the research aims to include these requirements to reduce the indirect environmental impact of the chilled ready meals, the points are discussed in this context. A summary of the opportunities and challenges is presented in Table 11.

Table 11. Summary of opportunities and challenges identified.

Opportunities	Challenges
• Reduce the carbon footprint caused by transportation by increasing the fill rate • Increase the fill rate by reducing the empty areas caused by the handles • Improve relationships with actors in the supply chain, such as retailers, to optimize for apportionment and increase fill rate	• Obtain information related to the order size and projection from the retailer in Sweden and in other markets • Test the new design to be sure that the new model does not reduce functionality for the consumers

5.4.1 Opportunities

GHG emissions generated during transportation can be reduced by including transport requirements in the tray design process and increasing the fill rate. This reduction occurs as more trays will be transported by the temperature-controlled trucks, reducing the carbon footprint per tray. As the SRS crates are used by the biggest retailers in the Swedish market, the impact of considering the crate dimension in the design process can be multiplied. In order to increase the fill rate, the dimensions of the primary packaging should be adapted to the available SRS crates, following the proposition made by Grönman *et al.* (2013). These crates already follow the recommendations by Santén (2012) as they are modular and stackable, which contribute for transport efficiency in this packaging level.

Communicating these configurations to the customers to ensure they are applied is key for the success. By taking a leadership role in the supply chain regarding packaging logistics, the relationships with the different actors could be improved. Collaboration with the big retailers is vital to get the information on the order points and the forecasts for considering the actual applicability of the designs. Moreover, reducing the number of crates used during transportation may have a positive effect on aspects as energy and water consumption for the retailer, which are not considered in this research.

Considering that the company does not only operate in Sweden but provides packaging across the works, there is an opportunity of increasing the reduction of the impact across borders. Evaluating each market and the supply chains in each country might give great insight, as one packaging solution might not fit all.

5.4.2 Challenges

Trucks might not always be fully loaded as their shipment depends on the retailer's order. Reducing the impact will depend on market variables and order planning, which Micvac does not control. Acquiring knowledge to obtain a design that will also respond to apportionment needs depends on the level of cooperation between actors in the supply chain is achieved. Cooperative models have been proposed as part of sustainable practices in supply chain management (Zimon, Tyan and Sroufe, 2019). Cooperation between actors must be prioritized, which could be challenging in different contexts. Investing in building a cooperative relationship can lead in a competitive advantage for the company (Brody *et al.*, 2008).

Customized tray designs for minor players in the market might not be economically feasible for the customers due to the significant investment in the molds needed. These challenges are being faced by adapting preexisting tray models from the supplier, which might not always fulfill the transport requirements. The strong relationship with the current supplier might keep Micvac from looking for other suppliers inside the specific market attended.

Finally, as packaging design has an impact on consumer perception and on the sales of the product (Olsson and Larsson, 2009), the changes made should be tested with the consumer in usability and acceptance tests. This could be challenging as it needs collaboration with the Food Manufacturer to be successfully made.

6 Conclusions and Suggestions for future research

The answers for the three research questions are presented below, along with the theoretical, practical, and social implications of the research. Recommendations for Micvac and further suggestions for future research are also presented in the chapter.

6.1 Conclusions

The opportunities and challenges of including logistic requirements in the packaging development process at Micvac for reducing the indirect environmental impact of chilled ready meals' packaging were successfully identified and explored.

During the process, it was identified that the packaging design has an impact on the environmental performance along the supply chain, proving what was suggested in literature in a real case context. The packaging design has proven to have an impact on the transport fill rate, and transport efficiency currently accounts for 22% of the CO_2e emission generated along the Micvac's supply chain (if the food production is not considered). This information was not previously available for the company, and it could impact the drivers they choose when aiming to reduce their environmental impact. The company now knows that the current packaging material production is the factor that contributes the most to the GHG emissions, followed by waste handling (due to low consumer sorting), and transport along the supply chain.

Moreover, it was identified that Micvac currently considers only product, production, and customer requirements. In this sense, the possibility of including logistic requirements to lower their environmental impact is recommended based on the analysis of their current portfolio. Micvac's current packaging have fill rates of 25-38% in the SRS crates used for the ready meal's category. This is valuable new information that could help them improve and see the opportunities for increasing these values.

Opportunities on increasing the fill rates by redesigning the packaging were identified if transport requirements are included during the design process. By considering the secondary packaging in which the packages will be transported the fill rates can be increased. Nevertheless, some challenges identified involve the lack of control on the order size from the retailer's side. This could be overcome by increasing collaboration with them during the design process and share information of the forecasted sales for the category.

The theoretical implications of these findings are related to a better understanding of the relationship between fill rate and apportionment on secondary packaging, which was not deeply highlighted in previous studies. It was found that it is crucial to consider the crate order size (the retailer's needs) to ensure that the maximum fill is achieved in practice. This means that designing the trays only based on the secondary packaging, without considering the number of products that are needed to be transported per crate, may not reduce the environmental impact. Cooperation between the actors is imperative to understand the needs and requirements along the supply chain. This means that the retailer should communicate with the team in charge of packaging design to give insights on purchasing behavior for perishable products. This enables designer to match the maximum number of trays that can fit per crate with the actual number demanded by the retailer to be fitted. Additionally, the contribution of this empirical study can also help to have a better understanding on the challenges of including logistic requirements in ready meal's packaging in practice. Even though packaging material is the main contributor of the carbon footprint in the present study, the struggle to find alternatives that could withstand the temperatures needed for microwave pasteurization, and authorized for food contact, are scarce. Moreover, the challenge of increasing the fill rate and considering the recommendations for microwave cooking appear to be challenging without more updated information on the heat transfer behavior with current microwave oven designs, as the literature available might not be the most recent.

The practical implications of the results are related to the applicability of the finding to Micvac's case. Taken into consideration the crate dimensions during the packaging design process can be easily done if SRS crates are considered, and an example and how can this be applied showed an increase from 33% to 47% in the present study. However, it will be challenging to get insight to ensure that the apportionment of the trays per crate are aligned with the retailer's demand. Additionally, other companies in the field can learns from the findings in this study and take advantage of the potential benefits found.

The social implications of the study are related to the purpose of the research, as striving for the reduction of negative environmental impact is directly related to the survival of society and future generations. Reducing the environmental impact of chilled ready meals through packaging design is directly related to the environmental aspect of sustainable design for sustainable development. In Hellström and Olsson (2017) addressing Fill rate problems in the packaging system is a direction of the compass, as well as Protection, Material Use, Apportionment, User-friendliness, and Information & Communication. The main impact is related to the Planet and Profit aspects of sustainable design, as less transport and less use of secondary reusable crates imply less use of other resources such as water, less cold warehouse volume needed per tray, and less handling of pallets which reduces costs. Nevertheless, these efforts are to be combined with additional aspects to pursue sustainable development of the generations.

The United Nations established the Sustainable Developments Goals in an effort to align global efforts to collaboratively address different issues affecting the world related to the three dimensions of sustainable development (United Nations, no date). This research aims to reduce the climate impact in the packaging industry, which could be related to SDG 13: *Take urgent action to combat climate change and its impact,* and SDG 12: *Ensure sustainable consumption and production patterns*. Increasing the fill rate of the packaging system might reduce the greenhouse gas emissions per tray transported, contributing to target 13.2 of integrating climate change measures in the packaging industry by integrating environmental requirements in their design process. The results of this research will help Micvac identify a course of action for reducing their impact and showing their commitment to these goals with practical changes in the future design of their trays. Nevertheless, further effort is needed to keep addressing this goal and target 12.2 on efficient use of natural resources, as the main carbon footprint generated in the industry comes from fossil fuel-based packaging materials production and combustion due to low sorting and recycling levels. By addressing the two aspects presented, it is possible to contribute even more to this goal.

Some limitations of the research are related to the research design. As a case study research was conducted, there are limitations on the type of analysis and degree of confidence the results can offer. Statistical analysis cannot be performed with the type of data gathered, which limits the possibility of generalizing the results. Additionally, even though one representative of each supply chain actor was reached, the results are limited to their sole perspective, and does not consider the different areas within each company. Because of the COVID-19 pandemic, the possibility of doing observations regarding material handling and storage conditions along the supply chain was limited (e.g., the food manufacturer did not allow visits). The latter also limits the study as no additional details that could complement or cross check the information obtained during interviews could be gathered.

6.2 Recommendations for Micvac AB

Based on the results and findings of the thesis, it is recommended for Micvac AB to consider logistic requirements during the packaging design process. Designing the trays based on the available SRS crate dimensions in a good track for improving the fill rate and eventually reducing the environmental impact during transportation. It is also advised to collaborate with the retailers and food manufacturer to get insight about the order sizes and improve the apportionment for these actors. This action can help to ensure that the efforts put into designing based on logistic requirements have a real benefit in the supply chain. The logistic requirements should be included at the start of the design process along with production, product, and customer requirements. Nevertheless, logistic requirements should never compromise production or product requirements, as neglecting the last two can provoke food waste or food safety issues (such as poor cooking or burnt edges).

It is also recommended to research more on packaging materials that could help them reduce the current impact. Changing to new materials should be taken with care, as they should provide similar barrier properties and be adapted to the country-specific waste management systems. Collaboration with the food manufacturer to ensure that proper communication of recyclable characteristics and disposal guidelines is crucial for reducing the overall environmental impact of the current or future material selected.

6.3 Future research

Results show significant opportunities of reducing the environmental impact by exploring less resource-intensive materials that could be used without compromising the shelf life and protection of the current materials used. Additionally, alternatives to PVC could be evaluated as the waste generated from the valves are currently being incinerated and PVC does not only generate GHG emissions when burned, but also additional components. Regarding packaging end-of-life, it appears that the main challenge is on communicating the recyclable aspect of the tray. Further research could be done in this aspect in relationship with consumer research and collaboration with the food manufacturer, as they decide the label designs that impact on consumer behavior.

Studying market trends on ready meals in collaboration with food manufacturers and retailers can help get a better understanding of the order dynamics. As the order size significantly influences the ability to acquire high fill rates, it is essential to understand this phenomenon and evaluate how stable they are to guarantee that the transport requirements will not vary significantly. This is important to be able to apply the findings in this report fully.

Additionally, further research could be done on the nutritional value of the ready meals sold to reduce the weight of the meal without compromising the value and reducing food waste. The weight that the current trays hold depends on the meal contained; therefore, there is an opportunity or research related to the nutritional value of the meals sold and how to reduce the weight and volume that should be transported. Consumer requirements can also be studied, so the packaging size and meal weight could also help reduce the food waste of unfinished ready meals. Moreover, as the environmental impact of the ready meal is related to the location of the ingredient providers, further analysis could be done by including the transportation of the ingredients in the methodology. A life cycle assessment could be performed to identify areas of improvement and detailed information on other environmental aspects not covered in this research.

Packaging for food products that need to go under in-package microwave pasteurization process have important constrains due to the heat transfer phenomena during the process. More research can be done to fully understand the internal heat transfer behavior in different packaging geometries and designs. The latter can also be combined with research on different recipes with varied water and salt content. Even though there has been research on this field, it might be interesting to evaluate how the use of the evacuation valve can influence the heat transfer phenomena using the Micvac microwave ovens.

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Appendix A Project plan and outcome

The project plan can be observed in Figure A.1, while the outcome is depicted in Figure A.2. The overall time structure was maintained during the process. The data collection process lasted longer than expected because of the lack of time available from the actors in the supply chain. However, other tasks that did not need the results from these data were carried out parallel to prevent the project from delaying.

Additionally, to improve the feedback process, additional sessions with the supervisor were scheduled along the timeline when needed. The latter is pictured in the diagrams, which become more frequent as the deadline for the final draft approached.

Overall, the project was successfully managed along the process, all the challenges that appeared were overcome, and additional effort was put in when needed.

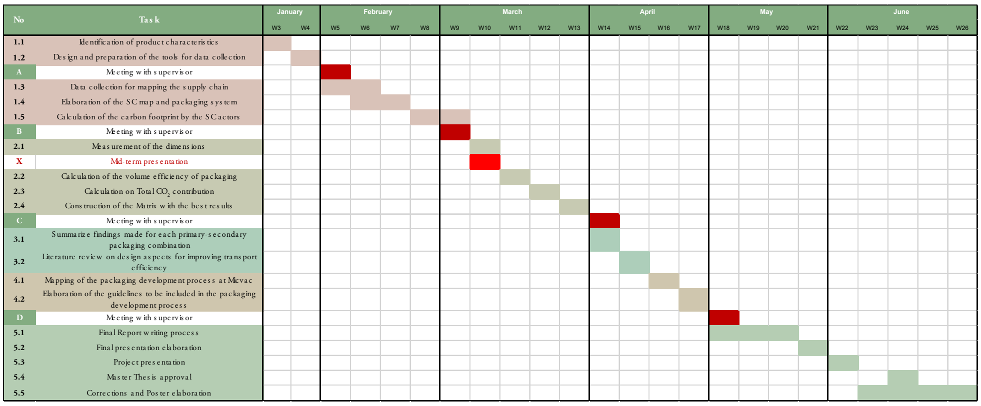


Figure A.1 Project plan

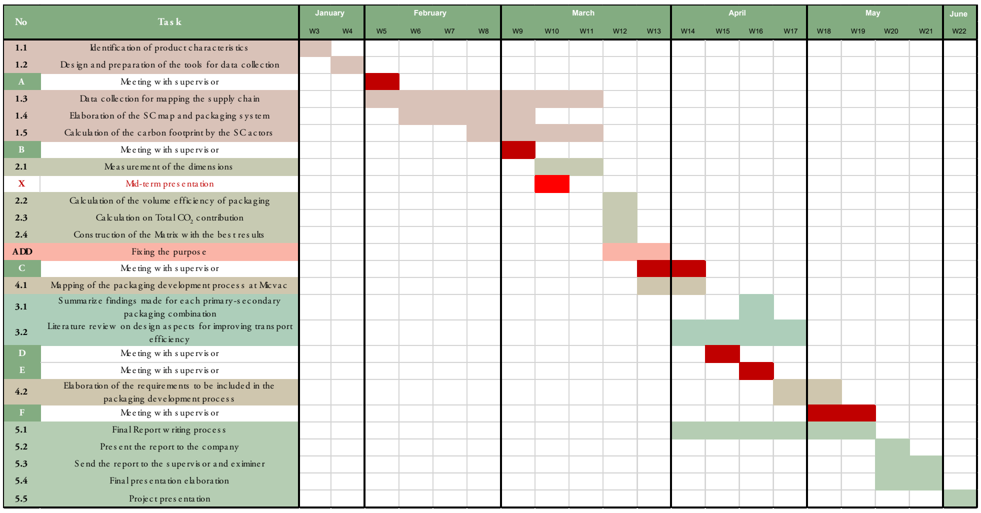


Figure A.2 Project outcome

Appendix B Data collection tools

B.1 In-depth interview guide

A single in-depth interview was conducted in the present research with the purpose of mapping the product development process at Micvac, the company that was subject to the case study. The following questions were used as a guide when addressing the person that has overseen the tray design process for the following 15 years. Before the interview, the intention of mapping this product development process of the Micvac trays was communicated to the interviewee.

1. Please tell me about your background (education, work experience) and your current position.
2. Can you tell me how the packaging function is organized at your company?
3. Which areas are involved? Is there cooperation between areas?
4. Does the product development process at your company consider logistical needs or requirements? Is the logistics function involved in packaging development?
5. Do you consider any specific environmental requirements?
6. What do you think are the most important measures to reduce the environmental impact from packaging of your products?

B.2 Semi-structured interview guides

B.2.1 Questionnaire for Marketing Director at Micvac related to the Product Development Process

1. Please tell me about your background (education, work experience) and your current position.
2. Can you tell me briefly what are the main functions of the Marketing department at Micvac?
3. Can you explain the role of the Marketing department when a new packaging product is being developed? (At what stage are you involved in the project?)
4. What type of requirements does the Marketing department for the new packaging product that is being developed?

5. Do you consider that the marketing requirements are related to the environmental requirements? Why?
6. What do you think are the most important measures to reduce the environmental impact from packaging of your products?

B.2.2 Questionnaire for Micvac: valve producer – outbound questions

Regarding supply chain characteristics and material flow

1. Can you please tell me about your role in the company and your years of experience?

Overall supply chain

First, I will ask you some questions related to the material handling processes inside Micvac.

2. Can you describe the material flow inside Micvac's operation? What processes concern the inbound logistics?
3. Can you please describe how the valves are handled once they are produced? (Automatic or Manual). Are any special tools used for handling the packaging system?
4. How many valves are packed in one secondary package? Can you describe the secondary and tertiary packaging used?
5. Do you have the data of the carbon footprint of producing the valves?

Transportation

6. How are the valves packaged to be transported to the food manufacturer?
7. Which transportation company is used?
8. Characteristics of the production site?
9. How many pallets fit in one truck?

B.2.3 Questionnaire for Micvac: valve producer – inbound questions

Regarding supply chain characteristics and material flow

1. Can you please tell me about your role in the company and your years of experience?

Overall supply chain

First, I will ask you some questions related to the material handling processes inside Micvac.

2. Can you describe the material flow inside Micvac's operation?

Lidding film

3. How many trays can be sealed with one roll of lidding film?
4. How is the lidding film packed?
5. How many reels fit in one pallet?
6. How many pallets fit in one truck?
7. How much does the roll of film weigh?
8. Where is the lidding film produced?

Micvac trays

9. What are the characteristics of the steel crates used for transporting the Micvac trays?
10. How are these steel crates transported back to Faerch?
11. How long does it usually take to transport the trays from Czech Republic to Lantmännen?

Micvac valve

12. How long does it usually take to transport the valves from Micvac to Lantmännen?
13. Do you have the characteristics of the trucks that are used?

Micvac Packaging

14. Who owns the pallets used in the supply chain?

Suppliers

15. Do you have the information about the production process of the plastic trays?
16. Do you have a contact in Faerch that I can contact to ask some questions regarding the production process?

B.2.4 Questionnaire for Lantmännen: Food manufacturer

The goal of this interview is to gather more information about the processes that are carried out by the actor involved in the supply chain of ready meals manufactured by the Micvac process. The information will be used to evaluate the supply chains in terms of packaging logistics, and the insight will be used for reducing the environmental impact and increasing the fill rate of the packaging system.

1. Can you please tell me about your role in the company and your years of experience?

Overall supply chain

2. Can you please describe the overall process for producing a gooh Ready meal?

3. Can you please describe how is the product handled? (Automatic or Manual). Are any special tools used for handling the packaging system? (Loading, unloading, and storage activities)
4. Do you use any equipment that uses fossil fuel?
5. Do you have the data of the carbon footprint of producing the product?

Transportation

6. How is the product packaged to be transported to the distribution center of the retailer? Can you describe the packaging used?
7. How many products fit in one crate? How many crates fit in one pallet? How many pallets fit in one truck? How are they arranged?

Assuming the product will end up in an ICA Supermarket in Gothenburg

8. Do you have the characteristics of the trucks that are used? What technology is used for refrigerating the cargo?
9. How long does it usually take for transporting the product to the distribution center of the retailer? What are the distances they need to travel?
10. Do you have a contact with the transportation agency?

Current tray design

11. Have you encountered any problems with the current tray design?
12. What aspects do you consider can be improved?

B.2.5 Questionnaire for ICA: Distribution center and wholesaler

The goal of this interview is to gather more information about the processes that are carried out by the actor involved in the supply chain of ready meals manufactured by the Micvac process. The information will be used to evaluate the supply chains in terms of packaging logistics, and the insight will be used for reducing the environmental impact and increasing the fill rate of the packaging system.

1. Can you please tell me about your role in the company and your years of experience?

Overall supply chain

I understand that Lantmännen sends their gooh-ready meal trays in blue and red SRS crates and pallets using Bring as a transport provider.

2. Can you please describe the process for receiving and storing a gooh - Ready meal?
3. Are there changes in the packaging?

4. Can you please describe how is the product handled when picking for delivery to retail stores? (Automatic or Manual).
5. Are any special tools used for handling the packaging system? (Loading, unloading, and storage activities) Are the products depalletized at the Distribution center?
6. Do you have the data of the carbon footprint of the equipment involved in handling this product?
7. What type of energy source is used?

Transportation

I understand that the gooh ready meals arrive at ICA Warehouse at Kungälv and later distributed to the retail stores across Gothenburg.

8. What type of transportation is used for?
9. Do you have the data on how much CO2 emissions are emitted per ton-kilometer transported?

B.3 Questionnaire questions

B.3.1 Email questionnaire for Faerch Plast s.r.o: Tray provider

1. As far as I understand, the trays are transported from your facilities in Czech Republic directly to the food manufacturers. In my thesis, I am studying the case of Gooh-Lantmännen. In this context I would like to make you some questions:
2. Can you briefly describe the manufacturing process for these trays?
3. I understand that the trays are packed in a plastic bag and then on steel cages for transportation. Is this manual or automatic?
4. What is the weight of the steel crates used? How are they recovered?
5. What is the transportation route for the Micvac trays when they are shipped to Gooh- Lantmännen? Do they travel only by road? Do they go by ferry? What is the distance and how long does it take from point to point? What are the characteristics of the transports used?
6. I understand that the shipping conditions might vary from order to order, will it be okay to assume road transport in semi-trailers for my study?

B.3.2 Email questionnaire for Scandiflex Plast: Lidding film supplier

As far as I understand, the reels are transported from your facilities directly to the food manufacturers. In my thesis, I am studying the case of Gooh-Lantmännen. In this context I would like to make you some questions:

1. What are the dimensions of the lidding film reels for this customer? How much do they weigh?
2. Can you briefly describe the manufacturing process of the film reels?
3. How are the reels packed? Do they have packaging to protect them during transportation? Do you use Wooden Euro pallets for transportation?
4. Where is your production plant located and how long does the trip take? (h and km.)

B.3.3 Email questionnaire for Bring Frigo AB: Transport provider from the Food manufacturer to the Distribution Center

1. Do you have the characteristics of the refrigerated trucks that are used? (Dimensions, fuel used - the most used kind of truck)
2. I am estimating the carbon footprint of the transportation of these products, I wanted to ask what is the CO2g/tkm of the refrigerated trucks you use.
3. What technology is used for refrigerating the cargo? Does it involve CO2 emissions?

B.3.4 Email questionnaire for FTI: Packaging waste handler

I am mapping the supply chain of packed ready meals (chilled ready meals sold on supermarkets). And one of my objectives is to calculate each actor's percentage contributor to the product's carbon footprint (from packaging suppliers until waste handlers). This information will help me better understand the whole supply chain and identify improvement opportunities to reduce these environmental impacts eventually.

In this context, the information that I am gathering from each actor in the supply chain involves their main internal processes and the main aspects contributing to the carbon footprint. As far as I understand, all the plastic packaging from this product should be recovered by FTI. Therefore, I would like to ask the following questions:

Regarding PP trays

What percentage of this packaging is not being recovered by FTI?

From the recovered fraction, which percentage is incinerated for energy recovery?

Regarding flexible multilayered films

What percentage of this packaging is not being recovered by FTI?

As far as I understand, all multilayered material is incinerated for energy recovery. Is this right?

Regarding the overall process

Can you describe the type of trucks used for collecting the packaging and the CO2/kg/km they emit?

After the PP trays have been classified in Motala, how is the packaging handled and transported to the recycling facility? Do you have the data of the average CO2/kg/km emissions for transporting it to the recycling facility?

The company did not reply to the questions above because they conflicted with ongoing projects they have. FTI did not collaborate by answering the presented questionnaire, nevertheless, they provided the most similar LCA process of the collection vehicles that is currently available from Ecoinvent.

B.3.5 Email questionnaire for Svenskplastatervinning: Plastic waste recycling

My name is Uli Hosse, I am a Master student at Lund University, and I am currently doing my thesis at Micvac studying the supply chain on the Gooh-Lantmännen ready meals, and how we can reduce their carbon footprint and therefore their environmental impact.

I have some questions regarding the recovering and recycling steps. As far as I understand, 49% of the plastic packaging is currently being recovered for recycling and around 50-70% is being recycled and the other fraction is used for energy recovery (this information I got from a lecture at Lund University from FTI).

1. Do you have any data on CoPP clear trays recycling rate?

Additionally, I was wondering about the sorting technologies that are used. As far as I understand, the sorting step is carried out in Motala, where NIR sensory technology is used.

2. Do you also use the Sink-float methodology for sorting the plastic?
3. Is it possible to know if this process involves any CO_2 emissions?

B.3.6 Email questionnaire for Renova: Waste handler in Gothenburg

In my understanding, plastic packaging in Gothenburg is supposed to be handled by FTI, but in some cases, the wrongly sorted plastic can end in your facilities.

I was wondering if I can get more information in this matter regarding the collection process that you have, the carbon footprint generated per kg of waste handled, and the amount of energy that can be generated from this waste. It will be very useful to know a general overview of how waste is treated in your facilities.

B.3.7 Observation protocol for ICA Supermarket: Retail store in Gothenburg

The protocol was constructed based on the suggestions presented by Phellas, Bloch, and Seale (2011).

A mobile phone was used for recording the unloading process of product at an ICA Supermarket store. Non-verbal behavior was recovered from the recording, including details on the secondary packaging used for different types of ready meals that are currently sold by the retailer. Details on the truck and tertiary packaging were also recorded. Based on the observed activities, an activity map was constructed.

Appendix C Process map activity symbols

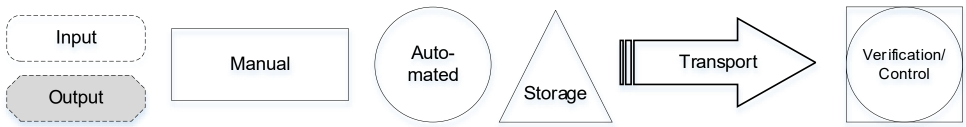


Figure C.1 Identification of process map activity symbols

Figure C.2 Color code for the process map activity symbols

Appendix D Modelling in Stackbuilder

D.1 Supplier's packaging configuration

D.1.1 Faerch plast s.r.o

The roll cage container and pallet configuration can be observed in Figure D.1Figure . The efficiency calculated is 90.8% as the cage has almost the same dimensions of the pallet and there is some available space on top in comparison to the recommended maximum height of 1255 mm.

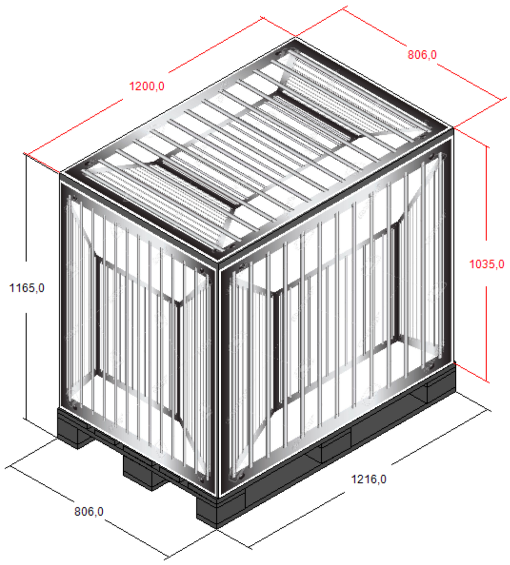
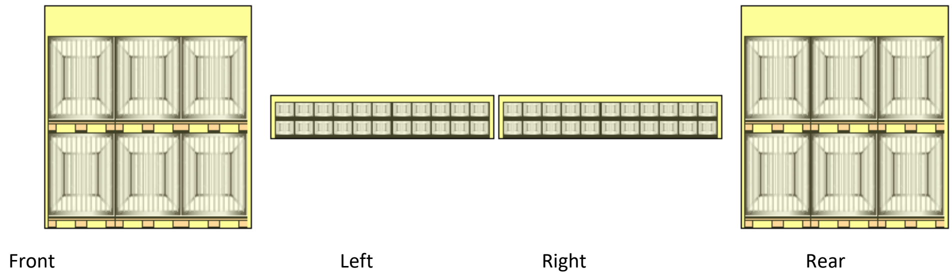


Figure D.1 Steel Crate in Euro Pallet that transports trays from Faerch Plast s.r.o

As for the configuration in the truck, a Semi-Trailer dimensions of 13700 x 2480 x 2650 mm and admissible load of 40 t was considered for the analysis. Figure D.2 shows the configuration inside the truck. It can be observed that there is space available on the top of the cargo (66 pallets with 1 steel cage each fit in the truck). Nevertheless, the maximum shipment is restricted due to volume availability.



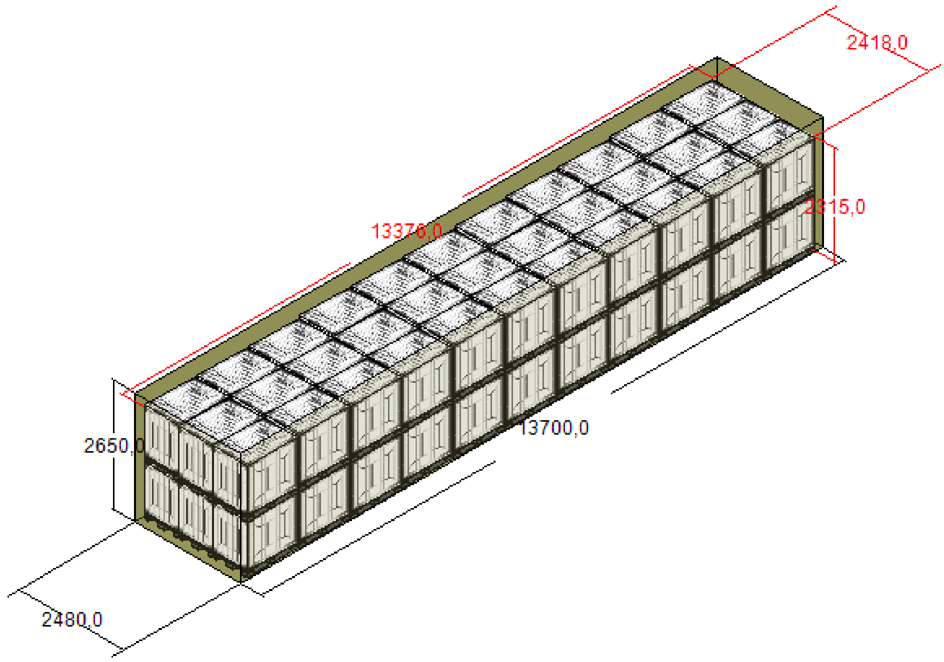


Figure D.2 Truck configuration that transports trays from Faerch Plast s.r.o

D.1.2 Micvac AB

The reels of Micvac valves are accommodated in cardboard boxes as shown in Figure D.3. The fill rate in this case is 70.1% due to the cylindrical shape of the reels. Figure D.4. shows the cardboard boxes piled up in 5 layers in a pallet, which has a 99% of fill rate. Currently the pallets are only filled in 3 to 4 layers, as their order do not require bigger quantities.

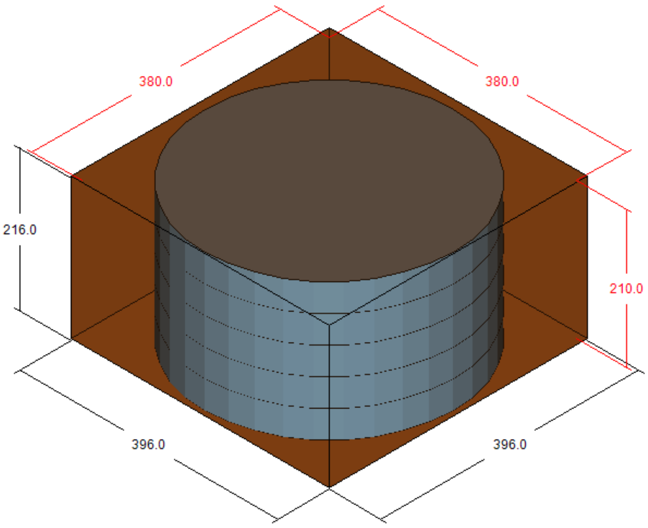


Figure D.3 Cardboard boxes in Euro Pallet that transports valves from Micvac AB.

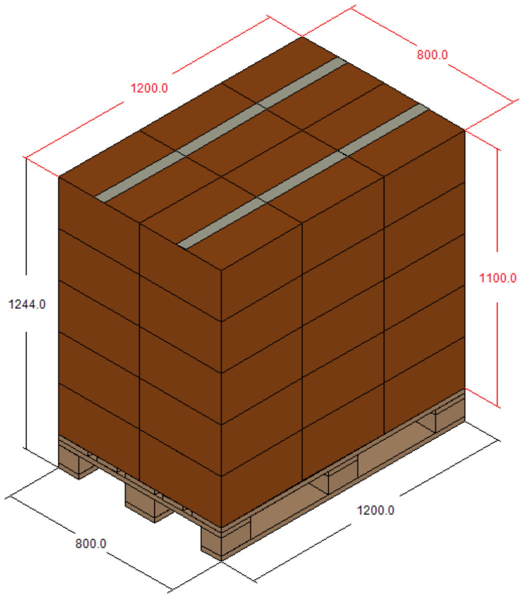


Figure D.4 Cardboard boxes in Euro Pallet that transports valves from Micvac AB.

Based on the information for a Rigid truck 7.5-12t by NTM, a Tail lift truck of 7 500 x 2 450 x 2 200 mm dimensions and 12 t admissible weight was considered for the analysis. Figure D.5 shows that the is available space on the top area pf the truck. Nevertheless, the cargo is restricted due to the maximum height of the pallets and the available volume.

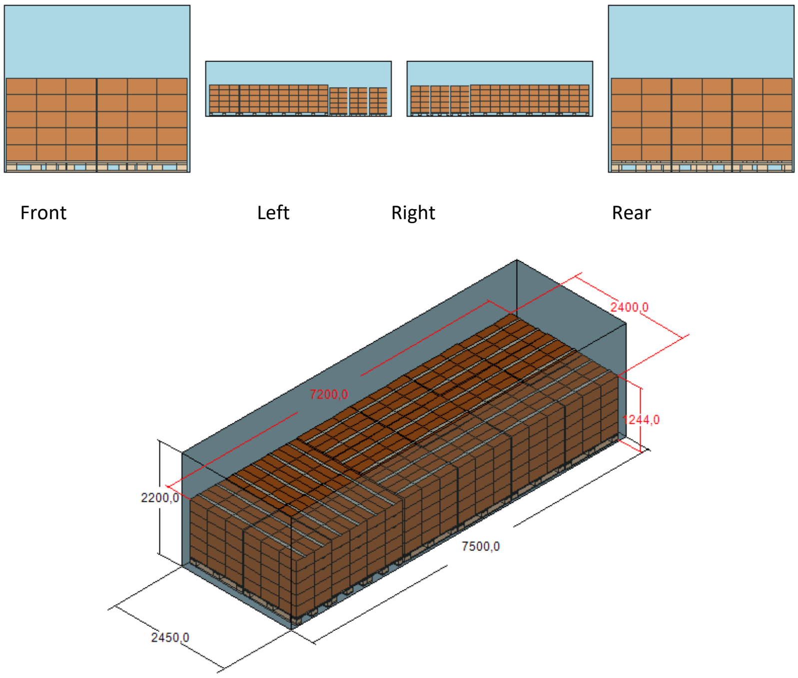


Figure D.5 Truck configuration that transports valves from Micvac AB.

D.1.3 Scandiflex Plast AB

The reels are piled up and centered in the pallet as shown in Figure D.6. This configuration leads to a low efficiency of 42.9% due to the void space surrounding the reels and the available height up until 1255mm. According to Scandiflex Plast AB, the maximum weight capacity in the transportation trucks is of 7.5 t. Based on this information, the truck configuration is depicted in Figure D.7.

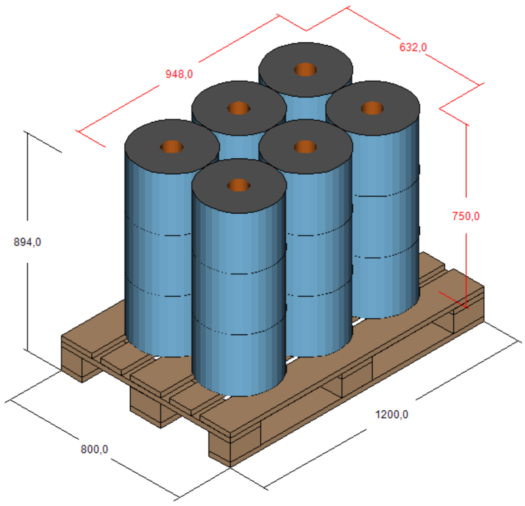


Figure D.6 Reels in pallets from Scandiflex Plast AB.

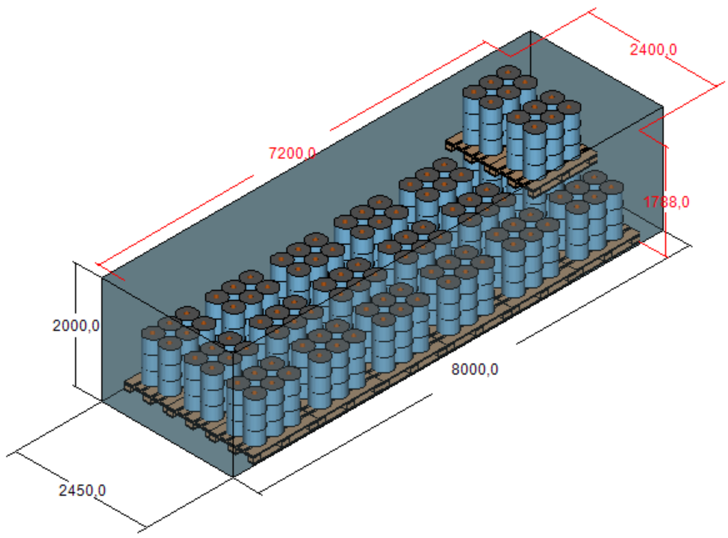


Figure D.7 Truck configuration that transports reels of lidding film from Scandiflex Plast AB.

D.2 Packaging configuration from the Food manufacturer to the Retail store

Due to the vacuum characteristics of the primary packaging, the fill rate of the content (ready meal) is considered 100%. This can be observed in Figure D.8. Due to the vacuum created during the packaging process, the height of the product is reduced from 45mm to 41mm.

Figure D.8 Tray with ready meal content.

A simplified scheme of the internal configuration of the trays inside a Half pallet 120 red SRS crate in depicted in Figure D.9. If the trays were to be considered rectangular, the fill rate in the box would be approx. 80%.

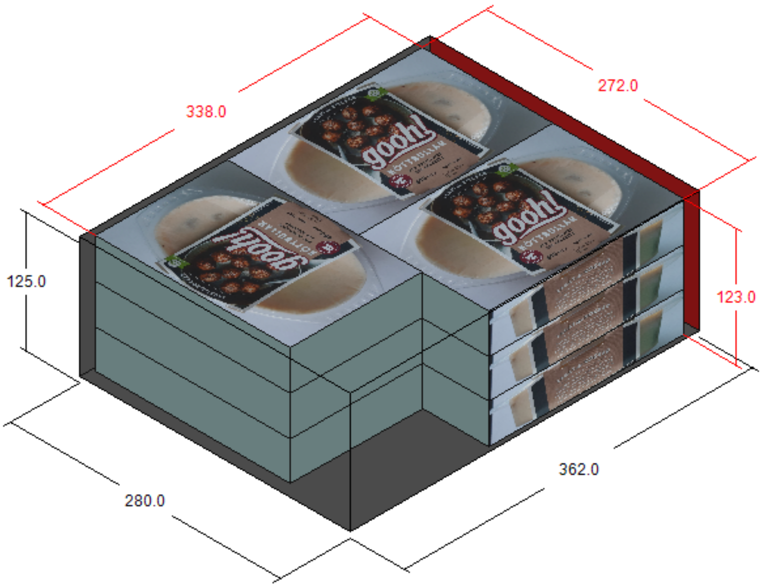


Figure D.9 Approximate configuration for gooh ready meal trays in a Half pallet 120 red SRS crate.

SRS crates are designed in a modular system, therefore the fit with the SRS Full pallet, as observed in Figure D.10.

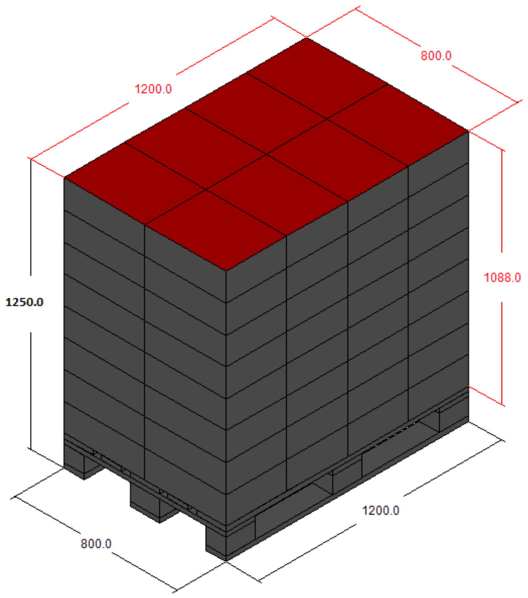


Figure D.10 Approximate configuration for gooh ready meal trays in a Half pallet 120 red SRS crate.

These pallets are transported in refrigerated temperature by Bring. It will be assumed that the transportation is done in 13 t temperature-controlled trucks.

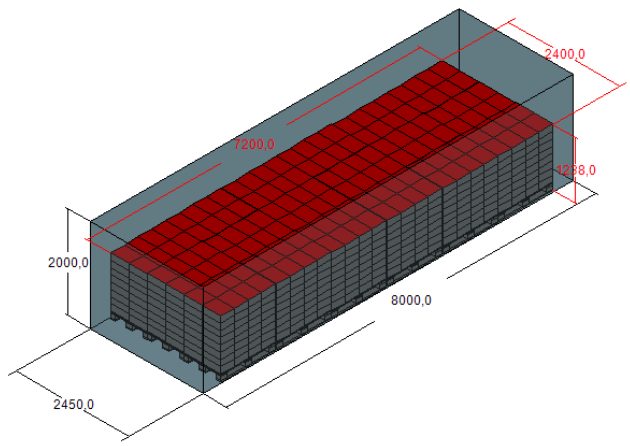


Figure D.11 Approximate configuration for gooh ready meal pallets in a semi-trailer truck.

The configuration of the crates in the roll containers is similar to the configuration in a half pallet, considering they have the same available space inside, with the difference that the available loading height for a loading container is of 1400 mm. An approximation can be observed in Figure D.12, where 10 layers of 4 crates each is depicted. This configuration has a fill rate of 96.5% considering the maximum height of a roll container is 1680 mm.

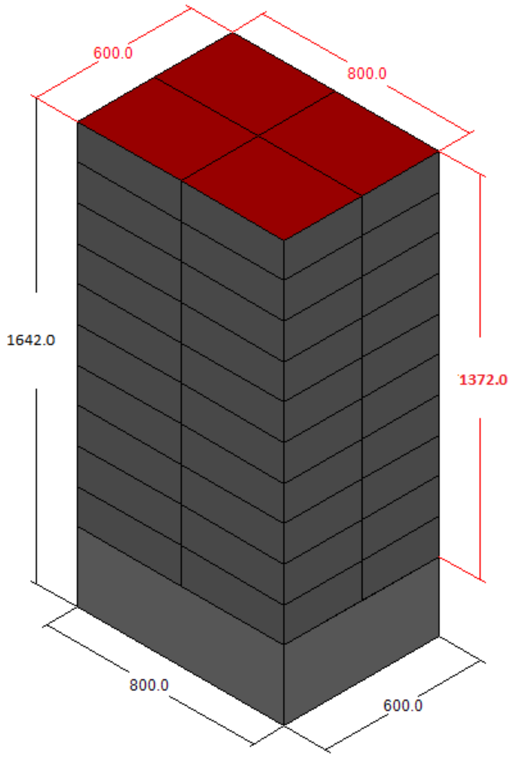


Figure D.12 Approximate configuration for gooh ready meal trays in a roll container

For internal truck transportation, ICA uses different truck sizes depending on the rout and type of retail stores that will be replenished. According to their head of packaging and traceability, a truck can hold 30 pallet places in in the trailer and 18 pallet places in the car, giving a maximum of 48 places for a normal truck. In some trucks, double stacking is possible, and with high and sinkable floor, the maximum goes up until 150 roll containers with a maximum weight of 60 tons. For the purpose if this study and considering that the type of retail store is a supermarket, the dimension of a rigid truck 7.5-12t with 30 pallet spaces will be considered.

Table D.1 Packaging characteristics along the supply chain for the Flextray Oval 400g with a meal produced by Gooh AB.

Packaging level	P^1	S^1	T^1	T^2
Description	Tray with plastic film	SRS red crate	SRS Full Euro Pallet	Roll container
Material	CoPP tray Multilayered plastic Cardboard label	Polypropylene with bale arms in polyamide	Polyethylene with friction surface and steel reinforcement	Steel
Dimensions	202 x 136 x 41 mm	400 x 300 x 148 mm	1200 x 800 x 150 mm	734x854x1680 mm without wheels 1410 mm
Weight	0.02 kg	0.760 kg	14.8 kg	29 kg
Capacity	0.40 kg product	9 units of P^1	1000 kg Or 64 units of S^1	600 kg or 56 units of S^2
Additional details	Tray has a vacuum appearance	Stackable and nestable	Reusable with RFID technology	It has an adjustable tray which can be attached depending on the height of the crates transported by the container.
Picture				
Source	Observation	(Svenska Returnsystem, 2017c)	(Svenska Returnsystem, 2020)	In store observation

Appendix E Transportation routes

E.1 Faerch Plast s.r.o to Food manufacturer

Table E.1 Transportation route from Trays Supplier to Food Manufacturer

Start location	*End location*	*Transportation mode*	*Distance*
Færch Plast s.r.o, Techniků 535, Doubí, Liberec, Chequia	Gooh AB Snickarvägen 9 Järna, Sweden	Truck with trailer 34-40t by Road	1670 km

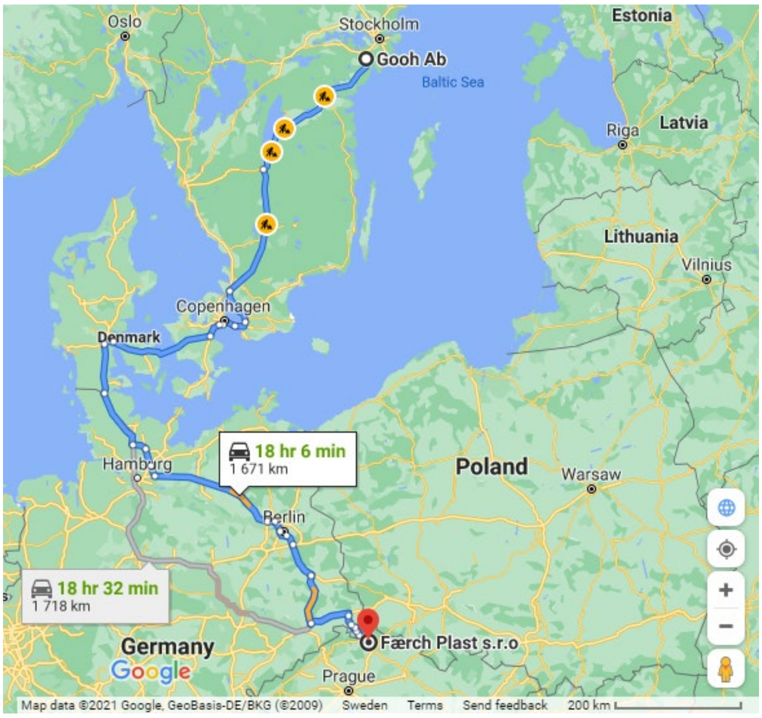


Figure E.1 Approximation on the transportation route film from Faerch Plast s.r.o. to Gooh AB.

E.2 Micvac to Food manufacturer

Table E.2 Transportation route from Valve Supplier to Food Manufacturer

Start location	*End location*	*Transportation mode*	*Distance*
Micvac AB, Flöjelbergsgatan 10, Mölndal, Sweden	Gooh AB Snickarvägen 9 Järna, Sweden	Rigid truck 7.5-12 t	424 km

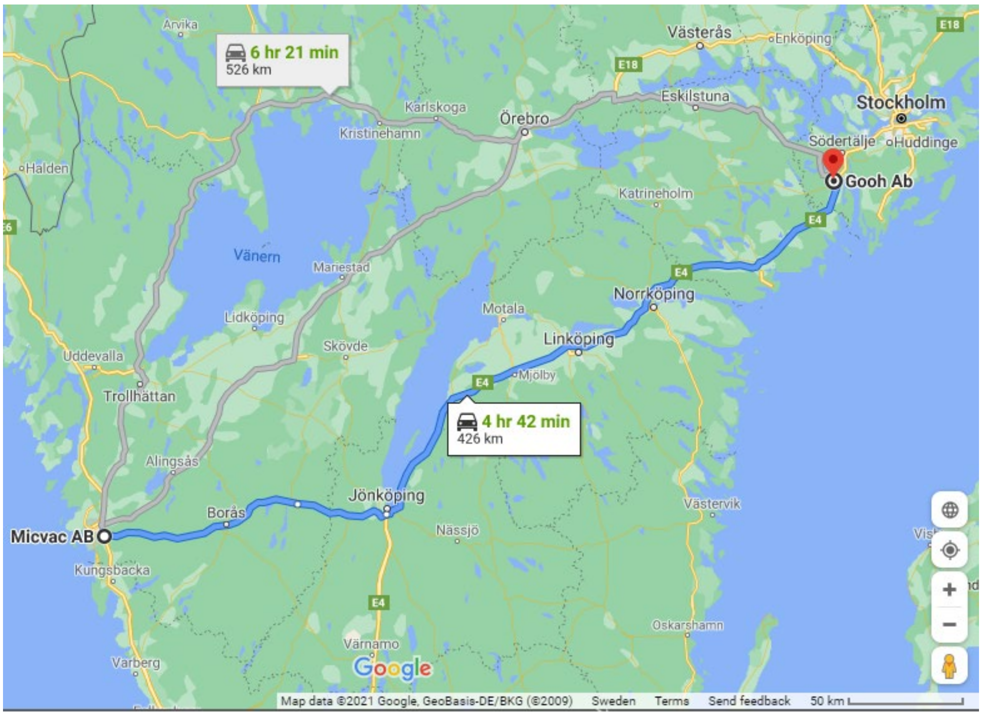


Figure E.2. Approximation on the transportation route film from Micvac AB to Gooh AB.

E.3 Scandiflex Plast AB to Food manufacturer

Table E.3 Transportation route from Plastic Film Supplier to Food Manufacturer

Start location	*End location*	*Transportation mode*	*Distance*
Scandiflex AB Drevgatan 17 Landskrona, Sweden	Gooh AB Snickarvägen 9 Järna, Sweden	Rigid truck 7.5-12 t	532 km

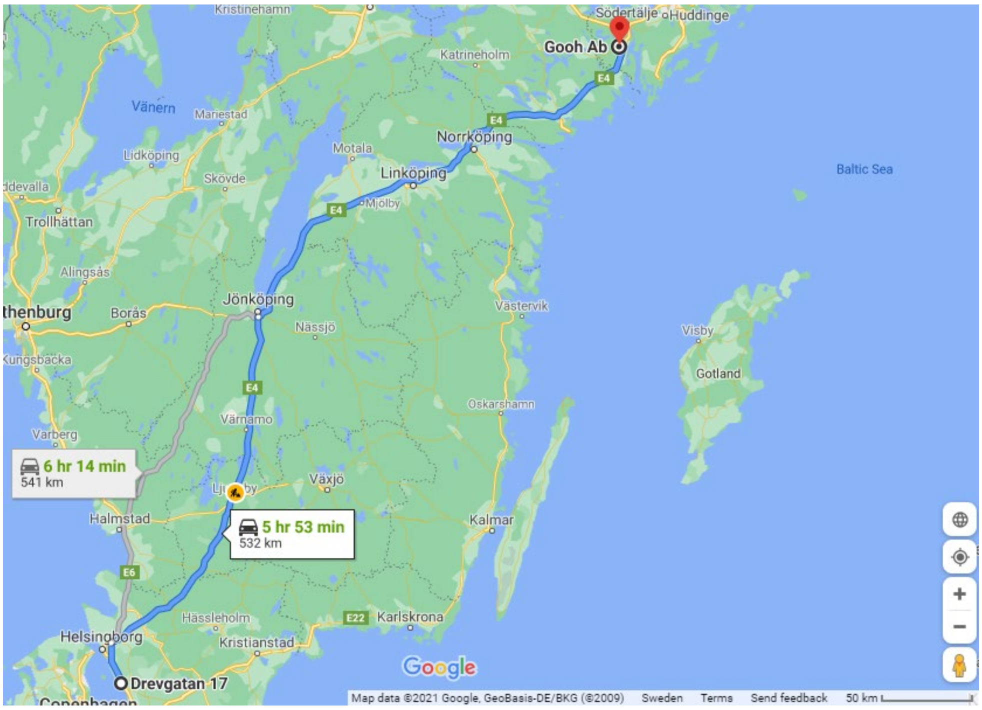


Figure E.3 Approximation on the transportation route from Scandiflex Plast AB to Gooh AB.

E.4 Gooh AB to ICA warehouse

Table E.4 Transportation route Gooh AB to ICA warehouse

Start location	*End location*	*Transportation mode*	*Distance*
Gooh AB Snickarvägen 9 Järna, Sweden	ICA centrallager, 442 40 Kungälv, Sweden	Bring - Temp controlled Transport 18 pallet 13 t	447 km

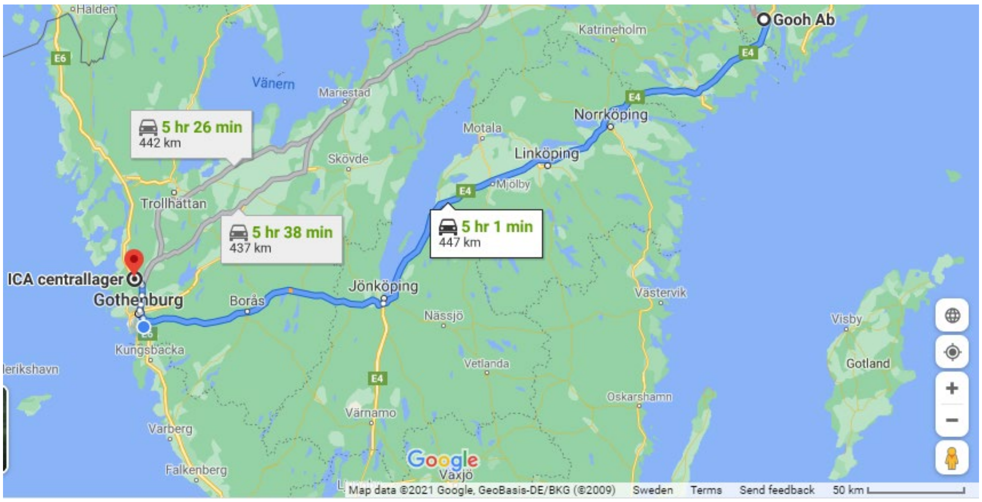


Figure E.4 Approximation on the transportation route film from Gooh AB to ICA Central warehouse – Distribution center

E.5 ICA warehouse to ICA Supermarket

Table E.5 Transportation route from ICA distribution center to ICA supermarket

Start location	*End location*	*Transportation mode*	*Distance*
ICA centrallager, 442 40 Kungälv, Sweden	ICA Supermarket, Brunnsbotorget 3 Gothenburg, Sweden	Rigid truck 20-26 t	20.5 km

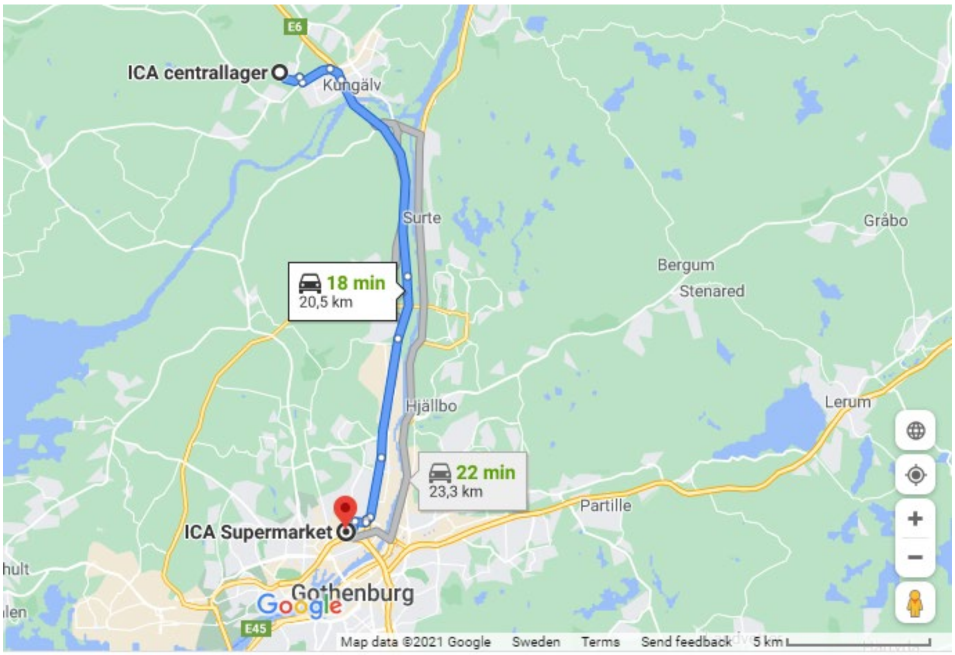


Figure E.5 Approximation on the transportation route film from ICA Central warehouse – Distribution center to an ICA Supermarket in Gothenburg.

E.6 Consumer to waste handlers

Table E.6 Transportation route from consumers to Renova

Start location	***End location***	***Transportation mode***	***Distance***
Consumer household	Renova AB - Sävenäs von Utfallsgatan 29, Göteborg, Sweden	HVO, biogas and electricity truck	variable

Table E.7 Transportation route from consumers to FTI – Motala sorting station

Start location	***End location***	***Transportation mode***	***Distance***
Consumer household	Vickerkullavägen 2, Motala, Sweden	Municipal waste collection service by 21 metric ton lorry - Diesel	variable

Appendix F Calculation results of the carbon footprint in the supply chain

F.1 Packaging material references for calculations

The following values were obtained from technical Datasheet and specifications of each of the primary packaging components.

Table F.1 Packaging material weight for the primary packaging

Component	Weight [kg]/product	Material
Tray	0.01995	CoPP
Valve	0.00059	PVC
Lidding film PA	0.00131	PA
Lidding film PP	0.00246	PP
Total	0.02432	

F.2 Identification of stages in the supply chain

Based on the work of Molina-Besch (2017) and Pålsson *et al.* (2013), three main stages in the supply chain were identified (Figure F.1). The manufacturing of the packaging material and the transport from the three main suppliers to the food manufacturer are part of the *Packaging material inbound* operations. The transport of the finished product from the food manufacturer until the retail store are part of the *Moving the product* stage. As mentioned before, and based on the work of Molina-Besch (2017), the transportation to the consumer household was not taken into account as it depends on the consumer behavior of the purchaser, which is not inside this project's scope for the carbon footprint calculation. The waste handling operations and collection activities are part of the *Packaging material outbound* stage for this analysis.

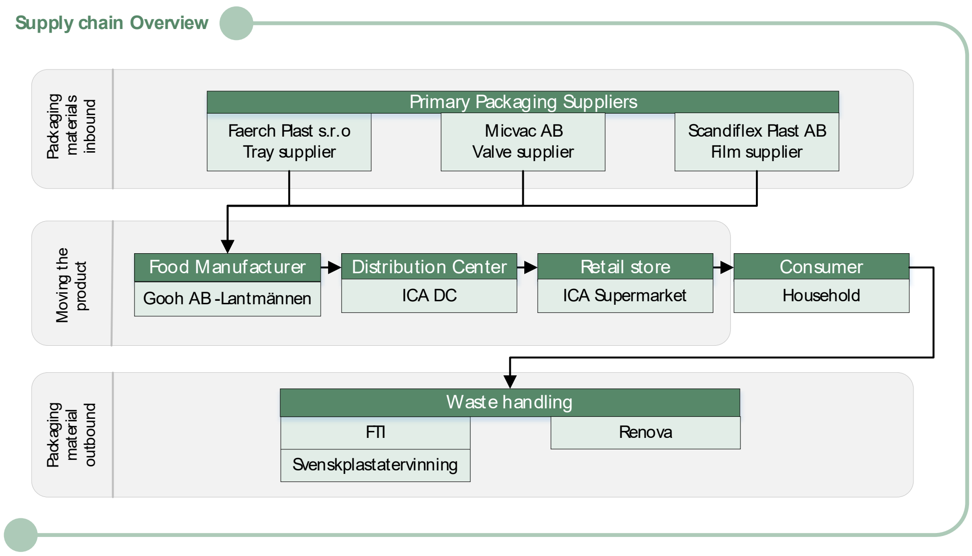


Figure F.1 Identification of the three main stages in the supply chain of Micvac ready meals.

F.3 Packaging systems considered in the stages

The packaging systems considered for the carbon footprint calculations are presented in Figure F.2 to F.6.

Supply chain step: Tray supplier to Food Manufacturer

Product:	Trays		**Primary packaging:**	Steel cage plastic wrap					**Tertiary packaging**	Steel pallet		**Transport**	Truck with trailer 34-40 t	
Dimensions:			Inner dimensions:			Outer dimensions:			Dimensions:					
length	202	mm	length	1150	mm	length	1216	mm	length	1216	mm			
width	136	mm	width	756	mm	width	806	mm	width	806	mm	Admissible load weight:	40000	kg
height	45	mm	height	995	mm	height	1165	mm	height	1165	mm	Weight of the content:	8320	kg
Weight	0,01995	kg	Weight	52	kg				Weight	0*	kg	Tertiary packages	66	units
			Admissible load weight:	450	kg				Admissible load weight:	1000	kg			
			Weight of the content:	74	kg				Weight of the content:	126	kg			
			Component capacity:	3712	units					1	units			

* Included in the Steel Cage weight

Figure F.2 Packaging systems considered for the Tray supplier to Food Manufacturer stage

Supply chain step: Valve supplier to Food Manufacturer

Product:	Valves		**Primary packaging:**	Corr. carboard box (C-flute)		**Tertiary packaging**	Wooden Euro Pallet		**Transport**	Rigid truck 7,5-12 t	
Dimensions:			Dimensions:			Dimensions:					
length	380	mm	length	400	mm	length	1200	mm			
width	380	mm	width	400	mm	width	800	mm	Admissible load weight:	12000	kg
height	42	mm	height	220	mm	height	144	mm	Weight of the content:	10980	kg
Weight	3,82	kg	Weight	0,4	kg	Weight	25	kg	Tertiary packages	18	units
			Weight of the content:	19	kg	Admissible load weight:	1000	kg			
	6000	valves/roll	Component capacity:	5	units	Weight of the content:	585	kg			
							30	units			

Figure F.3 Packaging systems considered for the Valve supplier to Food Manufacturer stage

Supply chain step: Film supplier to Food Manufacturer

Product:	Sealing film		**Tertiary packaging**	Wooden Euro Pallet		**Transport**	Rigid truck <= 7,5 t	
Dimensions:			Dimensions:					
length	316	mm	length	1200	mm			
width	316	mm	width	800	mm	Admissible load weight:	7500	kg
height	250	mm	height	144	mm	Weight of the content:	7189	kg
Weight	18,58	kg	Weight	25	kg	Tertiary packages	20	units
	4923	trays/reel	Admissible load weight:	1000	kg			
			Weight of the content:	334	kg			
				18	units			

Figure F.4 Packaging systems considered for the Film supplier to Food Manufacturer stage

Supply chain step: Food Manufacturer to Distribution Center

Product:	Ready meals		**Primary packaging:**	Tray+sealing film+valve		**Secondary packaging**	SRS half-siz 120 red crate		**Tertiary packaging**	SRS Full Pallet		**Transport**	Bring -Temp controlled 13t	
			Dimensions:			Outer dimensions:			Dimensions:					
Weight	0,4	kg	length	202	mm	length	400	mm	length	1200	mm			
			width	136	mm	width	300	mm	width	800	mm	Admissible load weight:	13000	kg
			height	41	mm	height	148	mm	height	150	mm	Weight of the content:	5541	kg
			Weight	0,0243	kg	Weight	0,76	kg	Weight	14,8	kg	Tertiary packages	18	units
			Admissible load weight:	0,4	kg	Admissible load weight:	8	kg	Admissible load weight:	1000	kg			
			Weight of the content:	0	kg	Weight of the content:	3,82	kg	Weight of the content:	293	kg			
			Component capacity:	1	units		9	units		64	units			

Figure F.5 Packaging systems considered for the Food Manufacturer to Distribution Center stage

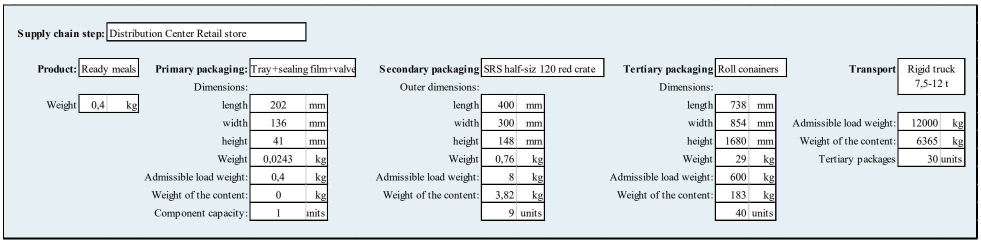


Figure F.6 Packaging systems considered for the Distribution Center to Retail store stage

F.4 Transport carbon emissions calculations

The Database from NTM (2021) give information regarding the carbon dioxide emission well-to-wheels per km for three different weight load factors, hence a linear regression was performed to obtain the values for the studied load factors. The regressions for the three types of trucks used in the supply chain is depicted in Figure F.7.

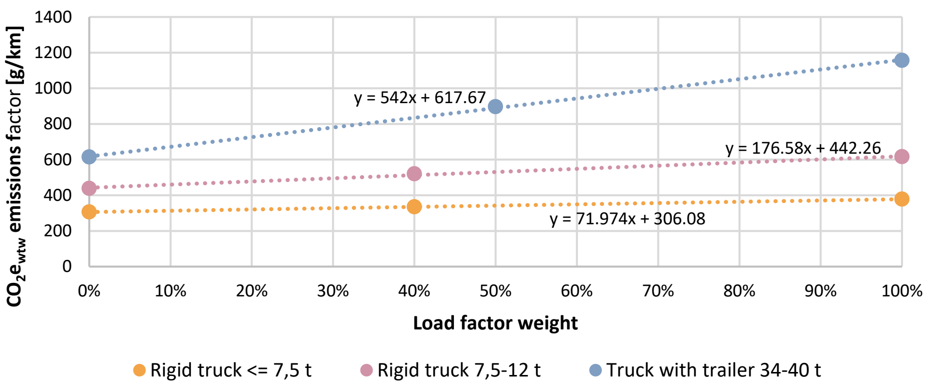


Figure F.7 Packaging systems considered for the Distribution Center to Retail store stage

The load factors calculated for each stage, along with the calculation factors are depicted in Table F.2. In all cases, but the transport from the film supplier to the food manufacturer, the load was constrained by volume. As all the routes are usually done by external transportation companies with warehouses in different parts of Sweden, it was not considered that the trucks will return empty to the point of origin. The only route in which this aspect was considered was during the transportation from the Distribution center to the retail store, as these trucks are usually dedicated for the use of the company. In the case of the transport of goods from the Food manufacturer to the Distribution center, the transport company provided information for calculating the CO_2e_{wtw}/tkm factor, this value was calculated as 118,79 gCO_2e_{wtw}/tkm considering a weight load factor of 45%.

Table F.2 Packaging systems considered for the Distribution Center to Retail store stage

Route	Vehicle type	Load Factor weight	CO_2e_{wtw}[g/km]
Tray Supplier-Food Manufacturer	Truck with trailer 34-40 t	21%	730,44
Valve Supplier - Food Manufacturer	Rigid truck 7,5-12 t	92%	603,89
Film Supplier - Food Manufacturer	Rigid truck <= 7,5 t	96%	375,11
Distribution Center - Retail Store	Rigid truck 7,5-12 t	53%	489,14

F.5 Additional considerations for the calculations

As mentioned in the Methodology section, Ecoinvent database was used for calculating the carbon footprint of the packaging materials production and waste handling. The items considered are shown in Table F.3. Fossil carbon dioxide, methane, and nitrous oxide emissions data was obtained and multiplied by their Global Warming Potential values for the calculations.

Table F.3 Packaging systems considered for the Distribution Center to Retail store stage

Packaging materials
Activity name
PP manufacturing Polypropylene production, granulate Ethylene production, average Propylene production PVC manufacturing Polyvinylchloride production, suspension polymerization Vinyl chloride production Ethylene production, average Chlorine production, gaseous PA manufacturing Nylon 6 production
Waste handling
Activity name
Treatment of waste polyvinylchloride, municipal incineration Treatment of waste polypropylene, municipal incineration PA waste incineration Activity name Municipal waste collection service by 21 metric ton lorry (50% full stop & go)

F.6 Tables of results per stage in the supply chain and factor

F.6.1 Packaging material inbound

Table F. 4 Packaging material inbound transportation carbon footprint emissions

Transportation		
Transport - Tray supplier to Food Manufacturer		
Transportation mode: Truck with trailer 34-40 t	730.44	g CO_2e_{wtw}/km
Shipping distance	1670	km
Load Factor weight	21%	
Equivalent maximum capacity in transport	244 992	No. Trays
Transport - Valve supplier to Food Manufacturer		
Transportation mode: Rigid truck 7.5 - 12 t	603.89	g CO_2e_{wtw}/km
Shipping distance	424	km
Load Factor weight	92%	
Equivalent maximum capacity in transport	16 200 000	No. Trays
Transport - Film supplier to Food Manufacturer		
Transportation mode: Rigid <= truck 7.5	375.11	g CO_2e_{wtw}/km
Shipping distance	532	km
Truck load	96%	
Equivalent maximum capacity in transport	1 772 308	No. Trays
Results per product		
Emissions for tray transport	4.98	g CO_2e_{wtw}
Emissions for valve transport	0.02	g CO_2e_{wtw}
Emissions for film transport	0.11	g CO_2e_{wtw}
Total CO_2e emissions per ready meal	**5.11**	g CO_2e_{wtw}

Regarding the packaging materials, the manufacturing of the three main components of the studied packaging (tray, valve, and sealing film) was considered for the analysis. The carbon footprint of the manufacturing of the other components of the packaging system was not considered for this analysis as it was out of the scope. Nevertheless, the total weight of the packaging system was considered for the emissions calculations during transportation.

Table F. 5 Packaging material inbound manufacturing carbon footprint emissions

Packaging material		
Packaging material - PP -Tray supplier		
Ready meal tray - PP	2167	g Co_2e/kg
Weight of a tray	0.01995	kg
Weight of Steel cage	52	kg
Pallet*	0	g Co_2e/kg
Weight of pallet	25	kg
Packaging material - PVC - Valve supplier		
Valve-PVC	1373	g Co_2e/kg
Weight of a valve	0.00059	kg
Weight of corrugated cardboard	0 .4	kg
Pallet*	0	g Co_2e/kg
Weight of pallet	25	kg
Packaging material -PA+PP - Sealing film supplier		
Lidding film-PA+PP	5480	g Co_2e/kg
Weight of lidding form for one tray	0.00377	kg
Pallet*	0	g Co_2e/kg
Weight of pallet	25	kg
Results per product		
CO_2eq emissions per tray	43 .24	g CO_2e
CO_2eq emissions per valve	0.81	g CO_2e
CO_2eq emissions per lidding film	20.68	g CO_2e
Total CO_2e emissions per ready meal	**64.73**	**g CO_2e**

* As explained by Pålsson *et al.* (2013), wooden pallets are reused and recycled. Thus, it this case it can be considered that their carbon footprint is zero for the matter of this analysis.

F.6.2 Moving the Product

Table F. 6 Moving the product transportation carbon footprint emissions

Transportation		
Transport - Food Manufacturer to Distribution Center		
Transportation mode: Temperature-controlled truck 13 t	113.08	g CO_2e_{wtw}/tkm
Shipping distance	447	km
Truck load	5.5	t
Equivalent maximum capacity in transport	10 368	No. Trays
Transport from Distribution Center to the Retail store		
Transportation mode: Rigid truck 7.5 - 12 t	523.85	g CO_2e_{wtw}/km
Shipping distance	20.5	km
Load factor weight	53%	
Equivalent maximum capacity in transport	10 800	No. Trays
Results per product		
Emissions from Food Manufacturer to DC	27.01	g CO_2e_{wtw}
Emissions from DC to retail store	0.93	g CO_2e_{wtw}
Total CO_2e emissions per ready meal	**27.94**	g CO_2e_{wtw}

Table F. 7 Moving the product material handling carbon footprint emissions

Material handling		
Material handling - the Food Manufacturer		
CO_2e emissions from free-fossil fuel energy	0	g CO_2e
Material handling in the Distribution Center		
CO_2e emissions from free-fossil fuel energy	0	g CO_2e
Material handling in the Retail store		
CO_2e emissions from free-fossil fuel energy	0	g CO_2e
Material handling in the Consumer house		
CO_2e emissions from free-fossil fuel energy	0	g CO_2e
Total CO_2e emissions per ready meal	**-**	**g CO_2e**

F.6.3 Packaging material outbound

Table F. 7 Packaging material waste handling carbon footprint emissions

Waste handling		
Waste transport for sorting and recycling - FTI		
Transportation mode waste recollection truck	3 071	g Co_2eq/tkm
Shipping distance, average	19.15	km
Truck max load	4.1	t
Equivalent maximum capacity in transport	168 618	No. Trays
Proportion handled by FTI	49%	
Waste handling for energy recover -FTI		
PP incineration	2 529	g CO_2eq /kg
PVC incineration	1 609	g CO_2eq /kg
PA incineration	2 455	g CO_2eq /kg
Proportion of PP for energy recovery	64%	
Transport from the Consumer house to the energy recovery facilities - Renova		
Transportation mode electric truck	0	g CO_2eq /tkm
Proportion handled by Renova	51%	
Waste handling for energy recovery -Renova		
PP incineration	2 529	g CO_2eq /kg
PVC incineration	1 609	g CO_2eq /kg
PA incineration	2 455	g CO_2eq /kg
Results		
CO_2e emissions collection from FTI (49%)	0.70	g CO_2eq
CO_2e emissions energy recovery from FTI (49%)	19.82	g CO_2eq
CO_2e emissions energy recovery from Renova (51%)	31.04	g CO_2eq
Total CO_2e emissions per ready meal	**51.56**	**g CO_2eq**

Table F. 8 Packaging material waste handling carbon footprint emissions

Area	Category	g CO_2e per tray
Packaging material inbound	Packaging material	64.73
Packaging material inbound	Transport	5.11
Moving the product	Transport	27.94
Moving the product	Material handling	-
Packaging material outbound	Waste handling	51.56
Total		149.34

F.6.4 Calculation for the carbon footprint of a ready meal

Table F. 9 Carbon footprint calculation for a meatballs and mashed potato 400 g dish

Ingredient	Percentage	Weight [g]	g CO_2eq / g meal	CO2 g eq
Meatballs	0.29	78		1 004.04
Beef	0.50	58	15.62	906.25
Pork	0.17	20	4.96	97.79
Potato	0.27	108	0,01	1,00
Cream - Milk approximation	0.055	22	0,60	13,27
Total CO_2e emissions per ready meal				1 018.31

F.7 Formulas used for the carbon footprint calculation

CO_2eq emissions during packaging material production

$$= \sum CO_2eq\ emissions\ stage\ X\ of\ packaging\ material\ production\ \left[\frac{gCO_2eq}{kg}\right] * Packaging\ material\ per\ tray\ \left[\frac{kg}{tray}\right]$$

X is defined as a specific stage in the production process for a specific packaging material that builds up a component of the primary packaging. All the contribution of each stage must be considered in the proportions related to the yield of each stage.

CO_2eq emissions transportation

$$= \frac{CO_2eq\ emissions\ \left[\frac{gCO_2eq}{t\ km}\right] * Truck\ load\ [t] * Shipping\ distance\ [km]}{Equivalent\ number\ of\ trays\ in\ maximum\ capacity}$$

CO_2eq emissions during incineration for energy recovery

$$= \sum (Proportion\ for\ energy\ recovery) CO_2eq\ emissions\ \left[\frac{gCO_2eq}{kg}\right] * Packaging\ material\ per\ tray\ \left[\frac{kg}{tray}\right]$$

Appendix G Calculations on the carbon footprint and volume fill rate for the tray-crate combinations

NTM values for CO_2eq emission factor for a Rigid truck of <=7.5 t was used for the calculation of the carbon footprint. The distance considered was 400 km.

Table G. 1 Volume fill rate of the tray/crate combinations

Volume Fill rate	Crate		
Tray	***X***	***Y***	***Z***
A	33%	33%	32%
B	37%	37%	36%
C	26%	35%	25%
D	26%	26%	38%
E	34%	31%	33%

Table G. 2 Details on the crates and pallet capacity

	Crate		
*Considering 18 pallets per truck	***X***	***Y***	***Z***
Crates per pallet	88	64	44
Weight of crate	0.71	0.76	1.21

Table G. 3 Approximate crate weights

Approx. weight of content in one crate [kg]	Crate		
Tray	***X***	***Y***	***Z***
A	2.81	3.91	5.41
B	3.23	4.54	6.25
C	2.60	4.53	4.98
D	2.42	3.32	6.34
E	3.22	4.21	6.23

Table G. 4 Approximate pallet weights

Approx. weight of content in one pallet [kg]	Crate		
Tray	***X***	***Y***	***Z***
A	262	265	253
B	299	305	290
C	243	305	234
D	228	228	294
E	298	284	289

Table G. 5 Number of trays per pallet

Quantity of trays in one pallet	Crate		
Tray	***X***	***Y***	***Z***
A	528	576	528
B	528	576	528
C	264	384	264
D	352	384	528
E	704	704	704

Table G. 6 Weight load factor considered for the truck load

Weight load factor	Crate		
Tray	***X***	***Y***	***Z***
A	63%	64%	61%
B	72%	73%	70%
C	58%	73%	56%
D	55%	55%	70%
E	72%	68%	69%

Table G. 7 Transportation factor [g CO_2e/km] of the tray/crate combinations

Transportation factor [g CO_2e/km]	Crate		
Tray	***X***	***Y***	***Z***
A	351.35	351.86	349.75
B	357.74	358.83	356.14
C	348.11	358.76	346.52
D	345.42	345.39	356.81
E	357.55	355.16	355.96

Table G. 8 carbon footprint per tray in each tray/crate combination

g CO_2e per tray	Crate		
Tray	***X***	***Y***	***Z***
A	16.53	15.17	16.45
B	16.83	15.47	16.75
C	32.75	23.20	32.60
D	24.37	22.34	16.78
E	12.61	12.53	12.56

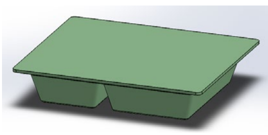
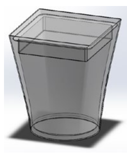
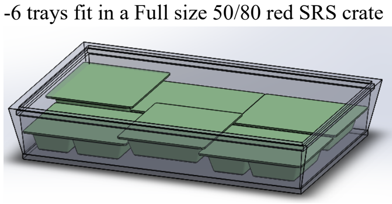
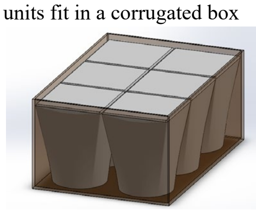
Table G. 9 carbon footprint per gram of food transported of the tray/crate combinations. Where red shows the highest and green the lowers value.

g CO_2e per gram of meal	Crate		
Tray	***X***	***Y***	***Z***
A	0.050	0.046	0.050
B	0.042	0.039	0.042
C	0.055	0.039	0.054
D	0.061	0.056	0.042
E	0.042	0.042	0.042

Appendix H Fill rate calculations on ready meals in the Swedish market

Two ready meal trays were studied to acquire accurate information of the current fill rate in the Swedish market. The calculations were made the same based on accurate measurements with a ruler (±0.5 cm) and CAD models, similarly as the methodology presented for the Micvac trays in the Methodology section. The information regarding the dimension is found in Table H.1.

Table H.1 Details on the ready meals observed in the Swedish market.

	Two compartment rectangular box 360 g	*Pastabox 300 g*
Trays dimensions		
length	207 mm	97 mm
width	175 mm	97 mm
height	41 mm	115 mm
Box dimensions		
length	-	102 mm
width	-	100 mm
height	-	125 mm
Components		
	-85% recycled PET tray with plastic lidding film -Paper sticker label	-PP Tray with plastic lidding film -Cardboard box
Appearance		
Packaging system details	-Food content in tray has an approximate fill rate of 49%based on direct measurements of food height in the primary packaging. -6 trays fit in a Full size 50/80 red SRS crate  Packaging system fill rate: 18%	-Food content in tray has an approximate fill rate of 41%based on direct measurements of food height in the primary packaging. -6 units fit in a corrugated box  Packaging system fill rate:29%