Environmental tool evaluation and databased benchmarking of sustainable packaging materials for Micvac technology

Uvejs Preza

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MASTER THESIS

micvac

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Environmental tool evaluation and databased benchmarking of sustainable packaging materials for Micvac technology

Investigative research and environmental impact evaluation of packaging materials suitable to be used in in-pack microwave pasteurization technology

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Abstract

In recent years, microwave applications in the food products have attracted increasing attention by the food packaging industry and the consumers due to their convenience, low energy and water usage and short processing time giving them a sustainable advantage over competing technologies. In-pack pasteurization represents one of the fastest developing technologies in preparing and delivering safe and high quality ready-to-eat meals.

Besides playing a fundamental role in preserving food products and reducing the environmental impact caused by food waste, packaging materials affect the environment during their life-cycle. This master thesis has been realized in collaboration with Micvac AB, a Swedish company specialized in ready meals packaging technology. This research aims to analyse the environmental impact performance of five selected packaging solutions which are suitable for use in microwave. To achieve this purpose, the author utilized an environmental tool founded on a tool designed in a previous study, which was progressively developed based on the conditions and specific requirements of the investigated value chain. Food manufacturers and retailers were interviewed to gather information on their requirements and environmental strategies. Additionally, ready meals market data trends were collected from Lund University databases.

These sources were integrated into some main findings which support the development and expansion of monomaterials in the food packaging industry. Among five evaluated solutions in this study, the monomaterials options performed the best in the evaluation tool, particularly the monoPP solution which received the highest score. This indicates an opportunity for the actors in the analysed supply chain to decrease their environmental impact, especially considering the anticipated EU legislative approval of recycled content for packaging in food contact.

Keywords: sustainable packaging, ready meals, in-pack microwave pasteurization, evaluation tool, environmental impact, material investigation

Executive summary

Introduction

Consumers are increasingly seeking healthy, convenient, and quick-to-prepare foods, making the selection of appropriate packaging materials complex. Packaging developers must ensure compatibility between the product and packaging materials, required shelf life, production line efficiency, cost, and environmental impacts. Microwave sterilization and pasteurization systems have gained attention in recent years for their effect on reducing adverse environmental impacts through efficient use of water and energy. Micvac AB is a solutions provider for in-pack pasteurisation of chilled ready meals with its technology consisting of in-pack cooking and pasteurization in a single continuous process.

This thesis project addressed the following research question: What is the most sustainable option in the market for Micvac packaging solution?

To answer this question, this project proposes the development of an evaluation tool for Micvac technology that incorporates various sustainability criteria to benchmark and evaluate a company's sustainable primary packaging. The proposed evaluation tool considers different sustainability criteria throughout the product-packaging life cycle.

Methodology

Firstly, a theoretical framework provides general information about packaging terminology and in-pack pasteurization technology definitions. To answer the research question, literature research and semi-structured interviews were conducted. The literature review encompasses conventional packaging materials and innovative packaging solutions on microwave technology for food applications. Additionally, EU legislation on packaging and packaging waste, market trends and trade organization policies on packaging materials, and current design-for-recycling guidelines were analysed. This review helped in the final selection of five solutions to be considered in the evaluation. Online interviews and email communications were conducted with relevant actors in the investigated supply chain. The utilized environmental impact tool is further described on its origin and the development it went through during the course of this study to properly analyse the selected solutions.

Results and discussion

The literature review saw numerous packaging solutions being generally divided into non-self-venting materials and self-venting materials. The selection of appropriate packaging materials must consider package thermal properties, gas barrier properties, mechanical properties, and food-package interactions. Active packaging systems have significantly changed the food production landscape due their properties and impact on reducing food waste, consequently reducing the environment impact.

The analysed Micvac packaging is comprised of three components: the tray, the lid film and the valve. The five evaluated packaging solutions are the following: the current Micvac packaging, monoPP, fiber-based, biopolymer, monoPET. The main differences between solutions are their trays, whereas the film and the valve are different in two of the solutions.

The new EC proposal in November 2022 introduced new measures on the compulsory targets waste reduction for member states and it is expected that this proposal will be turned in a new regulation approving recycled content in packaging (other than PET) for food contant applications and possibly establishing mandatory quota of recycled content.

In the analysis of ready meals and ready meals packaging markets from the data gathered from Euromonitor International, a growth is noticed in all seven countries investigated: Sweden, Norway, Finland, USA, France, UK, Spain. Many factors have influenced the shift of consumer perception regarding ready meals as unhealthy. Convenience, increasingly busy lives, and abundance of product varieties are some of the most common reasons which have pushed consumers to purchase more ready meals. It is forecasted that the growth will continue with noticeable differences between countries and the highest growth for ready meals and chilled ready meals is foreseen in Finland and Spain.

The environmental tool utilizes a lifecycle approach, but it is less complicated than an LCA and requires less input. The tool evaluates the environmental impact of a packaging system across four areas: packaging material, transport efficiency, influence on food waste, packaging end-of-life. Each assessment area includes several performance criteria, with five levels assigned to each criterion. The packaging solutions are scored from 1 to 5 based on their properties and level 5 is the highest level, indicating the best performance. In the end an average of all these criteria is calculated based on the importance of each area which was determined on the previous studies and assumptions made by the author. The evaluations were done in a Swedish context.

MonoPP showed the overall highest performance scoring an average of 2.96 out of 5. All the solutions have their strong performing areas and their weak ones, with the influence on food waste being highly in favor of the current packaging and monoPP due to the long-shelf life they provide to the product. As expected, in the packaging-end-of life area the fiber-based option performs the best due to high recycling rates of paper in Sweden.

Conclusion and suggestions for further research

The results of this study showed that a mono material PP solution is the most sustainable solution for the Micvac technology at the moment. This solution aligns with the requirements of the food manufacturers and retailers interviewed during the research. The proposed monoPP option conforms with the recent EU packaging proposal and would comply with upcoming EU legislation regarding mandatory incorporation of recycled content in packaging for food contact. However, it is important to consider other solutions as well as they did not score significantly lower than the monoPP. Much of the investigated innovative packaging solutions for microwave use are multilaminate materials with low production volume therefore it is expected that they would not perform optimally in the environmental tool due to difficulties in recycling packaging made of different materials and the lack of proper collection streams after they become waste.

The food manufacturers and retailers are also demanding monomaterial packaging and reduction of plastic content whenever possible without compromising the food safety and shelf life. Their environmental strategies include bold target goals such as reaching 100% recyclable packaging in this decade. These important actors in the supply chain are adjusting for the future legislative requirements of introducing recycled content in their packaging.

For further research it is suggested to review the technological feasibility and the economic viability of implementing the specific packaging solutions mentioned in this study within Micvac technology. Sourcing availability and process efficiency can be deeply investigated. It is also interesting to include more actors in the supply chain, particularly the consumers whose behavior determines the fate of the packaging after consumption. They would provide valuable feedback on the acceptance of different sustainable packaging options regarding ready meals. Another interesting area of future research would be to investigate the application of the proposed evaluation tool in other packaging solutions of Micvac particularly the thermoform.

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Mölndal, May 2023

Uvejs Preza

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List of acronyms and abbreviations

FTI	Förpacknings-och Tidningsinsamlingen
HFSS	high levels of fat, sugar, or salt
KPI	key performance indicator
LCA	life cycle assessment
MAP	modified atmosphere packaging
PCR	post-consumer recycled content
PPWD	Packaging and packaging waste Directive 94/62/EC
RTE	ready-to-eat
SRS	Svenska Retursystem

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1 Introduction

This section provides a brief overview of this study and its purpose. The background and motivation for the study will be discussed in detail, along with the research question and objectives. The scope and limitations of the study will also be outlined to allow readers a clear understanding of what to expect.

1.1 Background

With human societies becoming more conscious of sustainability, environmental impact has become a crucial issue in various industries, including food packaging. Customers worldwide are increasingly demanding sustainable and eco-friendly packaging and products, which puts companies under pressure to rethink and redesign their packaging processes. This necessitates active and equitable participation in supply chain processes (Asim et al., 2022). As perceptions of busy lifestyles and limited time have become prevalent, there has been a shift away from traditional family meals towards more convenient food options such as ready meals (Celnik, Gillespie and Lean, 2012).

Consumers are increasingly seeking healthy, convenient, and quick-to-prepare foods, making the selection of appropriate packaging materials complex. Packaging developers must ensure compatibility between the product and packaging materials, required shelf life, production line efficiency, cost, and environmental impacts. Policies range from bans or taxes on specific materials to voluntary programs, and decisions regarding packaging materials are influenced by diverse approaches in each country. Collaborative partnerships are leading the debate on sustainable packaging to balance functional requirements with environmental burdens (Verghese, 2008).

To cope with this concern, companies are striving to identify and incorporate sustainable practices into their operations. Consequently, many of them have started comparing their performance related to sustainability against industry standards and best practices (Villena and Gioia, 2020). This benchmarking process helps these organizations monitor and improve their environmental impact while also ensuring that they comply with ethical standards regarding the use of resources. By adopting sustainable methods throughout their supply chain processes, such as production, transportation, and disposal, companies can contribute positively towards creating a greener future for all stakeholders involved (Sani & Aziz, 2013).

Microwave sterilization and pasteurization systems have gained attention in recent years for their effect on reducing adverse environmental impacts through efficient use of water and energy (Tang, 2015). In addition, in-package pasteurization methods such as microwave pasteurization can mitigate the food safety hazards associated with e-commerce and the home delivery of prepared meals. Tang et.al (2018) examined the possibility of utilizing microwave pasteurization as a means of providing safe and high-quality ready-to-eat meals to consumers via various distribution channels and concluded that microwave pasteurization offers faster processing times and more uniform heating than conventional thermal agents such as steam or hot water.

In Europe, every documented commercial microwave pasteurization and sterilization system employs multi-mode heating cavities that operate at 2450 MHz (Tang, 2015) and the author argues that pasteurization systems are better suited for small to medium-sized food companies. The products' relatively short but adequate shelf-life under refrigerated conditions enables these companies to offer a variety of chef-inspired, nutritionally balanced, and/or traditional meals that are free from harmful microorganisms to customers in households, schools, nursing homes, and even international flights.

Micvac AB is a solutions provider for in-pack cooking and pasteurisation of chilled ready-to-eat (RTE) foods. Therefore, the company is delivering not only specifically designed packaging components such as trays, film, and valves, to its customers but also the specialized equipment such as the Micvac valve unit and the microwave tunnel where the process happens. Micvac’s patented technology consists of in-pack cooking and pasteurization in a single continuous process. The sealed trays containing the food are heated by microwave energy at 2450 MHz. The internal steam generated during heating helps distribute thermal energy in the headspace, leading to a decrease in nonuniform heating. Once the internal vapor pressure reaches a specific level, the valves open to vent the steam. Upon cooling, the valves close, creating a vacuum inside the containers. This approach reduces the impact of edge heating and significantly enhances food quality (Micvac method website, n.d).

This degree project focuses on benchmarking sustainable packaging materials in the food industry using Micvac technology as a specific example. Benchmarking is the process of comparing an organization's performance against best practices within its industry, intending to improve processes and ultimately achieve superior performance (Urošević & Dobrosavljević, 2018). One of the challenges in benchmarking sustainable packaging practices is the lack of industry standards and best practices (Peshkam, 2022). This study proposes the development of an evaluation tool for Micvac technology that incorporates various sustainability criteria to benchmark and evaluate a company's sustainable primary packaging. The proposed evaluation tool considers sustainability factors throughout the product-packaging life cycle such as material selection, recyclability, renewability, carbon footprint, and food waste reduction. Fostering environmental innovation in industrial packaging systems necessitates a collaborative supply chain strategy that mitigates environmental and commercial costs while enhancing the efficiency of the entire chain (Varghese & Lewis, 2007).

Thus, sustainable packaging materials are desirable from an environmental perspective. In addition, modifying packaging materials can impact not only perceptions of sustainability, but also has other advantages such as perceived taste and quality (Steenis et al., 2017). This study demonstrated the importance of packaging in shaping consumer perceptions of food products.

For any real progress to happen in terms of environmental sustainability, close collaboration between supply chain actors is mandatory. According to research (Beckeman, Bourlakis and Olsson, 2013), trust in the supply chain is lacking, information exchange is limited, and some manufacturers seek to collaborate horizontally with other manufacturers abroad. Adopting an "open innovation" mindset would benefit manufacturers and the entire supply chain by encouraging them to work and organize differently, while building trust.

1.2 Research question and objectives

The research question of this study is the central one that guided the research process and helped the author focus on what he wanted to investigate. The principal research question of this study was framed as: "**Among a wide range of different materials from several suppliers, what is the most sustainable option in the market for Micvac packaging solution?”**

To answer this research question, the following research objectives were pursued:

- To conduct a comprehensive review of the relevant literature on packaging materials and technologies for microwave applications in the context of European Union (EU) legislation and Swedish national guidelines. This objective seeks to provide a synthesis of the existing literature on the topic and to identify knowledge gaps that the study can address.
- To collect and analyze primary data on the environmental strategy and trends among Micvac’s customers and other companies that are leaders in the markets where Micvac is operating. This objective entails gathering data through appropriate data collection methods, such as email questionnaires and interviews, and subjecting the data to rigorous analysis to discern patterns and relationships between variables of interest.
- To identify the contextual factors that moderate the relationship between EU legislation, trade organization policies, and other stakeholders in

European markets. This objective aims to explore how various contextual factors, such as environmental strategies, waste hierarchy, and design, influence the relationship between these variables of interest.

- To evaluate the relationship between criteria in different life-cycle stages and their effect on the total environmental impact among the packaging solutions selected for comparison. This objective involves using grades according to specific assigned levels for each criterion to assess the relationship between the different phases of the supply chain and their impact on the final environmental impact.

By accomplishing these objectives, this study aims to advance the understanding of packaging sustainability and offer recommendations for a food packaging company in the decision-making process of selecting materials for future packaging. This facilitation occurs in the context of chilled ready meals that have been processed using in-pack microwave pasteurization. The findings of this study may inform policy and practice in fields such as sustainable packaging development and contribute to the growing body of knowledge on the topic.

The objective of outlining the life cycle map is to enhance the comprehension of the development team regarding the various processes involved in sourcing, manufacturing, using, and disposing of materials and waste, and to compare them with alternative formats of product-packaging systems. The life cycle map also serves as a means of engaging with suppliers, customers, government agencies, and waste management companies to gain insight into their operations and post-consumer waste management technologies and processes.

1.3 Scope and limitations of the study

The scope of this study is to benchmark the sustainable packaging practices of Micvac technology using an evaluation tool that considers sustainability criteria throughout the product-packaging life cycle. This study aimed to identify the packaging requirements of retailers and food manufacturers in the market and integrate these requirements with several packaging solutions that are theoretically suitable for in-pack microwave pasteurization. The goal is to examine the functional equivalency between ready meal configurations and explore how the choice of packaging material (PP, PET, paper, bioplastic) affects the environmental performance of the packaging. In the end, this integration attempts to suggest improvements to Micvac's sustainable packaging options.

The limitations of this study include its focus on Micvac technology as a case study, which may not be generalizable to other companies or industries. Some aspects and attributes specific to Micvac packaging need to be modified when evaluating other types of packaging solutions in other technologies. This editing is particularly relevant for packaging attributes that influence food waste, which is discussed further in this study. Additionally, the evaluation tool proposed in this study may not encompass all sustainability factors or be exhaustive owing to resource limitations. Furthermore, this study did not assess the economic feasibility of implementing specific sustainable packaging solutions within Micvac technology or evaluate consumer perceptions and public acceptance of sustainable packaging options. Despite these limitations, this study makes a valuable contribution to the field of sustainable packaging and benchmarking practices. It provides a framework for evaluating several sustainable packaging solutions that can be adapted and tailored to other companies in the food industry. Moreover, this study highlights the need for standardization of sustainability metrics and practices within the food packaging industry to facilitate benchmarking and improvement efforts.

Due to a limited timeframe and resources, the study investigated the central actors in the value chain, consisting of packaging producers, producers of chilled ready meals, retailers, and end consumers of ready meals. These system boundaries were chosen after internal discussion with Micvac and are presented in Figure 1 and the components of the current package are shown in Figure 2.

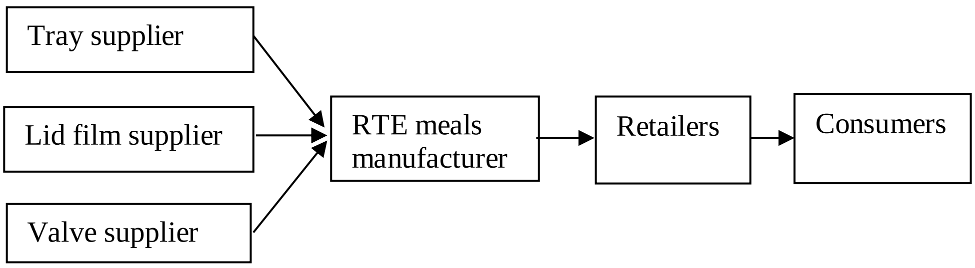


Figure 1. The supply chain of the ready meals packed with Micvac technology

Figure 2. The current Micvac tray, lid film and valve

2 Theoretical framework

This section presents the theoretical basis of this study. The author provides definitions related to packaging development, packaging in the supply chain and ready meals in microwave applications. In addition, the author explores the environmental impact of packaging and provides a holistic view of the packaging materials in the supply chain.

2.1 Packaging Development

2.1.1 Packaging system

Packaging has been defined in numerous ways. In one of the most cited pieces of literature, Paine (1981) defines packaging as: "A coordinated system of preparing goods for transport, distribution, storage, retailing, and end-use". According to the European Directive 94/62/EC: "Packaging shall mean all products made of any materials of any nature to be used for the containment, protection, handling, delivery and presentation of goods, from raw materials to processed goods, from the producer to the user or the consumer".

Lambert, Stock and Ellram (1998) mentioned that an effective packaging design relies on seven primary factors, which include standardization, pricing, adaptability of the product or package, level of protection, ease of handling, packability of the product, and the ability to be reused and recycled (Dahlborg and Johnsson, 2006). It is also crucial to consider the efficient use of storage space and ability to convey information.

According to Aggarwal and Langowski (2020), in a food packaging system, the typical functions of packaging are described as "PCCC", which stands for Protection, Containment, Communication, and Convenience. Marsh and Bugusu (2007) state that the main roles of food packaging are to protect food products from damage and external influences, to contain the food, and to provide consumers with information about the ingredients and nutritional value of the food, while secondary functions of food packaging include traceability, convenience, and tamper indication. Effective packaging can maintain the quality of food by including barriers that keep the moisture content and gas composition consistent (Awulachew, 2022), effectively extending the shelf life of food. Food packaging helps slow down the degradation of products, preserves the positive effects of processing, increases the amount of time a product can be stored, and upholds or improves the quality and safety of food. This is achieved by shielding food from three main external factors: chemical, biological, and physical. According to Hellström, Olsson and Nilsson, (2016) many authors have highlighted seven essential functions of packaging for the product which are described in Table 1.

Table 1. Packaging functions

	Specifications
Protection / Preservation	Protecting the contents of the package from damage caused by physical, chemical, climatic and microbiological factors, increases the amount of storage time for a product, upholds the quality & safety of food
Containment	Holding the content in an assembled unit and keeping it detached from the external environment, makes the products available to consumers
Apportionment	Helps in the efficient yield of products by dividing them into manageable sizes and portions, assists users in inventory management, contributes to the reduction of food waste by promoting the use of appropriate portion sizes
Unitization	Enables the packaging to be tailored to the specific needs of various stakeholders, ensures ease of handling during distribution in the supply chain
Convenience	Ensuring ease and convenience in using the packaging and its contents, making the making easy to open, carry, empty and dispose
Information	Assists users in identifying the contents of the package, provides instructions for proper and effective utilization of the product, can point out tampering
Communication	Makes packaging a significant marketing tool, affects consumer behavior, connecting the brand owner and the consumer, influences purchasing.

Sourced from information retrieved from Hellström, Olsson and Nilsson, 2016

Verghese (2008) described three typical packaging levels: primary (or retail) packaging – its role is to contain and protect the product in addition to contributing to the promotion of the product e.g. a glass bottle; secondary (or merchandising) packaging – holds and contains the primary packaging e.g. cardboard carton box; tertiary (or transport, industrial) packaging – facilitates the movement of the primary and secondary packaging e.g. wooden pallet with a stretch wrap film. The three typical packaging levels are illustrated in figure 3.

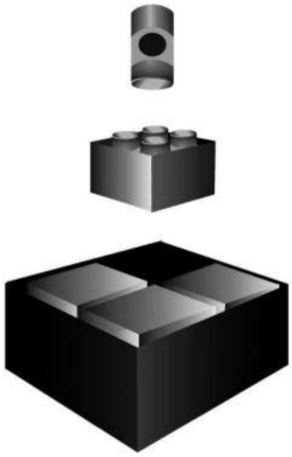


Figure 3. Packaging system levels **Source: Hellström, Olsson and Nilsson, 2016**

2.1.2 Sustainable packaging

The utilization of microwave technology is often recognized as an environmentally friendly method due to its low energy consumption and quick processing time. Consequently, the integration of sustainable microwave packaging and sustainable microwave processing contributes to the advancement of sustainability in the field of packaging science (Thanakkasaranee, Sadeghi and Seo, 2022).

The definition of sustainable packaging is not unified because there is confusion and misunderstanding among stakeholders in distinguishing the attributes that contribute to a sustainable packaging. The most important factors affecting the sustainability of a package are shown in figure 4.

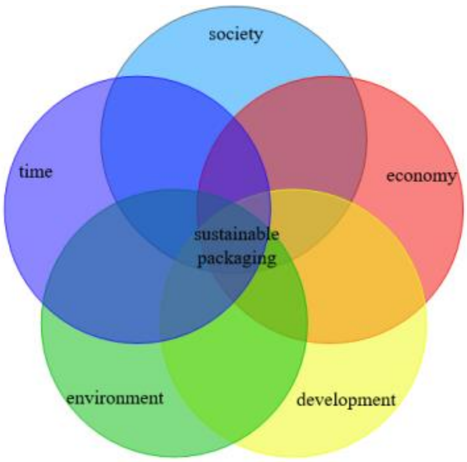


Figure 4. Sustainable packaging factors **Source: Kozik, 2020**

Lekesiztürk and Oflaç introduced a Sustainable Packaging Practices Model (SPPM) and outlined nine sustainable packaging practices that companies could implement to enhance their sustainability efforts. These practices include increasing awareness, developing sustainable raw materials and processes, minimizing packaging material and carbon footprints, reclaiming and reusing materials, conserving energy and utilizing sustainable energy sources, waste sorting and recycling, reducing water consumption and recycling water, obtaining certifications, and co-creating. Their research also highlights the challenges facing the sustainable packaging industry, such as the scarcity and high costs of sustainable raw materials, low demand for sustainable packaging, legal incompatibilities, and production and quality-related issues. Their study suggests that companies can use the proposed SPPM and sustainable packaging practices to improve their sustainability performance and address environmental concerns related to packaging (Lekesiztürk and Oflaç, 2022).

Nguyen et al. (2020) outlined three essential aspects of environmentally friendly packaging as perceived by consumers: the materials used, manufacturing process, and appeal to the market. These factors could be beneficial to packaged food manufacturers and marketers, as they create packaging choices that meet customer demands. This study proposes that packaging for food products, to be considered eco-friendly by consumers, should look appealing while also meeting their expectations regarding the materials used and the manufacturing process in terms of sustainability. It is important for companies to consider sustainable packaging solutions, as there is an increasing demand for such options from both consumers and governments (Nguyen et al., 2020).

Circular economy is a production and consumption model that emphasizes sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products for as long as possible. By adopting this approach, the life cycle of products is extended, in contrast to the traditional linear economic model, which follows a take-make-consume-throw away pattern and relies on large quantities of inexpensive and readily available materials and energy (European Parliament, 2015). This concept is centered on three principles, which are guided by design: minimizing waste and pollution, promoting the circulation of products and materials at their maximum value, and regenerating the natural environment (Ellen Macarthur Foundation, 2019). Kirchherr, Reike, and Hekkert (2017) defined the circular economy as an economic system that replaces the concept of "end-of-life" with the reduction, reuse, recycling, and recovery of materials throughout the production, distribution, and consumption processes. It operates at multiple levels, including the micro (individual products, companies, and consumers), meso (eco-industrial parks), and macro (cities, regions, nations, and beyond) levels. The objective is to achieve sustainable development by fostering environmental quality, economic prosperity, and social equity, thereby benefiting both the present and future generations. This transition is facilitated by innovative business models and responsible consumer behavior (Kirchherr, Reike and Hekkert, 2017).

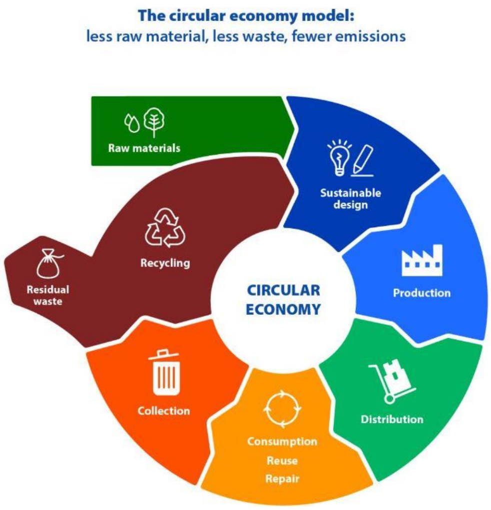


Figure 5. The circular economy model **Source: European Parliament, 2015**

2.1.3 Environmental impact of food packaging

2.1.3.1 Direct and indirect environmental impact

While the direct environmental impact of food packaging is generated by the manufacturing and disposal of packaging materials, the indirect environmental impact is caused by its influence on the life cycle of the food product, such as its impact on food waste and logistical efficiency. Molina-Besch, Wikström, and Williams (2018) found that the indirect environmental impact of packing is overlooked in current food life cycle assessment (LCA) practices. Based on these findings, their study advocates a more systematic assessment of the indirect environmental impact of packaging on future food LCAs. Packaging can be effective in decreasing food waste; however, it is crucial to consider consumer attitudes and behavior towards packaging. To make packaging more effective, it is necessary to study and develop packaging technologies that address the causes of household food waste (Brennan et al., 2021). Moreover, it is important to understand consumer perceptions and acceptance of these technologies. By doing so, it will be possible to create targeted strategies for packaging design that can help reduce household food waste.

2.1.3.2 Post-consumer waste

In ISO 14021:2016, post-consumer material is defined as material generated by households or by commercial, industrial, and institutional facilities in their role as end users of the product, which can no longer be used for its intended purpose. This includes returns of material from the distribution chain (U.S Plastic Pact).

2.2 Packaging in the supply chain

2.2.1 Packaging material in the supply chain

Packaging technology plays a crucial role in food processing, and the appropriate selection of packaging materials and systems is a vital component of both food processing and product design (Berk, 2009). The packaging materials considered in this study are limited to polymers and paper, as they comprise three components of primary packaging: the tray, lid film, and valve.

When choosing materials for packaging, several factors must be considered, such as the location of resource extraction, the efficiency of pallet and transport, and the availability of post-consumer waste management (Verghese, 2008). The packaging materials used for in-package pasteurization need to have several qualities: they must be able to seal when heated, be sufficiently sturdy to handle the processing conditions, provide sufficient barrier properties to maintain the required shelf life, and meet regulatory standards. In addition to these features, the cost of packaging also affects decision making (Sonar et al., 2022).

Generally, the inner section of packaging requires protection to safeguard the product, whereas in chilled or frozen environments, the external surface may also need to be coated to prevent condensation moisture. This helps to maintain the strength and durability of the packaging, preventing it from becoming brittle or fracturing. This coating is typically composed of polymers with various properties in the final packaging (Verghese, 2008).

There is a growing trend of using plastic polymer food packages in retail markets. Combining layers of polymers with unique functions offers flexibility in designing rigid containers or flexible pouches for thermally processed shelf-stable foods. Commonly used polymers in such packages include polypropylene (PP), polyethylene terephthalate (PET), and nylon 6. These materials are transparent to microwaves and are therefore suitable for in-package microwave sterilization and pasteurization processes (Tang, 2015).

Packaging materials that utilize flexible films with aluminum foil laminate possess excellent oxygen and moisture barrier properties, making them ideal for use in military ready-to-eat meals and specific food items in retail markets. However, such films are not suitable for in-package microwave heating processes, because they do not permit the penetration of microwave energy (Tang, 2015).

2.2.1.1 Fiber-based packaging

Fiber packaging is produced from pulp, which is a fibrous material derived from plant fibers that serves as the primary raw material for producing paper, paperboard, corrugated board, and other similar manufactured products. Being sourced from plant fibers, pulp is a renewable resource, ensuring its sustainability in the production process (Robertson, 2016). There are two main types of paperboards commonly utilized by food and beverage companies: corrugated containerboard grade is mainly used in the production of corrugated boxes utilized as secondary packaging, and boxboard grade is primarily used for creating folding cartons that are used as primary packaging. The latter can be manufactured from virgin wood pulp, commonly utilized for beverage cartons and frozen food packaging, or it can also be produced with a significant amount of recycled materials, primarily applied in packaging dry foods (Ceres, 2017). Multi-ply boards are created by combining one or more layers of web plies into a single paperboard sheet (Robertson, 2016).

Most cellulosic fiber materials possess favorable characteristics when it comes to their end-of-life properties, because they are often recyclable and can be processed within already established recycling systems in numerous countries (Schenker et al., 2020). However, cellulosic paper's inherent hydrophilicity due to plentiful hydroxyl groups in the molecule of cellulose restricts some of its applications. To be utilized in specialized purposes such as packaging, paper sheets must be made more hydrophobic (Chen et al., 2022). Other inherent limitations include its porous structure, limited microbial resistance, and low mechanical properties. These characteristics make it challenging to prevent the penetration of moisture and oxygen effectively resulting in a shortened shelf-life of food products packaged with cellulosic paper (Zhang, Xiao and Qian, 2014).

2.2.1.2 Polymer packaging

Polymers are composed of repeatedly connecting carbon building units known as monomers. The molecular structure, molecular weight, degree of crystallinity and chemical composition are factors affecting the properties of polymers (Robertson, 2016). Polymeric packaging is crucial for safeguarding food during transportation and storage and can endure mechanical and thermal stresses caused by traditional high-temperature retort or microwave-assisted food processing methods. To enhance the functionality of packaging, chemical substances may be added to polymeric materials. However, these substances may interact with food components and seep into food during storage or processing, compromising food safety and quality (Bhunia et al., 2013). Plasticizers, antioxidants, thermal stabilizers, slip compounds, and monomers are potential chemical migrants.

Migration refers to the process by which chemical substances present in packaging materials partition into food products (Guerreiro et al. 2018). Several factors influence the migration of chemicals from food packaging, such as the characteristics and composition of the food, temperature, duration of contact, type of packaging material, and properties of the chemicals involved (Arvanitoyannis and Kotsanopoulos, 2013). To investigate the migration of packaging compounds into food, scientists conduct experiments using food or food-like liquids that are exposed to various conditions such as traditional or microwave heating and storage (Bhunia et al., 2013). Analytical techniques, such as chromatography or spectroscopy, are used to measure the migration of chemicals, and from these data, researchers have developed models to assess the risks associated with such migration.

58million tonnes of plastics were produced in Europe in 2019 accounting for 16% of global production. Almost 40% of that quantity is used for packaging, representing the largest end-use market with the rest being distributed among sectors such as construction, electronic, electrical etc. Just over half of the plastics total quantity is composed of polypropylene (PP) and polyethylene (PE) with a large proportion dedicated to food packaging (PlasticsEurope, 2020).

Polyethylene terephthalate (PET) is a polyester with excellent tensile strength, although it needs to be oriented to achieve full strength. It is lightweight, flexible, chemically resistant, and temperature stable. PET products such as boil-in-bags and oven bags have been utilized. PET has good barrier properties for gases, odors, and lipids, but its water vapor permeability is high (Awulachew, 2022). Coatings of black or white PET provide heat resistance and act as effective grease barriers. Typical applications include ovenable trays, packaging for reheatable products, and baking products (Stora Enso, n.d.).

PP is a material that has a chemical structure similar to PE, but it is more durable and less oily. It can be found in the form of sheets, films, trays, and bottles that retain their shape when exposed to high temperatures, allowing them to be sanitized or filled with hot water. In addition, PP is resistant to grease and solvents, has good fatigue resistance, and is not prone to stress cracking. However, PP has poor cold-temperature resistance. Biaxially oriented PP films have been developed to improve the gloss, clarity, impact strength, and barrier properties against water and oxygen (Awulachew, 2022).

Polyvinyl chloride (PVC), being a thermoplastic material, can be easily processed using standard plastic processing methods like extrusion, calendaring, injection, and blow molding. PVC can either be rigid or flexible. Rigid PVC is characterized by its strength and hardness due to its lack of any additional additives. On the contrary, flexible PVC contains additives, such as plasticizers, which give the material softness and flexibility, allowing it to exhibit rubber-like elasticity and possess high tensile and fatigue strengths (Almqvist and Larsson, 2021).

2.2.1.3 Bioplastic packaging

When it comes to sustainable packaging of pasteurized foods intended for use with microwave technology, there are a few options to consider. To clarify the definition of bioplastics, it is important to understand that they can be categorized as bio-based, biodegradable, or a combination of both (European Bioplastics, 2019). It should be noted that bioplastics can also be non-biodegradable. Additionally, the term "bioplastic" does not necessarily imply that it contains any bio-based materials; it can be entirely composed of fossil-based components. Bioplastics can encompass various combinations, including being partially or fully bio-based, non-bio-based, biodegradable, compostable, or non-biodegradable, as long as they are not simultaneously non-bio-based and non-biodegradable (Borhauer, 2019).

Hatti-Kaul et al. (2020) highlighted the importance of rational polymer design for desired functionality and recyclability. Despite their spotlight, the production volumes of bio-based plastics currently constitute less than 1% of the total plastics produced, amounting to 335 million tons in 2016. This limited market share can primarily be attributed to the competition from inexpensive virgin plastics derived from readily available fossil resources, which often remain untaxed despite their carbon content. Additionally, the sourcing of biomass feedstocks and the lack of well-established recycling and disposal methods pose additional challenges to the adoption of bio-based plastics (Hatti-Kaul et al., 2020). It is important to note that very few biodegradable or compostable materials are suitable for microwave use; therefore, careful consideration must be taken to ensure that the chosen packaging is safe for use in microwaves. Bio-based polymers like polylactic acid (PLA), polyhydroxy butyrate (PHB), and poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) have exhibited favorable properties for food packaging, but their low thermal stability needs to be enhanced before they can be widely adopted by the microwave food packaging industry (Thanakkasaranee, Sadeghi and Seo, 2022).

2.2.2 Packaging logistics

The idea behind packaging logistics is to combine packaging and logistics systems to achieve greater supply chain efficiency and effectiveness. This can be achieved by enhancing both packaging and logistics-related activities. To accomplish this goal, one strategy is to focus on developing packaging that can benefit the logistical system, which is often referred to as logistical packaging (Saghir, 2004). Samuelsson (2003) highlighted the significance of packaging in logistics and how it offers competitive advantages to companies. By establishing long-term packaging strategies, businesses can enhance their efficiency and minimize expenses. Effective communication among stakeholders involved in the packaging process is critical for successful packaging logistics (Samuelsson, 2003).

In their book, Regattieri, Santarelli and Piana, (2018, pp. 273-303) discuss the importance of packaging in logistics and outlined several aspects that should be considered when developing a framework for packaging. The containment function of packaging is important for restraining the contents, whereas the unitization function allows primary packages to be grouped into larger, more efficient loads. Standardization of packaging sizes is considered optimal for logistics efficiency, although it may lead to less adaptability to change. The storage and distribution of products should also be considered, with technologies such as barcodes and RFID improving traceability and reducing delays and theft along the supply chain (Regattieri, Santarelli and Piana, 2018).

In their case study, Julius and Shan (2015) mentioned that according to Stock and Lambert (2001), inbound and outbound logistics activities involve the physical transformation of goods, resulting in providing customers with place, time, and form utility. The transformation of goods involves various operations such as transportation, which mainly alters the location of goods. On the contrary, warehousing primarily transforms the time utility of goods. In addition, handling encompasses smaller operations that are integrated while performing other logistics activities (Julius and Shan, 2015).

2.3 Ready meals

2.3.1 Ready-to-eat meals

Ready-to-eat (RTE) meals are food products that are considered safe for consumption without requiring any further preparation, although some people may choose to perform additional preparations, such as reheating for enhanced taste or appearance (U.S. Department of Agriculture, 2023). RTE meals are a convenient means of replacing traditional meals, and they have become increasingly popular due to their simplicity, safety, and convenience (Hillier-Brown et al., 2017). The demand for fresh and convenient RTE meals has been on the rise in recent years owing to different factors, such as busy schedules and changing consumer preferences for fast and easy meal solutions.

2.3.1.1 Chilled ready meals

As part of the ready meals category, chilled prepared meals offer convenience by streamlining the process of purchasing, preparing, and cooking food. This saves time and energy that would otherwise be spent searching for ingredients, washing them, and preparing them for cooking (Chilled Food Association, n.d.). In addition, these meals minimize waste by eliminating the need to purchase excessive amounts of ingredients that may go unused and end up being discarded. Moreover, during the manufacturing process, non-edible components, such as vegetable tops, bones, and peels, are removed before packaging, thus reducing waste that would otherwise be generated from domestic waste.

2.3.2 In-package pasteurization and active packaging

Before describing the Micvac technology, it is necessary to explain the pasteurization technique it is based on. Pasteurization is a heat treatment method in which food is heated to temperatures below 100 °C to mitigate potential health risks associated with pathogenic microorganisms in low-acid foods. Additionally, pasteurization is employed to prolong the shelf life of acidic foods by eliminating spoilage microorganisms and deactivating enzymes, thereby allowing the products to remain fresh for several days or weeks (Fellows, 2009). Food products are commonly pasteurized using thermal methods for commercial purposes. This can be achieved through hot-filling (cook&chill) or in-package process technologies. The growing demand from both the industry and consumers for food with enhanced sensory quality has spurred the advancement of microwave-assisted thermal pasteurization systems. There is also an increasing interest from consumers and industry in utilizing high-performance polymers and laminated paper packaging for pasteurized food (Sablani, Sonar and Tang, 2023). Punathil and Basak (2016) reviewed the microwave-assisted processing of different food products, where they compared the microwave cooking to the conventional cooking regarding weight loss, flavor score, effect on fat content, fate of the pathogens, retention of vitamins, moisture content.

Robertson (2016) classifies microwave packaging materials in three categories according to their properties. All plastic materials used in food packaging, paper products and glass are in the transparent category, meaning they do not react or absorb microwave energy. Microwave susceptibility includes the materials that can absorb microwaves and re-emit them as heat, which are named susceptors, typically thin metal films such as aluminum or iron. The third category is characterized by materials who can reflect microwaves without absorbing them. These microwaves-shielding materials are metalized thick films or aluminum foil (Robertson, 2016).

In-package pasteurization is defined as a food processing technique that involves heating a sealed package containing a food product to a specific temperature for a designated period to eliminate microorganisms and prolong the product's shelf life (Sonar, Tang and Sablani, 2022). Typically, the method includes packing the product into containers under vacuum and subjecting it to thermal treatment in a hot water bath at 70–90 °C or a microwave system. After the desired level of microbial inactivation is achieved, the product is rapidly chilled. This method reduces the risk of contamination after processing. However, the packaging material is also exposed to heating conditions during in-package processing, which is not the case with hot-fill processes. As a result, polymer packaging materials must be able to endure high process temperatures and water exposure during pasteurization while keeping intact their structural integrity, visual appearance, and barrier properties (Sonar, Tang and Sablani, 2022).

Active packaging technology is characterized as a means of improving the safety, quality, and shelf life of packaged foods. The primary objective is to modify or manipulate the atmospheric conditions of packaged foods during storage (Alves et al., 2022). In the European Union, Regulation (EC) No. 450/2009 outlines the particular requirements for active packaging materials. Article 3 of this regulation states that ‘active materials and articles refer to materials and articles intended to extend the shelf life or to maintain or improve the condition of packaged food; they are designed to deliberately incorporate components that would release or absorb substances into or from the packaged food or the environment surrounding the food; ‘intelligent materials and articles’ means materials and articles which monitor the condition of packaged food or the environment surrounding the food (Commission Regulation (EC) No. 450/2009). Oxygen absorbers represent the largest market for active materials, many of which have been evaluated and approved by the European Food Safety Authority (EFSA) (Dainelli 2015).

2.3.3 Micvac technology

Currently, Micvac packaging for ready meals is composed of three components: a PP tray, a polyamide-polypropylene (PA-PP) lid film, and a PVC valve. Each food package is equipped with this recloseable valve which is at the core of the packaging functionality. The trays are filled with fresh ingredients according to the food manufacturer’s recipe. Afterwards, the trays are sealed with a film which gets punched with a hole in its center. The hole is covered with a Micvac valve, which is a unique component of this process. The prepared trays pass through the microwave tunnel where they are cooked for 5-10 minutes. A higher amount of nutrients is retained in the food product because of the short duration of the heat treatment. The buildup steam inside the package is released by the valve which opens at a specific pressure point. The valve closes when the temperature and the pressure decrease, leaving a small quantity of steam in the package which condenses, thereby creating a natural vacuum. After cooking is finished, the trays are cooled naturally which is accelerated by their concave shape post-treatment. No preservatives are used during the process which is illustrated in figure 6.

The Micvac method represents the success of microwave pasteurization of ready meals, making it a very efficient process (Olaniyi, 2017). The food ingredients are packaged in trays, sealed with a lid film and valve, and then pasteurized, which reduces the risk of human contamination after the process is finished.

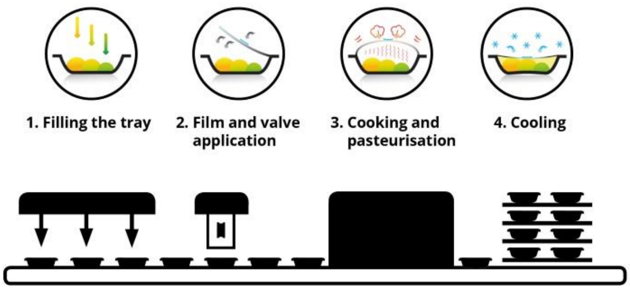


Figure 6. Micvac in-pack pasteurization technology   Source: Refrigerated&Frozen Foods, 2018

Larsson and Hjelmberg concluded that Micvac method is superior to other competing technologies because of its shorter pasteurization/cooking time, resulting in enhanced taste, nutritional value, color, and texture. Compared to other technologies, Micvac's chilled ready meals are easier to prepare and have a longer shelf life, except for autoclave and sous-vide, which may achieve the same shelf life. Micvac also boasts lower production costs, higher production efficiency, shorter payback time, and higher net present value for large-scale production than cook-and-chill. Micvac technique is a revolutionary innovation for producers of chilled ready meals, whereas for wholesalers and end customers, it represents an evolutionary innovation (Larsson and Hjelmberg, 2010).

Apart from the primary packaging, Micvac provides the equipment needed for in-pack pasteurization, including machinery for preparing and sealing the packaging material, as well as the microwave tunnel used for cooking. This comprehensive approach enables Micvac to have a deep understanding of the dimensions and processing capacity required for the process (Hosse Pastor, 2021).

3 Methodology

This section describes the research approach and design used in this study. The data collection and analysis methods are explained in detail. In addition, the development of an evaluation tool used to compare different packaging solutions is outlined.

3.1 Research approach and design

This research was devised as an investigative case study, with both qualitative and quantitative data collected. An investigative case study has been defined by Karlsson (2016, p. 7) as a research method that involves an in-depth and detailed investigation of a particular case, event, or phenomenon in a real-life situation. Through this qualitative research approach, the techniques of data gathering, and analysis are combined to produce a comprehensive and detailed understanding of the case at hand. A mixed methodology was used in this study to increase the depth of understanding by combining the elements of both quantitative and qualitative research.

This type of study was chosen because it allows the identification of the underlying causes, motives, and circumstances that contribute to a specific event or outcome, as well as the potential implications for future research and practice. Case study research is bounded by and depends on its context, which means that the study must include a sufficient description of the context (Karlsson, 2016). A thorough understanding of the supply chain and a firm grasp of the company's position are required for this study. This approach typically involves a combination of primary data collection methods, such as interviews, observation, and document analysis, as well as secondary data sources, such as literature reviews and archival research.

The research aim and research question were framed in the circumstances of investigating and benchmarking sustainable packaging materials that are suitable for the microwave technology pioneered by Micvac, which then proceeded to select the packaging solution with the least environmental impact in a holistic perspective. This selection was performed through a comprehensive analysis of different aspects of environmental impact using an evaluation tool that was designed in a previous study but was modified to fit Micvac's packaging requirements.

It is crucial to ensure coherence and alignment between all the components of a research project. A well-thought-out design for the data collection phase is necessary, which involves making decisions about the roles and responsibilities of all involved parties; determining the locations, timings, and methods to be employed at different stages of the research process; recognizing the researcher's role as a data collection instrument; and considering the research context and the participants and informants involved (Paradis et al., 2016). This project plan and its outcome are detailed in Appendix A.

An extensive system approach was adopted to evaluate the environmental impact of the product by considering all phases involved in its life cycle, thus encompassing a broader holistic perspective. Furthermore, the case study approach allowed for a comprehensive understanding of Micvac's supply chain and its position within it, which was crucial for identifying sustainable packaging opportunities. This approach allows for the examination of both objective and subjective factors that contribute to sustainable packaging solutions compatible with Micvac's microwave technology, thereby providing an in-depth analysis of the subject matter.

Furthermore, this approach recognizes the limitations of traditional life cycle assessments, as it incorporates other important factors beyond the environmental impacts that are essential to determining sustainability. The study utilized a case study research design because it facilitated the identification of the causes, motives, and circumstances that contributed to a specific outcome, and allowed for the exploration of the complexities associated with sustainable packaging solutions compatible with Micvac's microwave technology.

3.2 Data collection and analysis methods

Data collection is the process of collecting data to gain insights into a research topic (Taherdoost, 2021). There are various types of data and different data collection methods. As mentioned by Yin (2018), case study research relies on multiple sources of evidence; hence, mixed data gathering is an appropriate technique for this study. For this reason, various data collection methods were conducted during this study to obtain input from different stakeholders in the supply chain, which assisted the development of an evaluation tool for the company.

To keep the scope of the study manageable, five packaging solutions deemed most relevant to the Micvac processing and product–packaging system were selected by the author. Literature research was conducted, consisting of both scientific and grey literature on sustainable packaging materials suitable for use in microwaves, EU legislation on packaging and packaging waste, market trends and trade organization policies on packaging materials, and current design-for-recycling guidelines. The literature was obtained from both the Lund University databases and through a systematic review of relevant studies and articles utilizing Google Scholar. Search words included 'food packaging, 'microwave pasteurization', 'rigid packaging', 'sustainable material', '', 'design-for-recycling' as well as various combinations and phrases of the aforementioned words. Information was also retrieved from companies' websites linked to their environmental strategies and guidelines for design-for-recycling.

Virtual interviews and email communications were conducted with relevant stakeholders, such as suppliers of the three packaging components: tray, film and valve, brand owners which are customers of Micvac, and retailers. Semi-structured interviews were chosen for the purpose of this study as it is a widely used data collection method that involves posing questions within a predefined thematic framework (George, 2022). As they combine elements of structured and unstructured interviews, these interviews allow detailed and rich data owing to their open-ended nature and flexibility to ask follow-up questions. In this structure, patterns can be identified while enabling comparisons between the respondents' answers. A list of respondents in these communications is provided in Table 2.

Table 2. Details of the actors that were involved in the data collection process

Supply chain actor	***Communi-cation***	***Position***
Tray supplier: Faerch Plast s.r.o	Online interview	Process & Product Specialist
Food manufacturer: Lantmännen Cerealia	Online interview	Packaging Lead
Food manufacturer: Orkla Foods AS	Online interview	Senior Packaging Developer
Retailer: Dagab, Axfood	Online interview	Packaging Developer
Waste handling: Förpackning & Tidnings Insamlingen (FTI)	Email question-naire	Material specialist
Waste handling: Svensk Plaståtervinning	Email question-naire	Development Engineer

The participants held different positions in the companies they represented. The intention of implementing an interview-based qualitative study was to gain rich data and reach beyond the respondents' immediate verbal responses. The respondents were interviewed using open-ended questions supported by brief discussions. All interviewees received general questions several days in advance, and the interviews were conducted in early spring 2023, between March and April, see list of collaborators in Figure 7. A full list of the questions asked during the interviews is provided in Appendix B. Actors active in both the Swedish and international markets were consulted, such as Förpackningsinsamlingen or FTI (the Packaging Collection Service in Sweden), RecyClass, and the Fibre Packaging Europe Alliance.

Figure 7. Project collaborators and different stakeholders in the supply chain

Additional email questionnaires were also conducted with other stakeholders, such as potential material suppliers and Svensk Plaståtervinning (Swedish Plastic Recycling). Depending on the type of stakeholder, questions were developed and adapted to the organization's area of work.

The data collected through products datasheets, specifically the trays, was analyzed and presented using Stackbuilder software. The models are found in Appendix C.

The data for the ready meals packaging trends were taken from Euromonitor International which, for more than 40 years, has been engaged in publishing, market research, business reference, and online information systems. The company is a renowned supplier of market analysis and global business intelligence, producing worldwide reports for various regions including Western Europe, Eastern Europe, North America, Latin America, Asia-Pacific, Oceania, Africa, and the Middle East. These market reports are widely utilized in various industries for marketing and strategic planning purposes. It is part of the Lund University LUBsearch databases. Some data regarding the ready meals market was taken from the Statista website.

3.3 Development of the evaluation tool

3.3.1 Overview of the methods and tools used in the packaging industry

Different methods and tools are used in the food packaging industry to evaluate the environmental impact of the packaging materials. Tools and methodologies used to support sustainability assessment of a food business should be utilized in the first stages of the new food product development process and then be continuously updated when more information on the production processes and wider data on the food supply chain is gathered, because considering sustainability aspects beforehand potentially improves the overall sustainability result of the food business (Garcia-Garcia, Azanedo and Rahimifard, 2020).

As a method used to measure the environmental effects related to a particular product, life cycle analysis (LCA) is a principal tool utilized to assist decision-making for sustainable development (Hill, 2013). During an LCA, experts compile a list of the resources employed and the pollutants produced during the production and usage of the product. According to Hill, the standardization of LCA approaches aims to uphold adaptability while guaranteeing accuracy and comprehensibility in the resulting reports. Corporations, marketers, and regulators are the primary users of LCAs as a comparative tool for making informed decisions on their activities. The use of LCA enables the identification of "trade-offs" and prevents an increase in the carbon footprint, energy consumption, or emissions in one aspect of the process due to modifications made in another aspect or product formulation (Levy, 2017). For example, increased recycling of specific inflexible materials in a product may be balanced by the advantages of reducing sources by using flexible materials in other products. A significant outcome of LCA is the comparison of environmental emissions to a benchmark. This benchmark serves as a reference point for assessing improvements, such as reducing the amount of air pollutants that contribute to global warming, greenhouse gases (GHG) emissions, water effluents, solid waste produced after the product's use, or energy consumption throughout the product life cycle. Establishing this benchmark is a crucial aspect of LCA.

However, an LCA does not evaluate the performance of a product or its individual components. The principle of "functional equivalence" is inherent in LCA, presuming that the product functions according to its intended design (Levy, 2017). The outcomes derived from LCA are valuable to environmental specialists but may not be as applicable to other departments within the company. The team responsible for packaging development has minimal control over several aspects of the packaging life cycle, such as material production, supply chain transportation, and waste management procedures (Molina-Besch and Pålsson, 2019). Consequently, LCA-based findings may have limited significance for their work. Due to these limitations and other drawbacks mentioned by other researchers (Udo de Haes, 1993), the author determined that an LCA is not the proper tool to fit the scope and the capabilities of this degree project.

PIQET is another widely used environmental tool that assists companies in making informed decisions about packaging design. It provides a scientific basis for supporting and quantifying changes in packaging, as well as demonstrating and quantifying improvements in packaging. PIQET can help government, researchers, and non-government organizations understand the context in which companies must make packaging design decisions (Horne, Verghese, Fitzpatrick, Jordan, 2006). For example, it can help companies choose between a lightweight non-recyclable component and a heavier recyclable component. The use of PIQET demonstrates to company stakeholders such as customers, suppliers, shareholders, and government a continuous improvement approach to packaging sustainability.

Olsmats and Dominic (2003) presented the Packaging Scorecard, a packaging performance method with a comprehensive approach to evaluating the role of packaging in enhancing efficiency and value creation along the product supply chain. This tool has been tested in two case studies by its authors and is based on the analysis of packaging functional criteria, and the Balanced Scorecard management theory, which evaluates organizational performance from various perspectives. Their conclusions suggested that the Packaging Scorecard is a valuable tool for gaining a systematic understanding of the performance of packaging across the entire product supply chain. The Packaging Scorecard has been used by other authors in their works, for instance to evaluate the performance of frozen meal packaging system in the cold supply chain (Dhamodharan, 2019). Despite its accepted value in supporting the decision-making process, the tool has been criticized for having broad factors that are not divided into subcategories, making it difficult to precisely weigh the factors. The subjective views of respondents may also affect the scores given to packaging solutions, and the lack of explanations for the given scores is another criticism (Dahlborg and Johnsson, 2006). This tool was not utilized since the purpose of this thesis is to evaluate specifically the environmental impact of the packaging which although it is included in the Packaging Scorecard method, it is not the purpose for which it was developed.

3.3.2 Importance of the tool to the company

In order to meet Micvac's ambitious goals for lowering its environmental footprint, the packaging designers of the company require a reliable tool that provides trustworthy results and facilitates decision-making. According to Lindahl (2006), an environmental tool should be user-friendly, easily understandable, adaptable to the company culture, require minimal set-up time and inputting of data, and present results in an appropriate visual format. Additionally, it must address relevant issues, and offer reliable and applicable results.

To develop sustainable packaging, companies must clearly define their strategies and approaches and communicate them extensively among their employees (Verghese, 2008). This aids in making informed decisions and trade-offs. The product-packaging development process should integrate environmental assessment tools, and employees must be trained to understand their importance and usage.

The suggested tool in this project will evaluate Micvac packaging regarding its environmental performance by using the evaluation tool to compare actual and potential future packaging formats in the future. This model benefits Micvac by enabling its packaging development team to make quick and comprehensive evaluations of new packaging projects that could rise based on the demands of the markets where the company is operating.

Furthermore, this tool serves as a blueprint that can be used further by the company to evaluate the environmental performance of their competitors' packaging, thus strengthening its value proposition and offer in the market. Consequently, Micvac will have another framework at its disposal which will facilitate the company's path towards achieving a competitive advantage to other alternative technologies for RTE meals, such as cook-and-chill, retort, sous-vide regarding sustainable production processing.

The implementation of an environmental evaluation tool for packaging design is crucial for Micvac to achieve its sustainability goals and remain competitive in the market. Additionally, this method facilitates the achievement of the company's goal of reducing its environmental footprint by providing reliable and measurable information about the environmental performance of packaging solutions analysed in this paper. This information is estimated to be highly relevant for the company's packaging development team to take more environmentally conscious decisions about their packaging, as well as enabling comprehensive evaluations of new potential packaging.

Overall, the environmental evaluation tool proposed in this project can greatly benefit Micvac in terms of making informed decisions towards sustainable packaging design and setting itself apart from its competitors.

3.3.3 The tool framework used to evaluate the packaging solutions

The evaluation tool was constructed using a comprehensive literature research of existing sustainable packaging practices and metrics applied in other industries combined with the specific requirements of Micvac. The basis of the proposed tool is a simplified environmental evaluation method, named the Environmental Evaluation for Food Packaging (EEFP) tool. The tool was developed by Molina-Besch and Pålsson in collaboration with Orkla Foods, an international brand owner which is also a customer of Micvac in Norway. The academic researchers worked on an iterative process to create the EEFP, which evaluates packaging systems based on packaging criteria sorted into four areas representing the life-cycle steps of packaging material production, transport, household, and end-of-life. This tool enables a parallel assessment of eco-efficiency and eco-effectiveness in a life cycle perspective and takes into account various factors contributing to packaging sustainability. Upon conducting a thorough evaluation of the LCA screening results for three distinct packaging cases, it has been observed that there were no notable differences in the outcomes generated by this tool (Molina-Besch and Pålsson, 2019). Despite its lack of complexity and LCA scientific accuracy, this tool boasts numerous advantages such as being easily accessible to individuals without specialized knowledge about LCA methodologies. Additionally, relevant input data is readily available within typical packaging development projects. Furthermore, usage of this tool promotes collaboration among different departments within an organization due to its user-friendly nature (Molina-Besch and Pålsson, 2019).

Therefore, the tool has already been revised and verified in its original article, so it is outside the scope of this project to verify the results of this study evaluation by comparing them with screening LCA results. The author contacted H. Pålsson, one of the authors who created the original tool through email communications. After a brief description of the desire to use the tool and the granted permission to use it for the purpose of this thesis, the author clarified some questions and points of interest with the designer of the original tool which were beneficial in the comprehension, modification, and utilization of the tool to achieve the objectives of this research. Afterwards, the author constructed the tool layout utilizing Microsoft Excel version 2304 software program.

3.3.3.1 Modifications of the tool tailored to this specific study

The author tailored parts of the original tool to fit this project and adapted it to Micvac's needs before applying it to the packaging solutions selected for this project. The modifications were made in accordance with the company's requirements and prospects of future use of the tool. These specific requirements were identified through consultations with various departments within the company as well as external material. The edited tool structure reflects better the view of the author regarding the evaluation of the packaging solutions.

The third area of the tool, which in the article of Molina-Besch and Pålsson (2019) covers the influence of household food waste, was edited to include influence on food waste from all the supply chain phases. One reason for this change is the design and information attributes which make up the third area of the original tool framework have miniscule differences between all packaging solutions. Therefore, new design and attributes were established during three internal meetings with a Micvac team consisting of the CEO, the packaging manager, the project and innovation director, and the technology manager. During these meetings, it was decided that it is interesting to evaluate the effect on food waste of the relevant attributes of Micvac packaging throughout the life cycle of the product, instead of limiting it to household consumer waste. As the tool is meant to be used in the future to evaluate other packaging solutions from Micvac or its competitors, it is important to select attributes that go beyond the packaging material aspect. Different supply chain phases need to be considered which generate relevant information to all actors, giving in turn a holistic view of food waste. It is particularly relevant to include in the tool the processability of the package, its processing concepts and how that affects the food waste in the product.

Since microwave-assisted pasteurization plays a fundamental role in the Micvac technology, monitoring and ensuring the stability of parameters of time and temperature during pasteurization is essential. If time is not long enough or the temperature is not high enough, whole batches of production can be wasted due to food safety not being achieved. Additionally, the ingredients supply needs to be balanced during the production phase. The oversupply of perishable food ingredients can lead to their waste if other ingredients are missing from the storage. A bigger production run, i.e a quantity of units that are produced continuously by a production line (Spacey, 2017), means a smaller food waste in the production site.

Another main modification of the original tool was the estimation of an overall value for the environmental performance of each packaging solution. The lack of a single value for the overall environmental impact performance can make it difficult to pinpoint which packaging system performs best when there are trade-offs between the four areas. Compared to the other solutions, a packaging can perform better in one area but worse in three other areas. To make it easier for the packaging developer and the layman reader to draw conclusions from the results of the assessment, a final score was drawn as an average of the averages of the criteria in four assessment areas, where each area’s average has a different relative importance in the final score. The authors of the EEFP tool suggested the prioritization of the areas of packaging material and influence on food waste over transport efficiency and packaging end-of-life as according to the literature it is the former areas who have the highest impact on the environment (Molina-Besch and Pålsson, 2019). The author concurs with this observation and puts the highest relative importance in the following order: influence on food waste, packaging material, packaging end-of-life, transport efficiency.

Food products produce different amounts of emissions based on their type, production method, transportation among other factors. Animal-based products account for 58% of all food emissions because of the burping of ruminants and the production of manure, both of which are sources of methane (Poore and Nemecek, 2018). According to Hosse Pastor (2021), a Micvac's meal content represents 88% of the carbon footprint, while 12% is attributed to the packaging material, waste handling, and transportation. However, this figure represents only the carbon footprint, referred to as the sum of greenhouse gases emissions expressed in carbon dioxide (CO_2) equivalents (Mello, 2021), which is just one measurement of environmental impact. The environmental footprint includes other factors as well, such as terrestrial acidification and eutrophication. Additionally, this value shows the carbon footprint of the whole meal which takes into account all the stages of producing a 400g ready meal. However, in the tool only the food waste is being evaluated, which makes up a lower amount than the whole food product. Around 14% of the food produced around the world is lost during the period from harvest to retail while an estimated 17% of global food production is wasted (United Nations, 2022). These figures represent all food products, which are assumed to consist mostly of fresh and highly perishable products. Pasteurized ready meals have an extended shelf-life due to their method and despite insufficient data on their food waste, it is assumed to be lower than the global waste % of all food products. Furthermore, the attributes which make up the third area of the tool were decided after meetings with the Micvac team. Thereby, the performance criteria and their respective levels were not determined on empirical data and accepted standards, but they were based on the experience of the company's packaging developers and discussions on what they have come across during their work. Based on these reasons, the author decided to set the influence of food waste in the tool result as 44%, at half of the carbon footprint generated by an average ready meal as mentioned by Hosse Pastor (2021).

Klimatkompassen® is an environmental tool created by Tingstad, a supplier of disposable, workwear, containers, and cleaning products, in collaboration with the Research Institutes of Sweden (RISE). This tool simplifies sustainability and allows for easier comparisons between different products with the aim of establishing a sustainable system where the market can access previous decisions made and comprehend their impact at the end of the chain (Research Institute of Sweden, n.d.) The tool evaluates the products through four climate categories namely materials, circularity, transport, production. Each category has a different weight in the product's final score, specifically material 45%, circularity 30%, transport 15%, production 10% (Tingstad, n.d.). These values are similar to those reported by Hosse Pastor (2021), who analysed the CO_2 emissions along the supply chain of a Micvac ready meal, concluding that, excluding the food waste, the packaging material contributes 43% of the total carbon footprint, waste handling makes up 35%, followed by the transportation at 22%. The higher importance of the packaging material phase compared to the end-of-life phase is in agreement with an LCA research which concluded that the production phase of trays used to package meat have a predominant influence over the end-of-life stage on the final environmental results (Maga, Hiebel and Aryan, 2019).

Relying on these results, the author concluded that the relative importance of the in the final score of packaging performances to be distributed as follows: the influence of food waste 44%, packaging material 28%, packaging end-of-life 19% transport efficiency 9%. However, these values are easily modifiable in the tool if the company deems it necessary to update them when the circumstances change in the supply chain. If Micvac is interested in increasing a factor's importance in the final result, based on their strategy and recent findings on waste in the ready meals market, it is advised to change these percentage weights accordingly and cautiously.

4 Results and Findings

In this section, the author presents the results of the study. An overview of the packaging materials investigated is provided, followed by a comparison of the different packaging solutions selected for the evaluation tool. The advantages and disadvantages of different packaging materials for microwave use are also described. The writer analyzes the regulatory and market trends affecting the ready meals and their packaging materials markets.

4.1 Overview of the investigated packaging materials

Thanakkasaranee, Sadeghi and Seo (2022) categorized functional packaging materials designed for microwave applications into two distinct groups: non-self-venting materials and self-venting materials. The former group includes materials exhibiting high-temperature and dimensional stability; heat-enhancing materials such as polymeric nanocomposites containing clay or carbon black; high mechanical strength materials such as cellulose-based polymer composites; fiber-based materials with modified atmosphere (MAP) including many paper trays in the ready meals market. Self-venting materials are characterized by having an incorporated mechanism which safely releases the buildup steam during microwaving. Some applications include temperature-resistant materials maintaining a balanced sealing strength-peeling ease property such as multilayer structures of PP and PE; microperforated venting materials such as specific PET/PE layers which when melted, they create holes in the multilaminate film allowing steam to escape the package; materials showing temperature-dependent permeability such as poly(ether-block-amide)/polyethylene glycol composite films and low density PE/paraffin wax composite films (Thanakkasaranee, Sadeghi and Seo, 2022).

Sonar, Tang and Sablani (2022, pp. 307-321) discussed the use of polymer packaging for in-pack thermal pasteurization technologies. To achieve the necessary properties for in-package processing, monolayer containers are not commonly used due to limitations of each polymer. Multilayer structures are used to attain desirable properties at an optimum cost, varying from 3-ply to 9-ply with an inner food contact/heat sealable layer, a barrier layer, and an outer heat stable, water-resistant and printable layer. Commercially pasteurized products are packaged in trays, films, or pouches with a wide array of oxygen barrier properties, but generally, products prone to oxidation are packaged in higher oxygen barrier pouches. Packaging materials must withstand high temperatures, humidity, and pressure during in-package pasteurization processes while retaining visual integrity and barrier properties. As shown in table 3, the selection of appropriate packaging materials must consider package thermal properties, gas barrier properties, mechanical properties, and food-package interactions (Sonar, Tang and Sablani, 2022). To maintain the quality of pasteurized products, packaging with low to medium gas barrier properties can be used as these products have a limited shelf life when stored under refrigeration. The quality loss caused by oxidation is mainly controlled by the oxygen transmission rate (OTR) of the packaging material, while the water vapor transmission rate (WVTR) determines the moisture losses during storage (Sonar, Tang and Sablani, 2022).

Table 3. The criteria and factors influencing the packaging selection
Source: (Sonar, Tang and Sablani, 2022)

Criteria	*Affecting factors and parameters*
Migration	Food-package interaction Nature of the food product
Gas barrier properties	Oxygen transmission rate (OTR) Water vapor transmission rate (WVTR)
Visual integrity	Package thermal properties: Glass transition temperature (T_g) Melting temperature (T_m)
Mechanical properties	Tensile strength Elastic modulus Elongation at break

Active packaging technology has revolutionized the way in which food products are stored and preserved. Active packaging involves adding substances to the packaging materials that help preserve or extend the quality and shelf life of the product. On the other hand, intelligent systems are designed to monitor the condition of the packaged food during transportation and storage, providing information about the quality of the product (Regattieri, Santarelli and Piana, 2018). These systems typically incorporate active agents that serve specific functions, such as antimicrobial or antioxidant activity. Active packaging systems can react to various food or environmental stimuli, which enables them to monitor and maintain food quality and safety in real-time. As a result, active packaging systems have a significant impact on reducing food waste (Alves et al., 2022). Active barrier films aim to maintain a modified atmosphere within a packaged food item for a longer period by adding an additional oxygen barrier to the packaging material. This is typically achieved by using high barrier materials like polyvinylidene chloride

(PVDC), ethylene vinyl alcohol (EVOH) and aluminum. Active barrier films include polymers that can absorb the oxygen entering from outside the package, thereby increasing its shelf life (Dainelli, 2015). Awulachew (2022) argues that the success of active packaging will depend on how well it is accepted and whether it is cost-effective for businesses and consumers. These factors will ultimately determine the future development and use of this type of packaging.

Active packaging is becoming more popular due to advancements in packaging technology and changing consumer demands. This type of packaging can help extend the shelf life of processed foods and is divided into two types: adsorbing and releasing systems (Awulachew, 2022). Iron-based oxygen absorbers, odor absorbers for vacuum-packed fresh and processed meat, anticounterfeiting solutions, antimicrobial packaging based on silver are just some commercialized examples of innovative smart packaging who have experienced a revived interest in Europe (Dainelli, 2015).

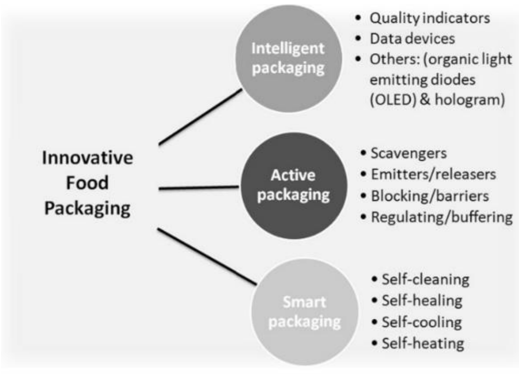


Figure 8. Active packaging as part of innovation in food packaging Source: Mlalila et al., 2016

Certain types of active microwave packaging can be specifically built to interact effectively with microwaves by including susceptors that are capable of absorbing electromagnetic energy and converting it into heat. Susceptors are commonly integrated into microwaveable food packaging to promote targeted heating and browning on the surface (Bhattacharya and Basak, 2016). Microwave susceptors consist of stainless steel or aluminum deposited on substrates such as paperboard or polyester films (Ahmed et al., 2017). They are typically composed of four primary layers, as outlined by Robertson (2016): a heating surface, typically made of biaxially-oriented PET; a thin metal layer, commonly aluminum deposited through a vacuum process; an adhesive layer, usually consisting of polyvinyl acetate; a substrate, commonly made of paper or paperboard.

Metal-coated polymeric packaging materials possess excellent barrier properties; however, their use is restricted due to limitations in recyclability, transparency, cost, microwavability, and stability (Thanakkasaranee, Sadeghi and Seo, 2022). There has been significant interest in polymers with high oxygen barrier properties, such as EVOH and PVDC. While PVDC offers an excellent oxygen barrier, it presents environmental concerns due to recycling difficulties and processing challenges. On the other hand, the barrier properties of EVOH are significantly influenced by moisture. To maintain the performance of EVOH, one effective approach is to laminate it with a water-resistant polymer like PP (Thanakkasaranee, Sadeghi and Seo, 2022).

According to Realini and Marcos (2014), in response to environmental concerns, there has been a growing interest and research focus in the past few years on biodegradable packaging materials. To address this issue, natural antioxidants have been integrated into biodegradable films to create antioxidant packaging systems. Polylactic acid (PLA), a versatile and compostable polymer obtained from natural sources, is easily processed. As a recent development, α-tocopherol has been integrated into PLA films to serve as an antioxidant packaging material (Realini and Marcos, 2014).

PP is one of the main polymers used in the food packaging industry, particularly when it comes to rigid food trays. However, despite its good properties in processing, the PP packaging material has its drawbacks from an environmental perspective. In a study conducted to estimate the environmental impacts of commonly used food containers, the authors found that polypropylene containers for single use have the most detrimental environmental impact, particularly in terms of their contribution to global warming potential (Gallego-Schmid, Mendoza and Azapagic, 2019). Their study also reveals that extruded polystyrene containers have the lowest overall impact because they require less material and electricity during production, but they are not presently recycled and therefore cannot be regarded as a sustainable alternative.

Despite its technological advantages, PVC is related to different environmental and health concerns owing to its chlorine content which when emitted during production or transport, produces a heavy negative environmental effect. Additionally, while a high recyclability is possible to obtain in pre-consumer waste due to ease of separate collection, in post-consumer waste recycling rates are quite lower. The recycling rates for PVC are limited due to the varying purity levels of the waste, leading to costly separation procedures. As a result, recycled PVC holds a low commercial value (Almqvist and Larsson, 2021).

The use of nanotechnology has led to progress in the food packaging industry, resulting in the creation of inventive packaging materials such as bioplastic polymers. The primary objective of innovative food packaging is to enhance the quality, safety, and longevity of food products, while also creating more affordable packaging materials, reducing labor during processing, producing convenient food items, minimizing the use of food preservatives, and monitoring food quality throughout the supply chain (Mlalila et al., 2016).

The FRESH project, a consortium of four participants coordinated by Huhmataki Molded Fiber Technology BV, aimed to create a high-end, cellulose-based alternative to existing plastic trays using a new laminating technology. The project, which ran for three and a half years finalizing in mid-2020, sought to significantly reduce the environmental impact of packaging materials by more than 80% over their life cycle compared to existing fossil-based materials. Its main objective was to develop a complete value chain, from material sourcing to end-users, that would demonstrate the technical and economic feasibility of a 100% bio-based and biodegradable ready meal packaging alternative. The end product was expected to have significant environmental, economic, and job creation benefits and could revolutionize the retail, catering, and remote operations sectors (European Union, 2023). A novel lamination method was utilized to combine DuraPulp, a patented mixture of cellulose and GMO-free PLA, with a new generation biofilm made from bio-based polybutylene succinate (BioPBS). According to the project authors, this created a high-end ready meal tray with the required technical properties such as low O2 barrier, heat resistance, and wet resistance (European Union, 2023). A study found that bio-based polymers have the ability to endure thermal processes, rendering them suitable for microwave applications and concluding that biobased and biodegradable films are practical for in-package thermal pasteurization (Sonar et al., 2020).

4.2 Comparison of the selected packaging solutions

Only one of the evaluated solutions in this thesis is currently operating, the current Micvac packaging. Meanwhile MonoPP represents a a newly introduced project of Micvac aiming to develop a feasible, viable and sustainable packaging option for its ready meals. The three remaining solutions are hypothetical packaging systems who are not in existence yet but have been theoretically approved for microwave usage by their manufacturers or by analysing their product datasheets. Since these trays have not been tested before in the Micvac method, it is unknown whether the pasteurization treatment will cause damages such as pinholes, broken seals, shrinkage, or delamination which would compromise product safety and quality.

According to their declarations of compliance, all the solutions comply with the EU Regulation 10/2011, therefore the overall migration does not exceed 10 mg/dm² or 60 mg/kg. The biopolymer tray turned out to be the most challenging option to find and evaluate due to a lack of commercial options that are purposefully manufactured for microwave suitability. The variability of the packaging materials available is another factor. The location manufacturing facilities of the packaging materials was restricted to the European continent due to the need of comparing the transport efficiency of the different packaging solutions.

4.2.1 Current Micvac packaging

The Micvac packaging is composed of an oval-shaped clear PP tray, which is suitable for microwave cooking and can tolerate temperatures from -21°C to 121°C. A multilayer film lid made of PA and PP is used to seal the tray and provides barrier properties to the primary packaging. During the pasteurization process, a PVC valve is added to the film, which allows water vapor to escape from the package. This valve, not in contact with the food product, is critical to ensure that the package is vacuum sealed once the product is cooled down (Hosse Pastor, 2021). The Micvac valve is unique to the method and performs others functions that were discussed by Larsson and Hjelmberg (2010). One of these functions is beeping during steam passage when the product is reheated in the microwave by the consumer, thus serving as a ready-for-consumption signal. Additionally, it assists the steam heating giving the possibility of a hydrated surface in the food product.

Designs and materials of the labels are chosen by the food manufacturers who are customers of Micvac. While the tray is recyclable, the lidding film and the valve are currently not recyclable and are instead being used for energy recovery through incineration (Hosse Pastor, 2021). The PP tray is manufactured in Czech Republic, while the film and the valve in Sweden. Faerch has partnered with Micvac for 15 years in the design of the current tray with a flexible bottom. It is thicker than other trays in Faerch portfolio because of the specific demands of Micvac process.

4.2.2 MonoPP packaging

The MonoPP packaging is an internal Micvac project who has been recently ideated and internally tested by the company. Due to concerns about recyclability and other sustainability factors described in the theoretical framework of this report, the company initiated a project about a monomaterial solution that would be added to the portfolio of Micvac packaging. The clear PP tray is the component that does not change, with its content and supplier being the same as the current packaging. The tray makes up 82% of the current packaging in weight, therefore it is easier to conduct innovative tests by keeping this component unchanged. The variable components are the film and the valve which are made of PP, with a thin layer of EVOH which accounts for less than 5% of the total content.

To qualify as a monomaterial packaging, the package must be made up of over 95% of one type of resin, such as PE, PP, or PET, and contain less than 5% of other resins or materials. This is confirmed by RecyClass, an initiative created by Plastics Recyclers Europe (PRE) to evaluate the recyclability of plastic films and enhance packaging design. According to Recyclass, if the EVOH concentration is less than or equal to 5% by weight, the packaging is regarded as having restricted compatibility for recycling, and if it is greater than 5% by weight, it will be regarded as being incompatible with recycling (RecyClass, 2023). Therefore, for high barrier films used in food packaging, less than 5% of EVOH content is commonly accepted to be classified as a single material.

The PP film and PP valve information is kept confidential on their quantities, suppliers, and their production locations. They have a lower weight than their equivalent components in PA/PP and PVC which makes the primary packaging lighter than the current packaging. This weight reduction can impact the amount of packaging units distributed along the supply chain; thus, it may influence the indirect environmental impact of the packaging system.

4.2.3 Fiber-based packaging

The fiber-based tray was selected from an online scouting of available commercial paper trays which are suitable for use in microwave. Since a direct contact with the manufacturer and supplier of these trays was not established, this product will remain anonymous in this report and will be further referred to as paper tray. This tray is being used to package ready meals in cook-and-chill and has not been tried with the Micvac method. It contains an inner laminated film of polymer which is in contact with food for barrier properties. This is in line with the innovative trend where a polymer layer is applied in a dispersion-coated paper and the thickness of this layer is carefully designed to achieve the desired barrier properties while minimizing any negative effects on the paper recycling (Schenker et al., 2020). The product considered for the analysis is sourced and manufactured in Sweden which has a more sustainable energy matrix due to relying less on fossil-free sources (Svenska kraftnät, 2023). The same PP-based film and the valve as for the monoPP packaging were considered to seal the tray in this hypothetical primary packaging.

4.2.4 Biopolymer packaging

The tray no. 71149 of Duni Group is microwaveable and suitable for packaging with MAP according to the product datasheet. The specific tray has dimensions of 250 x 159 x 43 mm and an inner volume 1100ml. It has a white color and is produced 100% from renewable materials. It is used both for cold and hot food products as it can be stored in refrigerator and freezer temperatures as well. The tray is made from bio polyethylene or “green” polyethylene (bio-PE) refering to its natural raw material. In an industrial environment, bio-PE can be produced from bagasse of sugarcane, which is fermented and turned to bio-ethanol. Afterwards, through dehydration it is converted into bio-ethylene, which its polymerization can be done conventionally to produce bio-PE. The content of the Duni tray is more than 50% PE made from sugarcane or rice husks, 10-40% of minerals such as chalk, and natural waxes make up the remaining less than 5% of the tray. The polymer is bio-based but not biodegradable. The trays are manufactured in Poland. Similar to the previous two packaging solutions, the film and the valve of the biopolymer solution which function as the lid of the tray, will be manufactured from PP.

4.2.5 MonoPET packaging

The MonoPET packaging is a hypothetical solution where its three components are made from PET. This polymer is considered one of the most versatile tray choices for the packaging of ready meals, with a high demand in Europe (Firoozi Nejad et al., 2021). The tray's content is crystalline PET (CPET). Most of the information about how the packaging would look like and behave was conceptualized by a meeting with Faerch, the suppliers of Micvac's current PP tray. The current CPET trays that Faerch produces are being used for takeaway ready meals which can be reheated by the consumers in a microwave or oven. However, some developments will be needed by Faerch before coming up with a feasible working solution for the Micvac process.

According to Faerch website, its CPET ready meal packaging meets the highest standards for temperatures ranging from -40°C to +220°C and retains its shape at high temperatures, making it the perfect material for chilled and frozen ready meals that are meant to be reheated (Faerch, 2022). However, this CPET tray has never been trialed with Micvac technology and during the meeting, concerns were raised about the behavior of the material during the pasteurization treatment as it is a very different material compared to the current tray. In warm conditions, PP is more robust than CPET, the latter softening when temperature goes above 70°C, where it transitions from a solid state to a flexible state, where it is malleable. At this point, the material is very weak & soft from 70-90°C which makes it difficult to control during this treatment phase. PP is a more stable material, with its softening curve being a straight line which increases until it drops all at once when the integrity of the package is lost during the process, thereby making it easier to predict and model its behavior.

Regarding processability, the Micvac concept works only with a very strong seal, which has to be strong enough to activate the valve which then lets the generated steam during pasteurization out. The main concern is whether the seal is strong enough to resist the steam pressure building up during pasteurization. The Faerch packaging developers assumed that may be the case, but only tests can show. Fortunately, it is easy to test this packaging scenario just by utilizing the appropriate moulds and producing some samples of trays. Additionally, for the process to work smoothly it is necessary to have a built-in weak spot in the tray in order to facilitate the creation of vacuum after condensation of the steam. As previously mentioned, the current PP tray has a weak bottom, and it is left to be determined in which part the CPET tray would have this functional weak spot.

Regarding the barrier properties, the CPET tray is 30 times better than the current PP tray. However, the PET film would perform worse than the current multilayer

PP-PA film. To properly determine the tradeoffs, it would be helpful to store the current ready meals in MonoPET packaging of the same design as the current Micvac packaging. This would allow a comparison of the solutions and evaluation of the better combination.

The weight of the trays would need to be increased by 25% because the trays need to be thicker and stiffer to endure the processing conditions. Therefore, a tray used for pasteurized ready meals would be about 20g, whereas for sterilized ready meals, the weight would be even higher but that is not in the focus of Micvac. The main interest in using CPET trays from an environmental perspective is their content which is made from 70% recycled post-consumer waste, on average. It is worth highlighting that PET is currently the only packaging material approved by EU legislation to have recycled content in contact with food products. Faerch has its own recycling company in Netherlands and their goal is reaching a tray-to-tray recycling stream which would constitute a closed-loop.

Another angle of analyzing the CPET trays is their impact on transport efficiency. The current PP trays have a high stacking height. If a lower stacking height is achieved with CPET trays, more trays could be placed and distributed in the same truck load. This factor would improve the volume efficiency of outbound transport which is a criteria in the tool used in this research. Furthermore, the design of the sidewalls of the trays, particularly their height compared to the base of the tray and to the current PP tray, would influence the transport stage. CPET trays are nestable same as the current trays so that is not expected to be a crucial factor.

A certain trade-off apparent from the beginning is the transparency of the tray, which would be impossible to achieve in CPET. The consumers would not be able to see the product inside the tray on the store shelves or during the microwave reheating. The effects of the product’s invisibility to consumer perception are presumably negative, although the extent of this negative prejudgment is unknown.

Regarding the PET film and the valve, the information on its dimensions is yet to be defined as Faerch does not currently produce flexible films. However, from discussions and scouting, it was deducted that the PET film would have a lower thickness than the current PP-PA film. Typically, the base PET films are manufactured to be quite thin, about 13-15 µm which are then laminated to produce the final film. Based on their experience, Faerch developers were positive about the possibility of laminating a film of 70 µm thickness, as it is a matter of putting enough layers of base films together. The current film they purchase in the market for their trays is 40 µm, considering that a thicker film would probably be needed for the Micvac process. The final thickness of a PET film will also depend on the type of converter that is used.

4.3 Analysis of the regulatory and trade organizations policies

With increasing concerns about food safety and sustainability, the packaging of RTE meals has come under scrutiny. To address these concerns, legislative acts by EU and national authorities, as well as trade organizations in Europe have developed policies to regulate the use of packaging materials for RTE meals. These public and private bodies have implemented several policies aiming to address these concerns by controlling, directing and monitoring the composition and properties of packaging materials used for RTE meals. A list of the most important EU legislation acts affecting Micvac directly or indirectly, can be found in Appendix E.

The European market has been mainly regulated by the Packaging and Packaging Waste Directive 94/62/EC (PPWD), which has served as the primary legislative framework. The main goals of the PPWD are focused on environmental protection. The directive aims to standardize national measures concerning packaging and the handling of packaging waste while ensuring a high level of environmental protection. The directive also includes provisions that promote the recycling, reuse, and other methods of recovering packaging waste instead of disposing of it in landfills (EUR-Lex, 2019). Additionally, the directive regulates the packaging materials that are sold in the European market to encourage a sustainable development-based economy. However, the recycling rates in Europe remain not at the expected level. An impact assessment from the European Commission (EC), found that the existing regulatory framework has deficiencies that hinder the profitability of recycling operations and put pressure on the investment in technology and supply logistics that are essential for ensuring that packaging is gathered, sorted, and recycled at a high level of quality (Parkinson, 2022). The European food-contact materials regulations and directives are extensions and specifications in line with Regulation (EC) No. 1935/2004 on materials and articles intended to come into contact with food.

Two methods are employed to regulate the utilization of recycled for food contact products. In the case of plastic, it can be depolymerized into monomers or oligomers, and must meet the same requirements as virgin plastics according to EC 10/2011 on plastic materials and articles intended to come into contact with food. Alternatively, if the plastic is mechanically recycled and transformed into pellets, EFSA will enforce the regulation (Ilyas et al., 2021). The EC has suggested a new proposal on November 30, 2022, to update the current EU laws on packaging and packaging waste. The main objectives of this proposal are to minimize the negative environmental impacts caused by packaging and packaging waste, and to improve the functioning of the internal market. The Commission aims to achieve these goals by decreasing the production of packaging waste, encouraging the use of a circular economy for packaging in an affordable way, and endorsing the use of recycled materials in packaging (Parkinson, 2022). The main actions proposed to achieve concrete improvements in the implementation of the regulation are represented in figure 9 (European Commission, 2022).

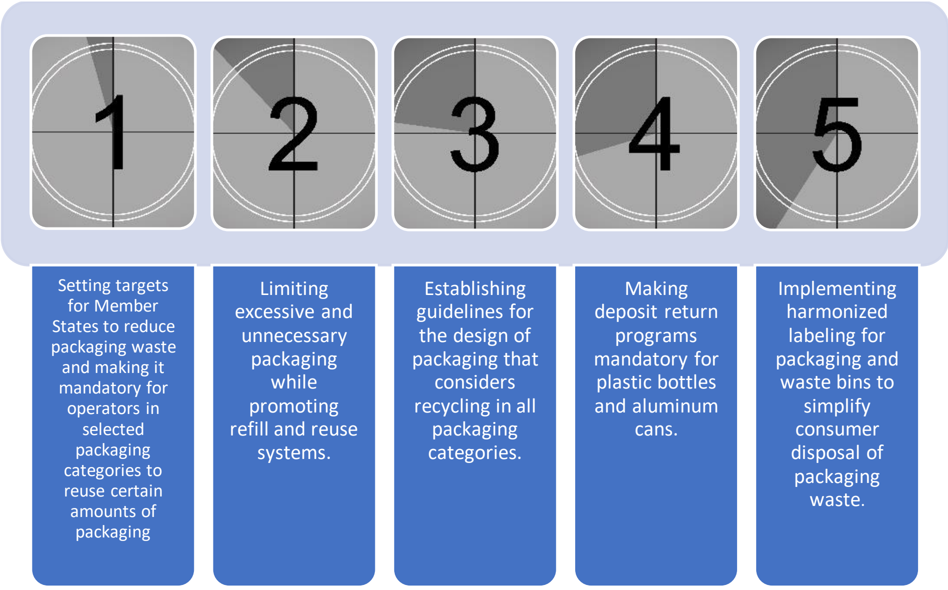


Figure 9. The key measures of the EC proposal on PPWD
Based on information retrieved from European Commission, 2022

Perhaps, the most noticeable measure of this proposal is the compulsory targets for waste reduction. The EU Member States will have to lower their packaging waste (per capita) by 5% by 2030, followed by an increase to 10% by 2035 and 15% by 2040, compared to 2018 levels. Additionally, all countries must establish deposit return programs for metal and single-use plastic beverage containers by 2029. Furthermore, by the end of 2025, 65% (by weight) of all packaging waste, including 50% of plastic, 50% of aluminum, 70% of glass, and 75% of paper and board, should be recycled (European Commision press release, 2022). These measures have not been welcomed by everyone in the industry, particularly the fiber packaging sector. The chair of "Fibre Packaging Europe," a group comprising eight trade associations representing various industries involved in forestry, pulp, paper, board, and carton production and recycling in Europe, expressed concerns about the introduction of compulsory targets for recycled content. They believe that implementing such targets would disrupt an already efficient system, which is responsible for 82% of fiber packaging being recycled in Europe, targeting 90% recycling rate by 2030 (EURACTIV, 2022). Additionally, focusing on encouraging reusability is not suitable for paper packaging.

4.4 Market trends in ready meals and their packaging

4.4.1 Ready meals analysis

The busy and fast-paced lifestyles of people around the world have given rise to a culture of convenience foods, including ready-to-eat meals (Tomašević, Radnović and Gašević, 2020). This trend of shifting from homemade meals to packaged foods has been observed in many countries, with the RTE meal market steadily growing in Europe, USA, India, China, and other countries. The RTE meal sector is projected to generate €530 billion in revenue by 2023, with an estimated compound annual growth rate (CAGR) of 5.64% for the 2023-2027 period (Statista, 2023). China is the leading contributor to the global market, generating €130.63billion in revenue in 2023. In the RTE meals segment, volume is expected to amount to 90.99billion kg by 2027 (Statista, 2023).

Euromonitor International, a worldwide provider of analysis and insights on market trends, competitive landscapes, and consumer behavior across various sectors, was the source of the following data on ready meals. The data on local currencies in Norway, Sweden, USA and United Kingdom (UK) was converted to Euros (€) to normalize the comparison between different markets. A summary of the most important data of ready meals and chilled ready meals is presented in Table 4. All countries have registered growth in the last year although not in the same rate. The country with the highest growth are shown in green and the country with the lowest growth is shown in red.

Table 4. Ready meals situation in some European markets and USA, 2022

Country	*Retail value sales of ready meals €milion*	*Sales Performance of ready meals (% Y-O-Y growth)*	*CAGR (2023-2027)*	*Leader brand in the market*	*Retail value sales of chilled ready meals €million*	*Sales Performance of chilled ready meals (% Y-O-Y growth)*	*CAGR (2023-2027*
Sweden	383	3.4%	2.6%	Dafgård AB	144.4	6.7%	5.7%
Norway	415	2.0%	2.0%	Fjorland AS	289	4.0%	3.0%
Finland	732	15.5%	5.4%	HK Ruokatalo Oy	661	16.0%	6.0%
Spain	1460	11.0%	5.0%	Nestlé España	457	12.5%	6.8%
USA	22894	4.0%	3.0%	Nestlé USA Inc	1677	7.3%	4.0%
UK	4359	14.0%	4.2%	Tesco Plc	2612	8.5%	4.9%
France	2980	4.8%	2.6%	Fleury Michon	1430	5.2%	3.7%

Sourced on information retrieved from Euromonitor Passport International, 2022

4.4.1.1 Sweden

In 2022, the retail value sales of the market increased by 3.4% in current terms, reaching €383 million. The chilled ready meals category exhibited the highest growth rate in 2022, with retail value sales increasing by 6.7% in current terms to €144.4 million. Dafgård AB, Gunnar held the largest market share in 2022, accounting for more than 20% of the retail value sales. The retail value sales of the market are expected to grow at a current value compound annual growth rate (CAGR) of 2.6% over the forecast period, which will result in retail value sales of €434.7 million, whereas the projections for the chilled ready meals stand at 5.7% CAGR and will reach to €190.4 million.

Sales of ready meals have decreased in 2022 compared to the peak sales during the pandemic. The decrease in volume sales is observed across the entire category but is still higher than pre-pandemic levels because many employees are still working from home. However, the current value sales are still positive due to inflation and increased prices, except for dried ready meals and quick recipe kits which are experiencing slight declines in current value.

Sales of ready meals and soups in 2022 are driven by health and sustainability trends, resulting in an increase in plant-based, vegetarian, and vegan options. In addition, there is a growing use of sustainable packaging in the ready meals industry to address consumer concerns about plastic waste.

In Sweden, the distribution of grocery products through the e-commerce channel has historically been underdeveloped. However, this changed during the pandemic as major grocery retailers invested heavily and quickly in online sales development and expanded their distribution capacity across the country. Consequently, there has been a significant increase in demand for online grocery shopping, which is expected to continue rising in a post-pandemic Sweden.

In 2022, frozen ready meals continued to dominate the market in terms of volume and are expected to maintain their position until the pizza category catches up. The convenience of frozen food is driving its popularity, but chilled ready meals are also gaining market share because they are considered fresher and tastier. As a result, frozen ready meals are expected to experience declining volume sales while chilled ready meals continue to gain share (Euromonitor International, 2022).

4.4.1.2 Norway

In 2022, the retail value sales in Norway increased by 2% to reach €415 million. Among all the categories, chilled ready meals experienced the highest growth of 4% in current terms, with retail value sales reaching €289 million. Fjorland AS maintained its position as the leading player in 2022, accounting for a retail value share of 31%. Over the forecast period, retail sales are expected to grow at a current value CAGR of 2% to €472 million, whereas the chilled ready meals have a 3% CAGR and will reach €336 million.

During the last year, the sales of ready meals in retail have suffered due to people returning to their pre-pandemic habits of eating out more, which has benefited foodservice but had a detrimental effect on the sales of meals. Furthermore, the resumption of cross-border trade and international travel has also reduced domestic sales. However, the increasing need for convenience among consumers who are resuming their pre-pandemic lifestyles, including commuting to offices, and engaging in social activities, has been a positive driver for ready meals. Nevertheless, this positive impact has not been substantial enough to offset the negative trends, leading to an anticipated overall decline, which is also expected for Norwegian grocery retail as a whole.

Fresh food products, particularly chilled products, are expected to perform well in terms of retail volume sales in the ready meals market as consumers increasingly prefer them. This preference is due to the belief that fresh products are more nutritious, which has been reinforced by the Covid-19 pandemic. Additionally, the growth of online grocery retailing in Norway, which was accelerated by the pandemic, and the competitive environment of meal kits are driving the rapid expansion of e-commerce as a distribution channel within the meals category (Euromonitor International, 2022).

4.4.1.3 Finland

The retail value sales in 2022 for this market increased by 15.5% in current terms to reach a total of €732 million. In alignment with other Nordic countries, the dominant category of the year was chilled ready meals, with retail value sales growing by 16% in current terms to reach €661 million. HK Ruokatalo Oy emerged as the leading player in 2022 with a retail value share of 26%. Looking ahead, retail sales are expected to continue growing at a current value CAGR of 5.4% over the forecast period, reaching €955 million. Chilled ready meals are projected to increase at a value CAGR of 6% and reach €875 million in retail sales.

To cater to the increasing demand for locally sourced produce, manufacturers are now providing clear information about the domestic production and ingredients used in their products. The preference of Finnish consumers for locally made products has been further amplified by the pandemic and the subsequent economic instability. This trend is expected to continue in the future, with more Finnish producers incorporating traditional flavors with high quality ingredients that are affordable (Euromonitor International, 2022).

The competition in the ready meals market is intensifying due to the availability of more restaurant-quality options at Finnish grocery retailers. With the closure of restaurants during the lockdown, some restaurant owners decided to launch their own lines of ready meals. Finnish consumers are willing to spend more on restaurant-quality ready meals, which has led to the introduction of new products.

4.4.1.4 Spain

In 2022, the retail value sales of ready meals in the market saw a growth of 11%, reaching a value of €1.46 billion. The shelf stable meals and chilled meals categories emerged as the top-performing categories in 2022, each recording a 12.5% increase in retail value sales, amounting to €646 million and €457 million, respectively. Nestlé España SA secured the leading position in 2022, with a 15% retail value share. The forecast period is expected to witness a rise in retail sales of ready meals, with a current value CAGR of 5% reaching a value of €1.86 billion, whereas the chilled ready meals have a 6.8% CAGR and will reach €635 million.

Despite a slight increase in unit pricing, the retail volume sales of meals persisted in rising in 2022, although at a slower pace compared to the pandemic year of 2020. Among ready meals, shelf-stable ones are the most favored, followed by frozen and chilled ready meals. In 2022, dried ready meals remained of little significance. The consumption of ready meals is mostly popular during lunchtime for individuals such as workers and university students.

The trend towards healthier ready meals is expected to continue driving category growth in the coming years, as consumers remain focused on maintaining their wellbeing and immunity in the wake of the pandemic. In the chilled ready meals category, dishes featuring meat, vegetables, and fish are expected to experience particularly strong demand. Lasagne and cannelloni are also likely to remain popular among Spanish consumers. Manufacturers are adapting their recipes to offer healthier options for these food types in response to consumer demand. Traditional Spanish dishes like paella, fideos, and tortilla are gaining popularity in ready meal format due to their familiarity among local consumers and the time-consuming nature of their preparation.

Supermarkets such as Carrefour, Mercadona, Alcampo, Lidl, and Aldi are incorporating sushi into their chilled ready meal offerings, and sushi sets are growing in popularity. The line between restaurant food and ready meals is becoming increasingly blurred, as some Mercadona supermarkets now offer a seating area where customers can consume ready meals or other prepared food sold by the chain. Inflationary pressure is causing more workers to choose ready meals for lunch rather than eating out, although many local workers still prefer to have a leisurely two-hour lunch in a restaurant (Euromonitor International, 2022).

4.4.1.5 USA

In 2022, the retail value sales increased by 4% to reach €22.9 billion. The dried ready meals registered the best performance, with retail value sales increasing by 9.7% to reach €2.8 billion. Nestlé USA Inc held the top position in 2022, with a market share of 13.5%. However, frozen ready meals remain the leader category accounting for 73% of the whole market. Looking ahead, retail sales are expected to increase at a current value CAGR of 3% over the forecast period, reaching €26.5 billion. Chilled ready meals, currently being a small category occupying only 7% of the market, are projected to increase at a value CAGR of 4% and reaching €2 billion by 2027 (Euromonitor International, 2022).

In the market, the health and wellness trends are dominant. Some manufacturers have been focusing on health concerns for a long time and have developed low-sodium versions of their products. However, now they are also incorporating organic ingredients and catering to vegan consumers.

4.4.1.6 UK

In 2022, retail value sales increased by 14% to reach €4.36 billion. The frozen ready meals category is showing the strongest performance, with retail value sales increasing by 10% to reach €1.18 billion. However, the dominant category in the market continues to be chilled ready meals with €2.6billion in retail sales. Tesco Plc holds the leading position in the market, with a retail value share of almost 18% in 2022. Looking ahead, retail sales are projected to continue growing at a current value CAGR of 4.2% over the forecast period, reaching a total of €5.36 billion, whereas the chilled ready meals are projected at 4.9% CAGR reaching €3.3 billion.

Retailers and manufacturers worldwide were affected since the global supply chain faced significant instability in cost and demand dynamics due to the Covid-19 pandemic and the war in Ukraine. As a result, shortages of raw food materials such as wheat and sunflower seeds occurred, causing price increases for the food industry. Major damage to harvests due to temperature fluctuations further exacerbated the situation. Manufacturers of ready meals and soups were impacted by shortages, and some responded by reformulating their products, while others reduced the amount of product per pack or cut products from their portfolios. Shrinkflation occurred because of these changes, and most companies applied price increases to maintain their margins. Despite facing significant price increases, many consumers maintained their eating habits, leading to a positive trajectory for ready meals consumption. This was largely due to the convenience that these products offer, although some consumers did cut back.

The convenience of consumption was a key factor in the success of RTE and ready-to-heat products, with frozen ready meals and pizza performing better than chilled options, highlighting the significance of not only convenience in consumption but also in storage. Consumers prefer products that can be stored for longer periods and heated quickly when necessary. Private label products have an advantage in pricing in light of the overall rising prices and maintained a substantial value share.

The UK market is anticipated to undergo modifications in the upcoming period because of regulations that target products with high levels of fat, sugar, or salt, (HFSS). The policy, which came into force in October 2022, will limit the visibility of such products in both physical and online retail spaces. In addition, from October 2023, promotional deals like buy-one-get-one-free will be prohibited for products that do not comply with the HFSS criteria. These upcoming HFSS regulations are predicted to have a more severe impact on the sales of ready meals due to the ban on promotions compared to the current restrictions on physical and online presence. Chilled and frozen ready meals, which frequently offer discounted prices for multiple meals, are expected to be most affected by this ban. Retail sales may face disruptions if manufacturers fail to reformulate their products to comply with the HFSS guidelines. The later implementation of restrictions in 2024 on online and television advertising is expected to have a minimal effect on the sales of meals.

Additionally, due to the rising demand for healthier meal options, the market of ready meals will see an increase in products that meet the HFSS guidelines, which will be offered by both branded and private label manufacturers. While the enforcement of additional regulations and administrative procedures is predicted to result in further price increases, the effects on ready meals will be relatively minimal, even for the more high-end varieties (Euromonitor International, 2022).

4.4.1.7 France

The current value of retail sales has risen by 4.8% to €2.98 billion in 2022. The category that performs the best is chilled ready meals, with retail sales increasing by 5.2% to €1.43 billion. The leading player in 2022 is Fleury Michon Groupe, with a retail value share of 18.6%. It is predicted that retail sales will have a current value CAGR of 2.6% and will reach €3.39 billion over the forecast period. The chilled ready meals have a 3.7% CAGR reaching €1.71billion.

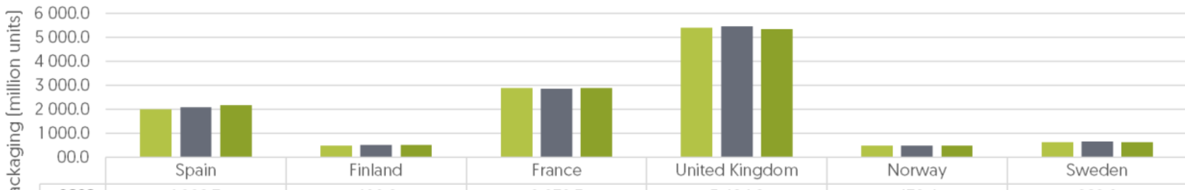
The chilled ready meals category is experiencing strong growth in current value terms in 2022, driven by new product launches and innovations featuring exotic international flavors. Consumers, especially younger generations, are seeking new taste experiences, leading to a shift towards Indian, Japanese, Moroccan, and other ethnic cuisines. Manufacturers are focusing on clean labels, minimal ingredients, and using locally produced ingredients to tap into localisation and sustainability trends. However, retail volume sales have declined in 2022 due to the recovery of the foodservice channel and consumers curbing their spending. Despite this, consumers are still interested in the origin of their food, and many want to support French farmers (Euromonitor International, 2022).

In an effort to be more environmentally friendly, several ready meals manufacturers are adopting paper and cardboard packaging for their products. Gelagri, Daunat, and Marie have all introduced new ranges with sustainable cardboard trays towards the middle of 2022. This trend is expected to continue as consumers increasingly seek out brands that are actively switching to recyclable and sustainable packaging. This focus on sustainability is likely to influence the production methods and ingredients used in ready meals in the future. Manufacturers may shift towards using local ingredients, renewable energy, and biodegradable and recyclable materials. These efforts will likely be communicated through brand marketing, as consumers are willing to pay more for environmentally friendly products.

4.4.2 Ready meals packaging analysis

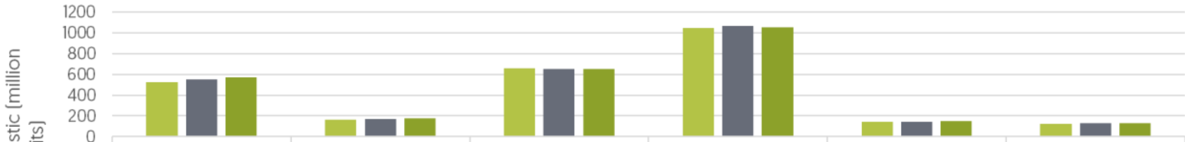
The standard tray is currently the most used packaging type for ready meals. However, there has been a significant increase in the use of pots for ready meal launches, with a growth rate of over 115% in the last five years (Packaging Insights, 2023). According to this source, non-specified plastic is the most prevalent material used for ready meal packaging, but there has been a 15% increase in the use of glass packaging for ready meals over the same period. Additionally, the leading environmental claim made by ready meal packaging is that it is recyclable.

The most recent available reports from Euromonitor International describe the situation in the European market of ready meals packaging. For this study, the focus was on the countries where Micvac is operating or target markets of the company. These countries include Sweden, Norway, Finland, France, USA, UK, and Spain. The statistics on ready meals packaging trends were found on Euromonitor International. The latest reports were published in 2022, with the forecast period being 2022-2027. The ready meals packaging data on sales volumes of total packaging, rigid plastic, flexible plastic and paper-based trays is presented in the following figures 10-13.



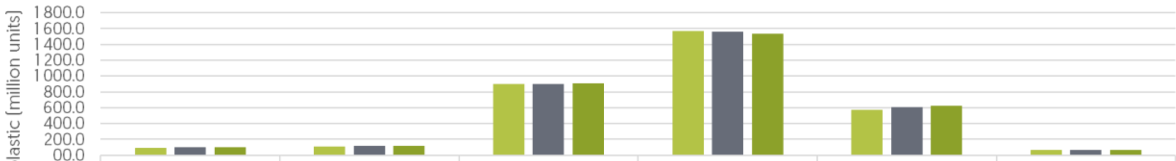
	Spain	Finland	France	United Kingdom	Norway	Sweden
2020	1 990.7	488.6	2 878.3	5 404.0	476.4	609.8
2021	2 092.9	505.5	2 867.3	5 447.2	487.5	642.8
2022*	2 157.1	515.1	2 868.6	5 355.5	489.9	624.7

Figure 10. Retail/off-trade volumes of total packaging in the main markets of Micvac Sourced on information retrieved from © Euromonitor International, 2022



	Spain	Finland	France	United Kingdom	Norway	Sweden
2020	521.6	165.2	655.2	1042.4	140.7	122.7
2021	553	172.2	649.2	1062	144.7	129.7
2022*	571.7	175.3	647.6	1053.1	146.6	132.4

Figure 11. Retail/off-trade volumes of flexible plastic in the main markets of Micvac Sourced on information retrieved from © Euromonitor International, 2022



	Sweden	Finland	France	United Kingdom	Spain	Norway
2020	96.2	110.3	898.3	1 567.2	576.9	68.7
2021	97.5	114.2	900.3	1 563.9	606.2	70.0
2022*	97.6	116.7	906.0	1 533.7	627.0	70.4

Figure 12. Retail/off-trade volumes of rigid plastic in the main markets of Micvac Sourced on information retrieved from © Euromonitor International, 2022

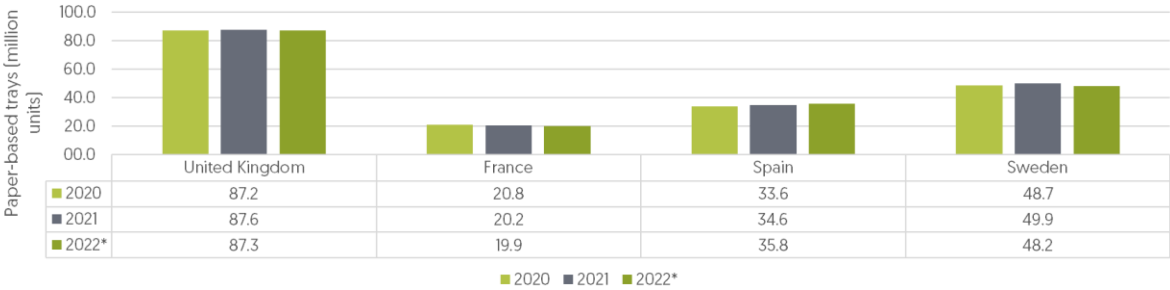


Figure 13. Retail/off-trade volumes of paper-based trays in some markets of Micvac Sourced on information retrieved from © Euromonitor International, 2022

A stagnation of packaging retail volumes was forecasted for 2022 in different countries in Europe and USA. The demand for the packaging materials depends on the size of the market, which is in correlation with the population of the country. However, this trend is not the same for the fiber-based trays which have significant more appeal and demand per capita in Sweden than in other countries.

4.4.2.1 Sweden

In 2021, retail packaging volumes increased by 5% to reach a total of 643 million units. Paper-based containers emerged as the top-performing packaging type, with a 7% increase in total retail packaging volumes, reaching 307 million units. However, a marginal negative CAGR is anticipated to cause a slight decrease in total retail packaging volumes, bringing the number down to 642 million units over the forecast period.

The demand for ready meals packaging continued to grow in 2021, especially for dinner mixes which recorded double-digit percentage growth in both 2020 and 2021. The pandemic led to an increase in home cooking, and dinner mixes were convenient options that included ingredients and instructions. However, the demand for packaging for shelf stable ready meals declined in 2020 and 2021 due to consumer concerns about their healthiness. Meanwhile, the growth of frozen and chilled ready meals slowed down in 2021 after a spike in 2020, but they remained popular due to consumers' desire for convenience and variation. Flexible packaging recorded growth in both years, and some innovative products were introduced, such as Lidl's vacuum-sealed ready meals.

The use of plastic trays in chilled ready meals is expected to rise, while metal food cans in shelf-stable meals are expected to further decline. Manufacturers are looking to transition to 100% recyclable packaging in response to growing consumer demand for sustainability, with Felix and Findus announcing plans to use recyclable materials in their packaging (Euromonitor International, 2022).

4.4.2.2 USA

In 2021, the total retail packaging volumes declined by 9% to 17 billion units. However, the "other packaging" category experienced growth, emerging as the best-performing pack type with a 5% increase in total packaging retail volumes, reaching 618 million units. Nevertheless, over the forecast period, the total retail packaging volumes are expected to increase at a CAGR of 3% to 19 billion units.

After the end of stockpiling during the Covid-19, there was a decline in sales, but they still remained higher than pre-pandemic levels. The packaging volumes of plastic pouches in dried ready meals saw growth due to convenience, while transparent packaging usage increased due to greater health awareness. As consumers prioritize recycling, folding cartons are expected to gain a larger market share. In addition, manufacturers will look for ways to make meal kits more sustainable (Euromonitor International, 2022).

4.4.2.3 Spain

In 2021, the total retail packaging volumes increased by 5% to 2.1 billion units. The "other packaging" category witnessed the highest growth rate among pack types, with total packaging retail volumes surging by 15% to reach 621,500 units. Moreover, the total retail packaging volumes are predicted to grow at a CAGR of 2% over the forecast period, reaching 2.3 billion units.

2021 witnessed a robust expansion of chilled ready meals. Although the growth rate of ready meals decelerated, it continued to show strength. Shelf stable ready meals made a brief comeback with metal food cans. Looking forward, sustainable packaging is expected to gain traction in the ready meals market during the forecast period, while the health and wellness trend is likely to disrupt the packaging of ready meals (Euromonitor International, 2022).

4.4.2.4 UK

In 2021, the total retail packaging volumes rose by 1% to 5.4 billion units. The "other packaging" category exhibited the strongest performance among the pack types, with total packaging retail volumes increasing by 11% to 46 million units. Nevertheless, the total retail packaging volumes are expected to decline at a CAGR of 1% over the forecast period, reaching 5.1 billion units.

Vegan and gluten-free options are becoming more and more available in UK ready meals, while brands are using recyclable alternatives to black plastic trays. Quinn Packaging and Faerch Plast are the companies behind two environmentally friendly black tray options. Quinn developed the Detecta black PET food tray, which is claimed to be entirely detectable in sorting systems and thus completely recyclable. The tray does not contain carbon black pigment; instead, the black color is achieved by a combination of primary and secondary color pigments. The concept attracted the curiosity of several UK retailers (Euromonitor International, 2022).

Faerch Plast has introduced a new product made from 80% post-consumer recycled mixed-colour PET, which can be detected by near-infrared technology used in UK recycling systems. This new tray has the same benefits as the previously used CPET black plastic trays, but with a natural colour that clearly communicates recyclability to consumers. In addition, Faerch has expanded its packaging range by introducing trays made from 100% recycled bottles and designed for fresh meat, poultry, fish, and plant-based options. Looking ahead, the growth of meal kits and premiumization is expected to drive the demand for alternative packaging solutions such as wooden trays and net kits, while a government initiative aimed at reducing child obesity could boost demand for folding cartons.

4.4.2.5 France

In 2021, the total retail packaging volumes experienced a slight decrease of 0.4%, reaching 2.9 billion units. The "other packaging" category demonstrated the most impressive performance among pack types, with a 29% surge in total packaging retail volumes, reaching 643,800 units. Nonetheless, the total retail packaging volumes are projected to grow at a CAGR of 1% over the forecast period, reaching 3.0 billion units.

The reduced risk of the pandemic and increased mobility of consumers in 2021 negatively impacted the sales of chilled ready meals, resulting in decreased unit volumes of packaging materials such as folding cartons, plastic trays, ready meal trays, and flexible plastic. Although dinner mixes recorded a positive sales increase, the growth rate slowed down considerably in 2021. These products are commonly packaged in folding cartons, flexible plastic and aluminum-plastic pouches. The increasing popularity of healthy ready meals led to the use of transparent packaging in chilled ready meals. To showcase the fresh, healthy, and appetizing content, mainstream players, including private label, are using transparent rigid plastic containers (thin wall plastic containers and ready meal trays) that are unprinted and packaged within a small piece of branded folding carton. However, the negative perception of frozen and shelf-stable ready meals with respect to health may result in underperformance in this category (Euromonitor International, 2022).

4.5 Results of the environmental perfomance tool

The structure of the evaluation tool was adopted from the article presented by Molina-Besch and Pålsson (2019). The tool evaluates the environmental impact of a packaging system across four areas which represent crucial life-cycle phases of packed food products. These areas include packaging material, transport efficiency, influence on food waste, and packaging end-of-life. A life-cycle approach is significant when utilizing eco-design tools. Each of the four assessment areas includes several performance criteria, with five environmental performance levels assigned to each criterion. The highest level, level 5, indicates the best performance. The tool's grid structure allows for a clear understanding of a packaging system's current environmental performance and identifies the optimal performance for each criterion (Molina-Besch and Pålsson, 2019). In this way, the tool equips the company with tangible targets to improve its environmental performance simply by looking at the higher levels as aims to be achieved.

As mentioned in the methods section, appropriate modifications to the third area of the tool were realized in accordance with Micvac requirements. For the criteria levels with units expressed as kg\kg packed product, each packaging solution was estimated to contain 400g of ready meal to allow a normalized comparison between them. This implies that the current and monoPP solutions are in vacuum conditions, whereas the fiber-based, the biopolymer and the monoPET solutions have headspaces with different fill rates according to their volumes. The evaluation is conducted only for the primary packaging because secondary and tertiary packaging, represented by SRS crates and EUR-pallets respectively, are used as a standard in the distribution of all packaging solutions in Sweden, thereby the environmental evaluation of these two levels is not in the scope of this study. Description of the areas and the general functionality of the tool is provided in the following sub-sections, where the overall information in first, second and fourth areas is sourced from the tool article created by Molina-Besch and Pålsson (2019).

4.5.1 Packaging material

To evaluate the environmental impact of packaging materials, four criteria are used to cover significant aspects: carbon footprint of the material, non-hazardous materials, renewable content, and recycled content. Figure 14 presents the defined environmental performance levels for each criterion of this area.

The material carbon footprint refers to the total amount of greenhouse gases released into the atmosphere during the production of packaging materials. This calculation is based on the quantity of materials used in the packaging system relative to the amount of product being packed (Molina-Besch and Pålsson, 2019).

The criterion of avoiding hazardous materials assesses the supplier's level of certification for using non-hazardous materials in the packaging. Many countries have laws in place to minimize the health risks associated with food contact materials. Therefore, producers need to ensure that the packaging materials for their products meet the legal requirements.

The criterion of recycled content evaluates the amount of recycled material used in each packaging option. This is linked to the previous criterion as using disposable packaging made of non-recycled raw materials depletes non-renewable and renewable resources, making it not sustainable in the long term.

CRITERIA	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Material carbon footprint	>= 0.3 kg CO_2-eq./kg product	0.2 to < 0.3 kg CO_2-eq./kg product	0.1 to < 0.2 kg CO_2-eq./kg product	0.05 to < 0.1 kg CO_2-eq./kg product	< 0.05 kg CO_2-eq./kg product
Non-hazardous materials	Certified fulfilment of legislative requirements for direct food contact materials and EU PPWD** heavy metal limits (complete packaging system) by suppliers	Fulfills level 1 requirements plus certified by suppliers that packaging materials are free from PVC/other chlorinated plastics (complete packaging system)	Fulfills level 2 requirements plus certified by suppliers that packaging materials contain no bisphenol A (primary package)	Fulfils level 3 requirements plus certified by suppliers that direct food contact packaging material does not contain engineered nano-materials and is not treated with preservatives or disinfectants (exeption for hydrogen peroxide)	Fulfils level 4 requirements plus certified by suppliers that no chemicals from the SIN list*** are intentionally added into packaging materials (complete packaging system)
Renewable content	Less than 20% renewable content	20%–60% renewable content	60%–80% renewable content	>80% renewable content (non-FSC certified)	>80% renewable content (FSC certified or similar third-party certification for biopolymers)
Recycled content	Less than 5% recycled content	>=5% – <25% recycled content	>=25% – <50% recycled content	>=50% – <75% recycled content	75%–100% recycled content

Figure 14. The levels for the packaging material area Source: Molina-Besch and Pålsson, 2019

4.5.2 Transport efficiency

The second area of assessment in the EEFP tool evaluates the performance of packaging in terms of its impact on transport efficiency within the supply chain. The tool places emphasis on the transport efficiency of packaging, as opposed to logistical efficiency, due to the difficulty of predicting the impact of packaging on storage and handling efficiency. Furthermore, most carbon emissions from logistics in most supply chains are attributed to product transportation, rather than storage and handling. Molina-Besch and Pålsson (2019) suggest that both inbound and outbound transport efficiency of packaging should be considered.

To accurately assess the environmental impact of transportation, it is necessary to consider multiple factors which include the level of utilization of the vehicle, the distance of transport, and the mode of transportation being utilized. The tool also compares the inbound load efficiency of different cases, allowing for a quantitative comparison which helps provide information on the relative differences between cases. The tool calculates the amount of product that is packed with the packaging material delivered in a standard truck to make this comparison. The materials are divided into three categories, high-weight if it weighs more than 250 g packaging material/ kg product, medium-weight if it weighs 100-250 g packaging material/ kg product, low-weight if it weighs less than 100 g packaging material/ kg product.

The evaluation of the efficiency of outbound transport is based only on the weight or volume efficiency of the packaging system since the mode of transport and the distance cannot be standardized due to variations between food manufacturers. To cater to the different restrictions in transport due to either weight or volume, the tool offers two distinct environmental performance level categories for outbound transport efficiency. When products weigh more than 416.6 kg on a Euro pallet, the transportation is restricted by weight for less than 416.6 kg, the volume efficiency is used instead. Differently from the original tool, in this analysis these values were calculated for a standard 7.5-12-ton truck with 18 pallet spaces. Figure 15 shows the defined environmental performance levels for each criterion of transport efficiency.

CRITERIA	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Inbound transport distance and mode**	Delivered by long distance road transport (>= 2,000 km) or delivered by airfreight	Delivered by road transport (>= 1,000 km)	Delivered by road transport (> 300 km - < 1,000km)	Delivered by intermodal transport (including max. 300 km road transport) or < 300 km road transport	Delivered by intermodal transport with mainly ship or rail (including max. 100 km road)
Inbound transport load efficiency	High-weight material delivered in final form, non-nestable	Medium-low-weight material delivered in final form, non-nestable	High-low-weight material delivered in final form, nestable	High-medium-weight material delivered unformed (e.g. rolls, blanks or in bulk)	Low-weight material delivered unformed (e.g. rolls, blanks or in bulk)
Outbound transport weight efficiency	< 60% product weight on pallet (of total pallet weight)	>= 60% - < 70% product weight on pallet (of total pallet weight)	>= 70% - < 80% product weight on pallet (of total pallet weight)	>= 80% - < 90% product weight on pallet (of total pallet weight)	>= 90% product weight on pallet (of total pallet weight)
Outbound transport volume efficiency	< 30% product volume on pallet (of total pallet volume)	>= 30% - < 50% product volume on pallet (of total pallet volume)	>= 50% - < 60% product volume on pallet (of total pallet volume)	>= 60% - < 70% product volume on pallet (of total pallet volume)	>=70% product volume on pallet (of total pallet volume)

Figure 15. The levels for the transport efficiency area Source: Molina-Besch and Pålsson, 2019

4.5.3 Influence on food waste

As mentioned in the methodology section, the third area of the tool was modified to include the influence of food waste from more supply chain stages than just the household consumer stage. The packaging solutions evaluated in this study were deemed with no significant differences between each other during the initial scanning of the design attributes presented in the original tool. Therefore, it was incumbent to identify new attributes specifically for the Micvac packaging which would be the criteria of this area and define levels for each of these attributes.

Shelf-life criterion is included to assess how each packaging solution affects the duration of the food product staying fresh and safe to consume. It is assumed that a longer shelf-life leads to less food waste as a product with a longer shelf-life has a longer timeframe opportunity to be distributed in the supply chain compared to a short-life product which is discarded quickly if it remains unsold or unconsumed by the consumer. The levels were defined according to the labelled shelf-life of typical ready meals in the market.

The fragility of the package evaluates the inclination of the packaging to break when it is mechanically or thermally shocked, which can lead to the package integrity being lost and food being wasted. This handling criterion is a relevant factor in many supply chain stages. However, it is assumed the biggest impact is on the distribution stage as the stakes of the losses are higher since a larger number of packages are dealt with compared to the other stages. In other words, mishandling a pallet which contains several packages leads to a larger food waste compared if a store employer mishandles primary packages in the retailer phase or a consumer having a package punctured in their vehicle.

Sealing efficiency examines the strength of the packaging seal. If the package is not properly sealed, it will burst during food manufacturing, therefore that product will end up as waste. Two factors are required for this criterion: achieving the proper peel and achieving the proper strength. If these factors are combined the packaging will not burst open during processing but will lose a part of its strength, just enough to make it possible to be opened easily by the consumer. Therefore, the sealing needs to be strong enough for the process and elastic enough for the end-use.

Appealing appearance estimates the scale of the packaging solution enabling an appetizing and attractive presentation of the ready meal to the final consumer. Two factors were considered for this attribute: the covering rate of the packaging sleeve in the primary package and the look of food in an unopened package from the consumer perspective. The sleeve directly affects the visibility of the food which is positively correlated with the consumer perception (Coucke et al., 2019). However, the sleeve is not something that Micvac is delivering to its customers, so it is outside of the company's dependence. Different manufacturers put the sleeve label in different formats according to their marketing strategies. The look of the food is a subjective factor regarding how pleasant or attractive the meal looks in the package. Three categories are distinguished in this regard: "invisible" which refers to the opaque packaging not allowing the consumer to see the food content from the unopened tray, "the mashed look" which is typical for the vacuum packaging and "the restaurant plating" which is affiliated to the ready meals in headspace packages.

Figure 16 shows the selected attributes of the third area of the tool and the appropriate levels of each attribute. For the sealing efficiency and the fragility of the package, the levels were defined by relative comparisons of the solutions with each other, not by descriptive levels assessing each packaging solution independently. Based on internal judgements, a packaging option was chosen as a reference for each attribute, scoring as the middle value 3 while the rest of the options' performances were evaluated compared to the agreed reference.

CRITERIA	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Shelf life	Less than 5 days	5-10 days	11-20 days	21-45 days	More than 45 days
Fragility of the package	*Relative comparison*	*Relative comparison*	*Reference*	*Relative comparison*	*Relative comparison*
Sealing efficiency	*Relative comparison*	*Relative comparison*	*Reference*	*Relative comparison*	*Relative comparison*
Appealing appearance	Invisible or mashed look with large sleeve coverage (>50%)	Mashed look with small sleeve coverage (<50%)	Mashed look without sleeve coverage	Restaurant plating with a sleeve coverage	Restaurant plating without sleeve coverage

Figure 16. The levels for the influence on food waste area

4.5.4 Packaging end-of-life

The evaluation of the end-of-life impact of primary packaging considers two aspects: the environmental effects when it undergoes typical waste management procedures such as separation, sorting, recycling, and incineration, and the likelihood and impact of littering if it is disposed of improperly in nature. The evaluation of the impact on existing waste management processes follows the waste hierarchy of the EU as outlined in the Waste Framework Directive 2008/98/EC, which ranks waste management processes in order of preference from most to least preferable: prevention, reuse, recycling, recovery, and landfill. Prevention is not considered a waste management process and is therefore not part of the evaluation. Figure 17 presents the defined environmental performance levels for criteria of the fourth area of the tool.

The criterion of separation and sorting pertains to the ease with which consumers can sort packaging for recycling and the feasibility of separating materials in existing recycling processes. The likelihood of consumers correctly sorting a package into the appropriate recycling category is higher when the package is made of a single material, as indicated by consumer studies.

The criterion for circular economy value is added to account for the importance of closed-loop material recycling for sustainable packaging material usage. The goal is to recycle packaging materials as much as possible without degrading their properties. Materials that can be recycled infinitely are more favorable than those with limited recycling cycles. The evaluation only focuses on material recycling, excluding composting of biodegradable packaging in natural cycles. This is due to the absence of suitable industrial composting facilities that can manage biodegradable plastic packaging in Sweden.

The amount of non-recycled waste assesses the average amount of waste, generated by the primary package, that cannot be recycled. Minimizing non-recycled waste is beneficial for the environment as it reduces emissions from waste incineration or landfill of household waste. This criterion is calculated by subtracting the average recycling rate for the packaging material on the target market from 100%, and then multiplying that percentage by the amount of packaging material.

The criterion of the impact in waste incineration is used to evaluate the environmental effects of the packaging solution when it is incinerated such as energy content of the packaging material and potential harmful emissions from incineration. As not all packaging materials are currently recycled at a 100% rate, some packaging solutions end up being incinerated or landfilled, depending on the target market. This assessment is only applicable to target markets where a significant portion of mixed household waste is incinerated, which is the case in the countries where Micvac is operating or planning to operate mentioned in the trends' subsection.

Although there are well-established waste management systems for packaging in the EU, there is still a possibility that packaging waste may be littered and end up in the natural environment. There has been significant research on the harmful effects of plastic waste that has littered in aquatic ecosystems. The tool evaluates the likelihood of a packaging solution ending up as litter and the environmental impact of leaving a specific material loose in nature to consider the littering risk.

CRITERIA	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Separation and sorting	Packaging consists of composite material that does not allow for material separation	Packaging consists of composite material/several material layers that are separated in the existing recycling process	Packaging consists of several materials that consumers can easily separate** before sorting (3 or more different materials)	Packaging consists of two materials that consumers can easily separate** before sorting	No need for separation and sorting:- Packaging consists of one type of material, or- Returnable package that is part of an organized deposit system
Circular economy value	Main packaging material is not recycled in currently existing recycling system (non-separable composite materials, PVC, black-coloured polymers, EPS and PS)	Main packaging material is part of an open-loop material recycling system where recycled materials lose value quickly (downcycling),	Main packaging material is part of an open-loop material recycling system where recycled materials lose value over time (downcycling),	Main packaging material is suitable for closed-loop recycling but partly recycled in open-loop systems (due to dyes, lacquers, alloys, etc.)	Main packaging material is part of a closed-loop packaging material recycling system with no/minimal share of virgin material input or reused package that is part of an organized deposit system
Amount of < 13 g	non-recycled waste non-recycled waste/kg product	> 39 g non-recycled waste/kg product	30 – < =39 g non-recycled waste/kg product	22 – < 30 g non-recycled waste/kg product	13 – < 22 g non-recycled waste/kg product
Impact in waste incineration	Material that potentially contributes to hazardous air emissions from waste incinerators (e.g. PVC)	Material with low energy content (e.g. glass and metals)	Non-chlorinated fossil-based polymers	Fibre-based material or biopolymer made from renewable feedstock	Fibre-based material or biopolymer made from renewable feedstock with sustainability certification (FSC certified or similar)
Littering likelihood	Light-weight package format (film, wrap, bag) with small and/or light-weight separable components (opening strips, straws, perforated parts)	Light-weight package format (film, wrap, bag) with solid and reclosable cap or without any separable components	Heavy/rigid package with small and/or light-weight separable components (opening strips,caps, straws, perforated parts etc.)	Heavy/rigid package with reclosable cap	Heavy/rigid package without any separable components
Littering impact	Package consists of >= 50% non-biodegradable polymers	Mixture of materials with < 50% – >= 25% non-biodegradable polymers	Mixture of materials with < 25% – > 0% non-biodegradable polymers	Mixture of materials without non-biodegradable polymers (e.g. steel and cardboard)	Package consists of 100% biodegradable material (biodegradable in nature)*

Figure 17. The levels for the packaging end-of-life area   Source: Molina-Besch and Pålsson, 2019

4.5.5 Results of the environmental performance tool

The scores for all attributes were collected and calculated for a final value representing the environmental impact performance of each packaging solution. Figure 18 depicts the dimensionless results of the packaging solutions evaluations, where 1 shows the worst performance or expressed differently the highest environmental impact, and 5 shows the best performance, i.e the lowest environmental impact. The packaging solution which showed the best performance was the monoPP packaging with a score of 2.96. It is followed by the fiber-based and the monoPET which are very similar in their result performances with a slight advantage of the fiber-based option. The solution with the lowest score of the environmental evaluation was the bio-based polymer option. However, it is observed that the packaging solutions do not show a significant difference in their results. The additional figures on the tool results for every assessment area can be found in Appendix F.

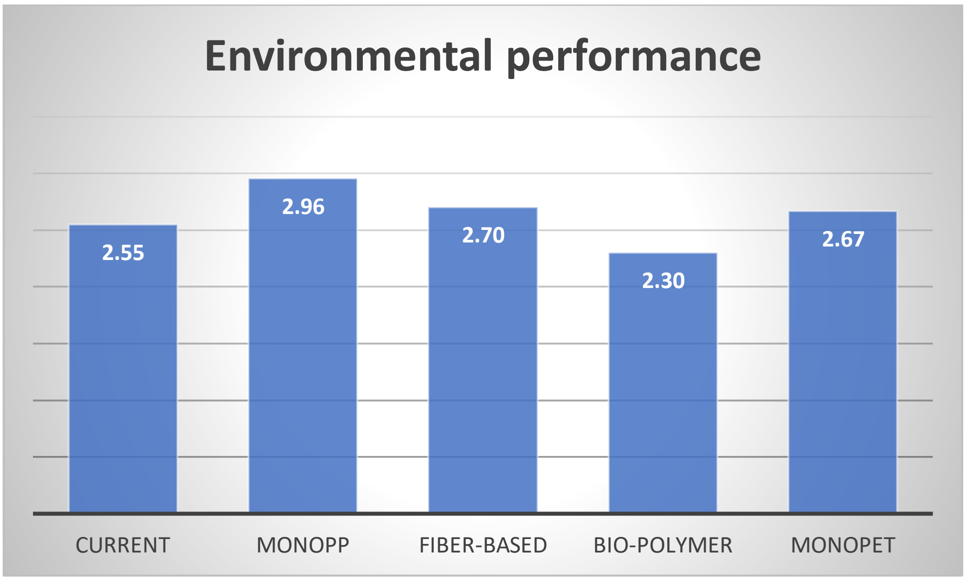


Figure 18. Results of the environmental performance evaluation for every packaging solution, 1.00 represents the worst environmental score and 5.00 the best environmental score.

5 Discussion

The author interprets the results and findings for every assessment area in this section, presents the requirements of key actors in the supply chain and discusses the implications for the industry. The limitations of the study are also mentioned, along with suggestions for further research.

5.1 Interpretation of the result and the findings

5.1.1 Packaging material

Due to their circular nature, the fiber option and monoPET show the best performance in the first area of the value chain, each having a 3.5 average score. The material carbon footprint data was gathered by contacting the supplier companies, in the case of monoPET and biopolymer; by available product datasheets of the trays, for the fiber-based tray; and in a previous study done in the case of the PP tray which is used in the current and monoPP solutions (Hosse Pastor, 2021). All the options were evaluated with the meal content being 400 g ready meal, which means the raw data for a tray footprint were multiplied by 2.5 to calculate the material carbon footprint in kg CO_2-eq./kg product.

The results show the evaluations of only the trays and not the whole primary packaging. This simplification was made due to the lack of information on the carbon footprint of the lid film and the valve production. It is estimated that this would not affect the tool score by a significant margin since the trays represent 82-95% of the content of the different packaging solutions, therefore making the trays responsible for the largest share of the carbon footprint in the primary packaging. It is worth noting that it is highly probable that the material carbon footprint of the fiber tray considers its whole value chain, and not just the material production as the rest of the solutions. Consequently, it is important to make the necessary adjustments in the tool results when establishing contact and verifying the results from the producing company.

Regarding non-hazardous materials, the current packaging performs the worst due to its PVC valve, which generates toxic emissions when it is incinerated, thus the final score is 1. The rest of the solutions were evaluated regarding their composition and verification from the original suppliers. Both the monoPP and fiber-based showed the maximum level score of 5, which guarantees the non-exclusion of SIN list chemical, identified by ChemSec (International Chemical Secretariat, n.d.) as being substances of very high concern (SVHC). The criteria for a SVHC are described in article 57 of Regulation (EC) No 1907/2006 (Registration, Evaluation, Authorisation and Restriction of Chemicals otherwise known as REACH).

On recycled content, the extinguished solution is the monoPET, certified by the suppliers with a 67% recycled content for the tray. This results in 65% recycled content for the whole packaging, which makes it substantially different from the rest of the solutions, none of which have recycled content. It would be interesting to see how this result changes once the upcoming EU legislation approves recycled materials other than PET for food contact. In this aspect, it is expected that the advantage gap of PET to the other packaging solutions will be narrowed.

A similar gap in the score appears in the renewable content criterion but in favor of the fiber-based and the biopolymer options, scoring 5 and 4 respectively. Since these two packaging solutions have their trays manufactured from raw natural sources, they do not exert the environmental impact that the fossil-based solutions do.

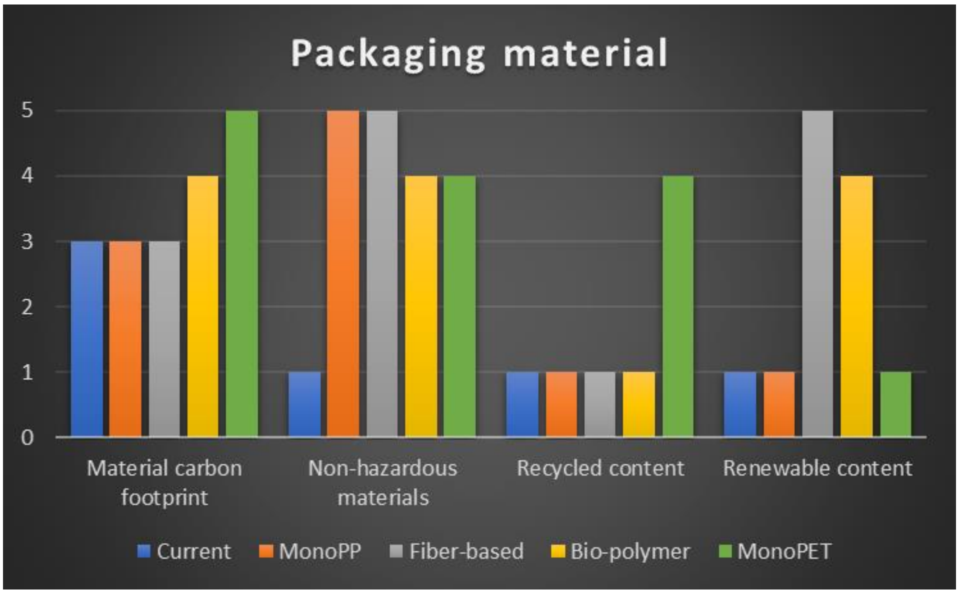


Figure 19. Environmental tool results for criteria of the first assessment area

5.1.2 Transport efficiency

The second area showed the most similarities between the solutions compared to the other areas. The monoPET has a slight advantage in its performance, scoring 3 on average of the criteria.

The results from the transport efficiency are impacted by the distance between the chosen suppliers for the packaging components and the food manufacturer, which was chosen to be Gooh AB, a Lantmännen company and customer of Micvac, which currently produces the ready meals in Järna, Sweden. The details on the transport distances for packaging components can be found in Appendix D, where the locations of the confidential packaging components are not specified. Since the packaging is made of three components a standardized average was calculated for the total distance, which was normalized according to the weight of each component in the final package. With varying percentages, most of the weight content belongs to the tray in all the solutions so the production location facilities of the trays are the major contributing factor in this criterion results. The current, monoPP and the biopolymer solutions have their trays produced in Poland which is more than 1500 km away from the food manufacturer where the components are delivered. This distance is attributed to their larger environmental impact and consequently a lower score in the tool. On the contrary, the paper tray produced in Sweden and the PET tray in Denmark, show a higher score due to shorter transport distances.

Regarding inbound transport load efficiency, all the solutions perform the same due to their similar weight which makes the packages a low weight type category. All the trays are nestable and delivered in their final form, while the films and the valves are delivered in rolls which can help avoid air being transported, making the transport of these components more environmentally friendly.

All the distributions are done by trucks of various sizes. However, for the purpose of this evaluation a standard truck of 7.5–12 ton was selected in the outbound transport. A major factor in the outbound transport efficiency is the configuration of the primary packages in the secondary packaging, represented by the SRS crates in the Swedish context. Stackbuilder software models, used to visualize these configurations and to calculate the volume and weight efficiencies, are found in Appendix C. The current and monoPP solutions are in vacuum conditions accounting for 100%, volume fill rate of the primary packaging. For the rest of the solutions the volume fill rate was calculated only on the weight of the ready meal, 400g divided by the total available volume of the tray. This assumption was made because of the lack of specific drawings for their trays. By this formula, volume fill rate resulted to be 50% for the paper tray, 43% for the biopolymer tray and 80% for the PET tray.

As mentioned in the previous section, for products with a Euro pallet weight of more than 416.6 kg, transport is restricted by weight. Since the calculations showed a result of a lower weight for the pallet of each solution, the volume efficiency was used instead of weight efficiency to indicate the outbound transport volume efficiency. The solutions had various results ranging from 13.8% for the fiber-based packaging system to 41.4% for the monoPET packaging system. These results are heavily influenced by the fill rate of the primary package, which is not 100% except for the current and monoPP solutions in vacuum. It is interesting to see how the scores would change if the other solutions were put in vacuum conditions although that would be difficult to achieve for the fiber and biopolymer options. If the fill rate of the monoPET package is increased by increasing the amount of ready meal in the package, it would show a higher score in this criterion.

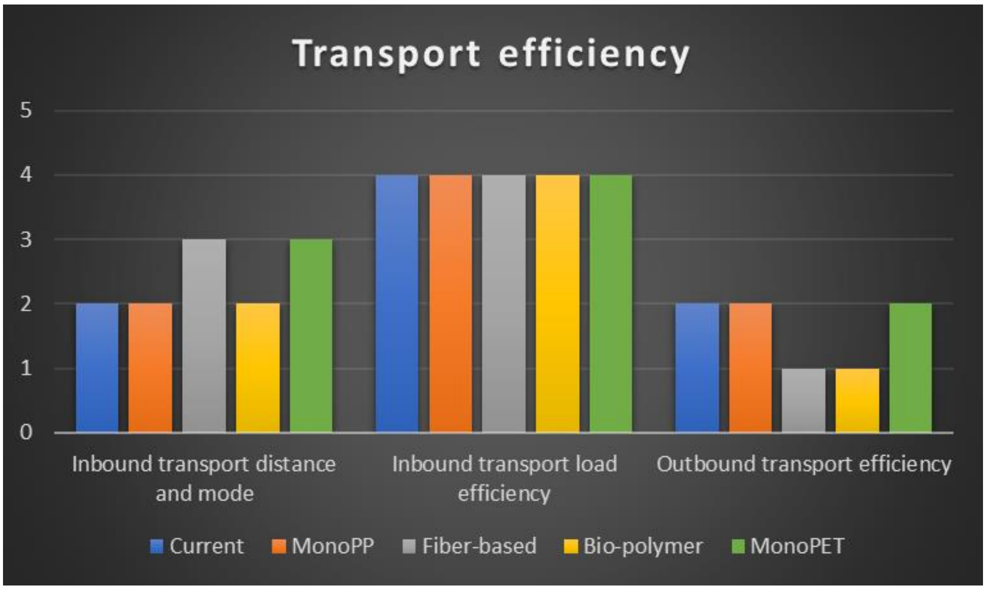


Figure 20. Environmental tool results for criteria of the second assessment area

5.1.3 Influence on food waste

During the discussions in the internal meetings, it was realized that identifying attributes of Micvac packaging should go beyond the packaging material rather it should include processing concepts or the processability of the package. It is important to highlight how difficult it is to produce efficiently with a certain package. This aspect is where Micvac packaging differs significantly from competitor products in the ready meals market, enabling the tool to address competitors packaging in the future by evaluating them through this model.

The boundaries of the system start from processing, excluding the production of food ingredients as Micvac does not have control over that phase and it would affect all the packaging options in the same way. Additionally, in the developed countries food loss is not as high as food waste which happens in the later stages of the supply chain, primarily the consumption stage (Ishangulyyev, Kim and Lee, 2019).

The current and monoPP solutions are likely to have the best performance in reducing food waste as they each have an average score of 3.5 on this area. These two solutions perform the highest in shelf-life since the current packaging keeps the food fresh for up to two months in refrigerated conditions, and the monoPP less than that but still it reaches the defined level 5 of the criterion. The biopolymer is expected to perform very low due to its vulnerability to the in-pack pasteurization process. Regarding a different bio-based material, Sonar et al. (2020) conducted a study to assess the viability of using bio-based pouches made from PLA and PBAT for in-package thermal pasteurization. Despite a noticeable reduction in the barrier properties of the films post-treatment, the PLA and PBAT-based pouches were able to preserve the quality of the products for up to 10 days when stored at 4 °C (Sonar et al., 2020). Due to a higher oxygen and water vapor permeability than the PP tray, the fiber and the PET trays are estimated to keep the meals safe and fresh to consume for only about two weeks, although this is to be confirmed by subjugating these materials to the Micvac process. Their headspace also plays a role in lowering the shelf-life of the ready meals packaged in these options.

Some factors impacting the food waste in the retailer phase also include the frequency of the discount campaigns. Also, if a retailer purchases an excessive amount of ready meals from the manufacturers, the final impact on the food waste would be lower with a longer shelf-life product which has a larger window until its expiration date. The European Chilled Food Federation (2006) states that a process with the same effect as heating to a temperature of 70 degrees Celsius for 2 minutes and 90 degrees Celsius for 10 minutes can result in a shelf life of up to 10 days at a temperature of 5 degrees Celsius, and 6-12 weeks at the same temperature (Sonar, Tang and Sablani, 2022).

Regarding appearance, the ready meals that are treated and stored in vacuum conditions look squashed and that would influence negatively on the consumer perception when grocery shopping due to the unappealing look of the product. Since the cooking is done inside the package, a perfect and smooth look on the surface of the food is not achievable resulting in a mashed appearance. This may lead to a smaller number of meals being sold which would result in more food waste happening from the expired products in the retailer phase. The fiber-based option scores the highest due to the printability of the paper tray. By utilizing this material property, it is possible to avoid having to use a sleeve altogether. Cost difference and environmental impact differ between numerous sleeve sizes and types. Removing all the packaging sleeves which serve no purpose except the information transmission would save natural resources needed to produce them and reduce costs for the actors along the supply chain, particularly the food manufacturers. Despite having the highest score, it is important to highlight that the paper tray can easily be ‘contaminated’ in the sense that it can be perceived as dirty by the consumer even if it is not. This perception can happen due to reasons such as water marks when water comes in contact with the tray during production filling stations or food parts sticking to the edges of the tray. Having stains on the outside of the tray may lead consumers to think the inside of the tray is dirty as well.

Except for the aesthetic visual part, the appeal of the food is influenced significantly by its taste. A product that is not enjoyable is likely to be discarded by the triggered by the poor taste perceived by the consumers. However, since most of the solutions evaluated in this study are currently not operating, it is not possible to estimate how the packaging materials impact the food quality and taste. In the future evaluations, it is recommended to conduct sensory tests with consumers to analyse the differences between the acceptability of the ready meals in the different solutions. This evaluation can give interesting conclusions if it includes competitor technologies of Micvac as well.

The level of sleeve coverage is the choice of a Micvac customer if they want it or not. The current Micvac packaging has a mix of customer choices, with some of them covering the whole tray while some of the food manufacturers do not cover the tray. To present a balanced score, a rating of 2 would be approximate as most sold volumes of the current packaging fall on the defined level 2. The monoPP has the same reasoning as the current packaging as the tray is the same in both options. However, monoPP is a new concept and is not marketed in the same volume amounts as the current packaging yet, therefore it is important to be tested in the future to see how the behavior of the customers will change regarding the sleeve of this monoPP solution.

Biopolymer packaging has headspace, same as fiber-based packaging which would give in theory would give the product a more appealing look compared to the first two options. However, it still needs sleeve coverage for the label which renders it to level 2. MonoPET has the worst performance in this category as the PET tray and film are opaque and do not allow the consumer to food product through the packaging. However, if a food product looks unappealing in the vacuum package, the invisibility could be a positive aspect instead of negative. Since whether a consumer wants to see the food through the package or not is based on individual preference, consumer tests with large number of untrained participants are necessary to get an accurate depiction of appearance criterion on a statistical level. This aspect is highly subjective and would have to be the subject of sensory testing which was outside the scope of this study.

Regarding sealing efficiency and processability difficulty, the current packaging is selected as the reference point to which the other solutions are evaluated to. For monoPP, it was observed that there is a smaller need for a high peeling force, making it easier to process. However, according to the packaging developers it has been quite difficult to seal a PP film. Due to the ongoing experiments on this option, it is expected that the processability of monoPP will improve, but further details are not stated in this study due to confidentiality. Assuming Micvac is supplied with an effective PP film which works properly with the tray, monoPP scores 4, the highest of the evaluated solutions.

With the paper tray, it will be very difficult to get good sealing efficiency. The inner film of the tray in contact with the food, is a PP laminate, so most probably the bonding between the inner film and the tray would be lower than between the top lid and the inner film of the tray. This will result in making it more difficult for the consumer to open the package. This reasoning stands for the biopolymer option as well due to its content. MonoPET has a lower sealing efficiency score. According to Faerch developers, when sealing the current tray, a fusion between packaging materials is formed, which is not the case when sealing PET. In this different type of sealing, a welding between materials is not achieved and getting a peelable solution to work in these circumstances is difficult or highly unlikely. It is probable to get a weld seal which can work but it would not be possible to peel it. Therefore, it might be necessary to pierce the film.

In the evaluation of fragility, mechanical shock and water resistance were the two considered factors considered. The fiber-based option received a low score because of its water affinity, which makes the package more prone to damage in high moisture conditions alongside the supply chain. The current package has the best performance because it is very rigid, due to its sturdy design, thickness, and PP material. Furthermore, the content of the film and the valve, PA-PP and PVC respectively makes this package very unlikely to break as it has been noticed by the Micvac team during their years of experience with this packaging. However, it is not rated as 5 due to some rare cases when this package when this package has been punctured. MonoPP scores lower due to its lid being a monolayer and thinner which presumably makes the packaging more fragile from the film on the top.

MonoPET is also more fragile than current packaging and can be quite fragile during transport. Considering its soft and malleable behavior during processing, it receives a lower rating than the monoPP which has been already proven to have a rigid tray. Biopolymer performs the same as monoPET because headspaces are also more fragile than vacuum packaging since there is only air behind the film and no support against a potential mechanical shock. This makes it more likely to be punctured by the handlers during the transport chain or by the consumers during the contact between different products packaging in their shopping bags. It is recommended to check and verify the fragility of each package can be further checked with drop tests and vibration tests, although they are used mostly for secondary packaging in the industry. Another aspect is that a small puncture is immediately detected in a vacuum package while the same puncture size can be unnoticed in a headspace package for some time.

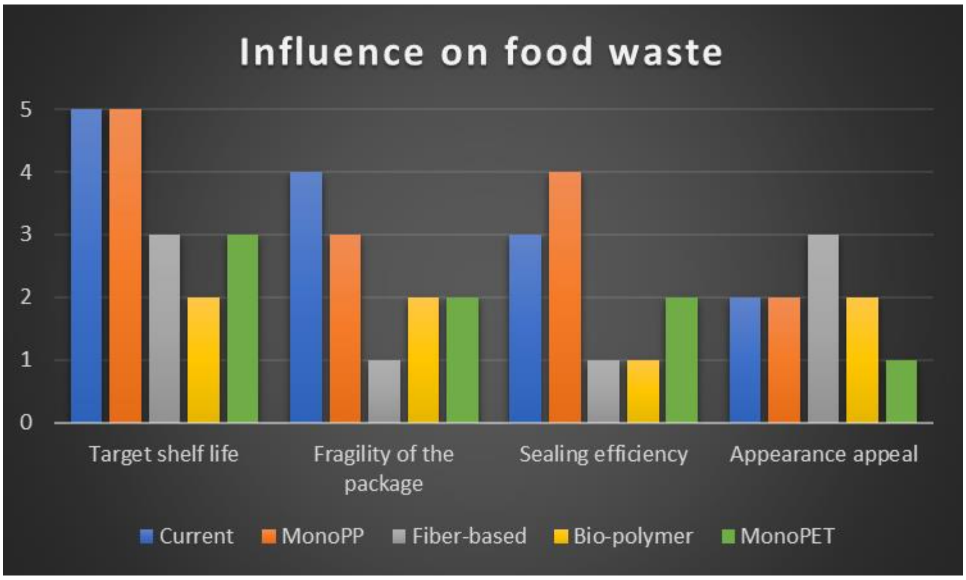


Figure 21. Environmental tool results for criteria of the third assessment area

5.1.4 Packaging end-of-life

As expected, the fiber-based option shows the lowest environmental impact in the post-consumption area of the product life cycle. The solution has a score of 3,17 while the lowest performance belongs to the current packaging with a 1,83 score. The monomaterial solutions of PP and PET are the most convenient for the consumers, as these options do not need sorting and their components can be discarded together in the same recycling bin. Even why in Sweden they can separately be put into the same collection bin for plastic packaging, still it is preferable to recycle lid films separately from trays, even if they are made from the same polymer type. The reason to that is that trays are recycled in rigid PP recycling facilities that most likely will separate films in the washing process to minimize cross contamination risks from other film materials such as LDPE but also label material containing a lot of printing inks. In the case of fiber-based and biopolymer it is easy to sort the tray and the film separately. Meanwhile, the current packaging performs the worst due to the valve and the film being different materials from each other.

In the circular economy value, the fiber and the PET trays perform the best by being part of an open-loop material recycling system but still losing value over time, as unfortunately the trays are not recycled in the same number of cycles as they are theoretically possible to. Currently, the number of recycling cycles is insignificant due to the low recycling rates observed in Europe. In the case of Swedish household plastic packaging, the recycling rate in 2022 was approximately 20%, with only a small portion of that being reused in packaging applications. Assuming that 50% of the recycled material is utilized for new packaging, which means that less than 10% of the packaging material entering the Swedish market comes from recycled sources, while 90% is made from virgin materials. Consequently, the recycled material gets diluted tenfold in virgin material with each cycle. By the third cycle, less than 1% of the original material remains from the first cycle. Moreover, it is challenging to trace the material as it is extensively traded among countries, being labeled as waste, recycled material, or packaging material. The biopolymer tray would not be recycled at all as there is a lack of a collection and recycling system for bioplastics in Sweden, which end up incinerated so that solution rates at the lowest level of 1.

To calculate the amount of packaging waste, email communications were conducted with FTI and Svensk Plaståtervinning in order to understand the recycling rate of specific plastic fractions in Sweden. The issue is that although the recycling rate for plastic in 2021 was 18%, so far there is no recorded data on the specific plastic fractions recycling rate. According to PlasticsEurope's "Plastics – the Facts 2020" analysis, the recycling rate of plastics in Sweden was 45% in 2018, whereas 20% of the plastics quantity in the market is represented by PP (PlasticsEurope, 2020). To get an approximate rate between this value and FTI plastic recycling rate in 2021, an estimated value of 26% recycling rate for PP was chosen to make the necessary calculations. According to a report published by the Swedish Environmental Protection Agency in 2020, the recycling rate of PET packaging waste in Sweden was at 34%, including PET bottles and trays. (Anderson and Swedish Environmental Research Institute, 2020). Meanwhile for the fiber tray, the paper recycling rate was 72% in 2021 in Sweden, making it the solution with the smallest weight recorded as waste among the five packaging solutions. Again, the biopolymer scores low because there are no industrial facilities for composting in Sweden, therefore there is no proper stream for these materials. Even if the tray was biodegradable, it would face the same issue, as well as some problems with microplastics that can contaminate the current streams. Consequently, all the biopolymer's weight is a waste in this evaluation, thus making it the material with the heaviest impact in this criterion. When calculating the amount of waste from the lid films and the valves it is important to highlight that the flexible plastic is not recycled today, but it is planned to be recycled at the new facility Zero in Motala, Sweden later this year. Therefore, the whole weight of the films and the valves are considered as waste in this study, but it is important to update the calculations in the near future according to the recycling rates of the flexible PP and flexible PET that will be treated in the aforementioned waste treatment site in Motala.

On the impact in waste incineration, the worst material from an environmental perspective is considered for the score. All the solutions rate the same except the current packaging which has the PVC valve giving it the lowest score. The rest of solutions have fossil-based polymers in the form of films and valves which rates them at level 3. It would be interesting to investigate the possibility of a biopolymer film manufactured from a renewable feedstock as this would increase the score of the fiber and biopolymer solutions.

Similarly, the score of all the solutions on littering likelihood considering that all packages are classified as rigid. However, they do contain separable lid films which would be possible to be littered therefore they do not belong to the maximum level for this criterion. In the littering impact aspect, the fiber tray has the best performance, attributed to the low content of non-biodegradable polymers represented only by the inner film of the tray, the film, and the valve. The current, monoPP and monoPET present the heaviest environmental impact when littered owing to their composition of only non-biodegradable polymers. The biopolymer also has a low score since the tray content, although bio-based, is overwhelmingly manufactured from a non-biodegradable source. It would be interesting to see the change in the results if another biodegradable material was considered for tray production.

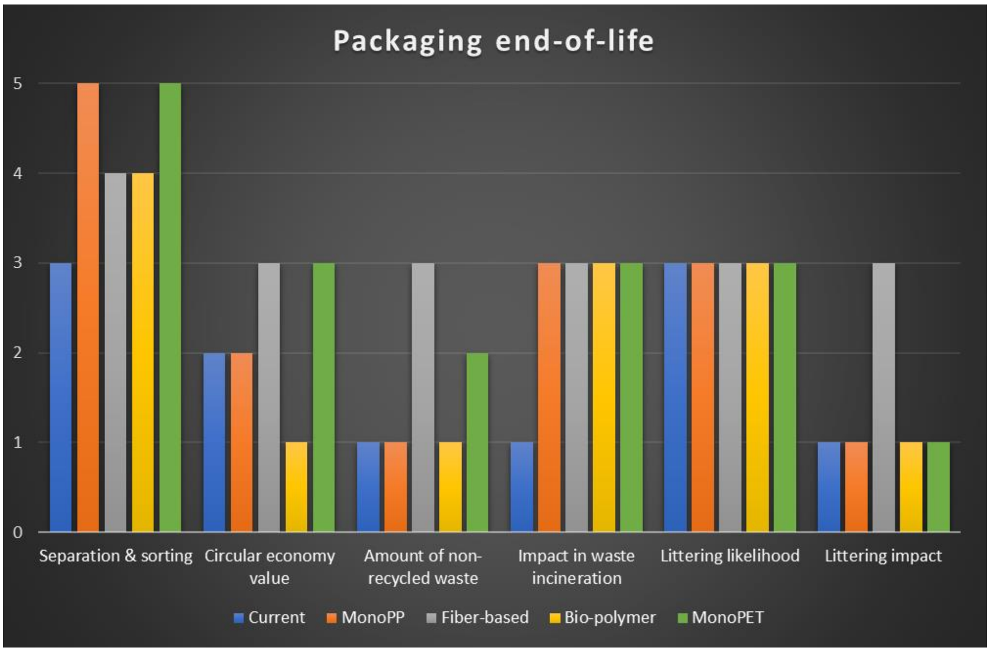


Figure 22. Environmental tool results for criteria of the fourth assessment area

5.2 Consumer and market considerations

Many companies have been trying to reduce their use of plastic packaging in response to consumer concerns for the environment. However, a negative trend has emerged where some companies are overpackaging their products with superfluous paper to give the impression of being more environmentally friendly, even though it does not reduce plastic waste. Studies with over 4,000 participants from the US, UK, and the Netherlands have shown that consumers perceive products with additional paper packaging as more environmentally friendly than identical products without paper packaging. This perception leads consumers to be more likely to buy the product and willing to pay more for it. Interestingly, consumers' perceptions of sustainability increase with the amount of paper used in the packaging. (Krishna and Sokolova, 2023). Unfortunately, the trend of overpackaging is more noticeable to consumers who are most environmentally conscious, and this could unintentionally encourage environmentally harmful practices. In their research, Sokolova, Krishna and Döring revealed that a "minimal packaging" label on plastic packaging can effectively address the false belief that overpackaged products are more eco-friendly. This approach can be particularly useful for products that require plastic packaging for protection during transportation and to extend shelf life. By using clear and direct communication, this method can help counteract consumer bias against the responsible use of plastic packaging, without resorting to additional and unnecessary paper waste. (Sokolova, Krishna and Döring, 2023).

Similarly in a study, van Bussel and other authors concluded that consumers are not well-informed about sustainability issues related to food. As a result, when advocating for sustainable diets, policy makers should not prioritize sustainability alone. Instead, they should prioritize health, taste, and price considerations. To help consumers make informed decisions, a clear and regulated sustainability labeling system is necessary (van Bussel et al., 2022).

Genuine investment in sustainability should accompany these marketing efforts. If a brand is using minimal packaging, it is important that they have actually taken steps to ensure that they are using the least amount of packaging possible, ideally with the oversight of a regulatory body or trade organization that maintains consistent standards. The labels from Carbon Trust, an independent organization and established expert on carbon footprinting, are good examples to verify that a brand is actively assessing and decreasing the amount of carbon emissions produced by its product. However, for companies seeking to package their products in a more responsible manner while still giving the impression of being environmentally friendly, a "minimal packaging" label provides a far superior option to the harmful trend of overpackaging (Sokolova, Krishna and Döring, 2023).

Another relevant aspect of the current situation in the market is the current contradiction between the EU implementing legislation to promote the collection, sorting, and recycling of packaging waste but at the same time prohibiting the using recycled raw materials in food packaging, with a few exceptions. This bottleneck causes these encouraged processes to not significantly reduce resource consumption unless the recycled materials are used to replace virgin raw materials. During the interviews held for this study, different stakeholders from the ready meals value chain expressed the desire and projected the extension of the range of recycled materials which will be allowed to be used in food packaging applications. In the industry, it is presumed that only mechanical recycling will not be able to handle the necessary quantities to supply the whole market, but additional innovative recycling technologies will be required.

5.2.1 Food manufacturers' requirements

Two separate online interviews were held with two of the largest customers of Micvac, namely Orkla Foods in Norway and Lantmännen Cerealia in Sweden. Despite their differences in market presence and product portfolio, both companies are producing chilled ready meals in the Micvac packaging. Some similarities and differences were noticed in their environmental strategy and considerations when choosing packaging for their products, derived from various factors such as the country where they operate, the markets they are exposed to, the requirements from their suppliers and partners in the supply chain.

Lantmännen's sustainability strategy is built on pillars representing the principles which guide the decision-making process. The company puts emphasis on reducing and eliminating the non-essential components from their packaging. This objective has the potential of minimizing environmental impact, cost, and enhancing convenience for the employees, customers, handlers, and the final consumers. So far, plastic has been the focus of the company's strategy. An annual target of reducing plastic usage by minimally 1% on a company level has defined Lantmännen's operations in recent years. Additionally, an ambition of having 100% recyclable packaging by the end of 2022 was set, which currently stands at a rate of approximately 90%. Since removing non-recyclable plastic is on their immediate agenda, they would be interested in changing the current Micvac film and the valve, to achieve full recyclability of their Gooh brand ready meal package.

Another significant KPI is the target ambition of having no (0%) virgin fossil-based plastic by end of 2030. This means that all the packaging would be manufactured from either bio-based source such as paper or bioplastic, or from recycled content of fossil-based materials. The fiber-based and biopolymer solutions assessed in this study are in favour in this regard, since the representative expressed that it is unlikely to achieve a closed loop by mechanical recycling for plastic materials in food contact by 2030. According to the Packaging lead of Lantmännen, in the future a large part of the packaging will be covered by bio-based packaging to fulfill their 2030 goal. The company expects the legislation to change regarding recycled content. Mechanical recycling will continue to be a challenge as it is more difficult for packaging which doesn't have a developed streamline like PET.

In a general view, the company is not proactively working in reducing food waste, as most of their products are non-perishable such as dry products, flour, cereals. In Lantmännen value chain, only 15% of the packaging is plastic, with the rest being mainly paper and cardboard. Therefore, the strategy is not focused on food waste, because it is not an impactful factor due to their products' nature. However, avoiding

food waste receives more attention in the projects on changing the packaging materials for products requiring cold chain such as chilled ready meals. Except for the challenge of keeping the food safe and fresh with monomaterials, not all packaging machines are set up to run monomaterials, since they can be quite old. So, a change of packaging materials would additionally require a cost analysis including changing the machines or updating the equipment.
Recently, Lantmännen has opened to a more holistic approach to its environmental impact instead of focusing just on tackling plastic problems. In the end of last year, the company adopted science-based targets (SBT) which provide organizations with clear guidance on the quantity of GHG emission reductions required to mitigate the most severe impacts of climate change (Science Based Targets, 2023).

Similarly, Orkla Foods attempts to use sustainable materials whenever it does not compromise with the shelf-life of the product. The strict regulations on recycled content in food packaging applications allow the company to only use 100% rPET on some limited brands. At the moment, no bio-based plastic is being used by Orkla as the market price is high, mainly due to the scarce quantity that is available. The company has previously discussed with Micvac about the opportunity of having the valve to be the same material as the tray. Therefore, a monoPET or monoPP solution would be welcomed by the company.
Orkla has an important target for all its packaging to be recyclable by 2025 and that rate stands at around 94% currently, due to some products which have laminates with paper and aluminum in their composition. However, the company is actively working towards finding suitable alternatives to achieve its target. The most recent change of Micvac trays from black to transparent was an important part towards that goal. By the same time in 2025, the company wants to ensure that 75% of its packaging is made from recycled materials, with the rate for specifically plastics at 50% recycled content or renewable materials. To measure the advancement of the strategy, Orkla is implementing LCA analysis, calculating the environmental impact from the point of receivement of raw materials to the point of the products leaving Orkla warehouse, thereby calculating the GHG emissions for the whole product-package system.
Similar to every food manufacturer, the priority of Orkla is to keep the food safe and fresh as long as possible, which makes it more important than sustainability of the package. To tackle food waste, the company has launched some campaigns centered around providing the consumers with ideas on how to use leftover food. Additionally, in collaboration with stores, Orkla has started using vegetables near the end of their shelf-life in recipes of instant soups. The company is also hoping for the technology of recycling systems to develop further in this decade, particularly chemical recycling. In this process, plastic waste can undergo depolymerization under specific conditions, resulting in the extraction of its constituent building blocks of carbon. These building blocks can then be utilized to reconstruct the polymer or transformed into alternative products (Hatti-Kaul et al., 2020).

A better solution of plastic recycling is encouraged to have more appropriate end recycling residue than the current one, which is unacceptable for food products according to interviewed packaging developer at Orkla. It was also noted that sourcing is a challenge to achieve the goals of the environmental strategy as there are limited amounts of recycled materials, even if they get approved by the legislation. There are concerns that the land for crops normally used to produce food will be utilized by the bio-based industry to raise crops such as corn for bio-based plastic. If the price to produce bioplastic is higher than the price of the food to be consumed, it will not be a sustainable industry model. This concurs with a study in which it was observed that expanding the utilization of bio-based materials presents difficulties concerning land use and land cover (Yang et al., 2022). This concern has made Orkla hesitant to use bio-based plastics in their packaging. However, producing bioplastic from leftover food could be a way to tackle that potential problem. Looking in the future, food packaging materials derived from renewable sources are expected to be composed of polymer and nanoclay blends, commonly referred to as bionanocomposites. This combination of materials aims to meet the specific barrier and mechanical requirements set by the food industry (Robertson, 2016).

Orkla would be interested in a cardboard packaging solution from Micvac, as the company is part of a plastic pledge which compels it to annually reduce the plastic amount it uses in its operations, similar to Lantmännen mentioned earlier. However, Orkla is against a paper tray solution containing a removable plastic layer inside. Another way of reducing the plastic content would be the decrease of the trays thickness which might needs to be tested if the corners are robust enough with less material.

5.2.2 Retailers' requirements

Dagab, the support company of Axfood which is one the biggest retailers in Sweden, holds the responsibility for managing the group's assortment, purchasing, and logistics operations. Its role is crucial in ensuring the smooth functioning of Axfood's product flow, from assortment and purchasing to warehousing and distribution. Dagab's optimization efforts are integral to Axfood's ongoing efforts to enhance efficiency and effectiveness in these areas (Axfood, n.d.). In the meeting with a packaging developer of Dagab, it was stated that they see a future of less packaging material and as little material as possible without compromising the product's shelf-life for sustainability. Removing unnecessary packaging components and reducing material thickness or downgauging, is crucial to minimize packaging waste, while ensuring that food safety standards are not compromised. This signifies that plastic is to be used only where it is essential. Another forecast is the preference for monomaterials and avoiding mixed materials, as much as possible. A paper-based option would not be preferable to the packaging developer since it will include a plastic layer in the tray to achieve the necessary barrier properties.

Despite the legal permission to produce a combination of paper and plastic if the paper content exceeds 51%, Dagab does not accept such a mixture packaging. The company aims for a 95% fiber – 5% plastic ratio in the products sold in their stores, but the minimum content of packaging must be at least 70% fiber. Therefore, initiatives of suppliers to increase the fiber content in the package without it reaching the 70% threshold, are not welcomed by the company because it is deemed as greenwashing.

The retailers don't prefer biodegradable or compostable materials as there is no system that treats compost industrially in Sweden. As a result, the retailers want to avoid packaging material ending up in the organic waste stream. The only occasion when it would be justified to use a bio-based option would be for a film which if incinerated has less environmental impact than incineration of plastic films, particularly for very greasy food products, for which the interviewed representative expressed the perception that consumers do not discard them at the proper recycling bin. For materials who end up in the general household bin, thus not collected for recycling or products who are likely to be littered in nature, a perspective of what is better to incinerate can be interesting to pursue. Following this line of thought, it would be interesting to study the consumer behavior of sorting and discarding the films from the tray in relation to the ready meal content.

Currently, Dagab has private label ready meals produced with MAP method in the same type of packaging format as Micvac - tray, film, label on top. In terms of investments, it is less complicated for manufacturers to set up and use cook-and-chill than vacuum because it is easier to process, needing a single machine and a sealing step. The interviewed company does not own any production factories, so they discuss and calculate food waste impact with their producers if the need arises to change the packaging format. Consequently, the tests are conducted by their producers. In general, the retailers have specific goals to reduce food waste in their operations which encompass all stores and all food categories, primary focusing on fruits & vegetables.

Different retailers have specific system guidelines for design which in the case of Dagab, is based on FTI and cross-referred with Recyclass guidelines. With the new proposal on packaging and packaging waste, expected to be followed soon by a regulation, they want to make sure they are coherent with the requirements of the future EU legislation. Therefore, Dagab is leaning more towards Recyclass instructions which are increasingly more coherent and collaborative with FTI (same guideline requirements by both). Dagab sends its specific guidelines to its producers for their packaging suppliers to inspect, since the material choice is usually outside of producer’s responsibility. If possible, mono material is always requested and weight reduction is the next requirement. PVC is listed as an unwanted material in all packaging formats and designs.

On its sustainability goals, Axfood aims to eliminate the use of chemicals listed in the SIN list, including bisphenol A, from products and packaging. The target is to achieve this goal by 2025. Axfood is actively promoting the SIN list as the industry standard for chemical requirements. Additionally, by 2030 at the latest, packaging materials for Axfood's private label products, including plastic, containerboard, and paper, will be made from renewable or recycled materials. The packaging for private label products will be designed to be recyclable by 2025. This retailer also aims to increase the proportion of paper labeled with the Forest Stewardship Council (FSC) certification.

Regarding recycled content, the retailers are trying to direct the usage of PET material only for food packaging applications since PET is the only material to have an approved recycling stream for food contact. They are waiting to see how the legislation and the situation in the market will unfold because at the moment there are not enough supply volumes needed of recycled material to reach the production goals. A scarce quantity is noticed throughout the industry which needs to be filled with alternative methods to mechanical recycling.

Whether the consumers will accept the greyish color of the recycled trays remains to be seen. However according to the retailers, it is assumed the consumers will agree on the new introductions as long as it is communicated properly that they are a more sustainable choice and reduce the environmental impact. A similar consumer reaction to the acceptance of discolored recycled PET bottles is expected. An example of a consumer awareness, in 2020 ICA released a line of "color of the day" trays, used for fresh ready meals. The plastic used in the new packaging is sourced from food containers and bottles collected in Europe. These collected items are thoroughly cleaned and melted to create fresh food packaging. The trays acquire their distinct color based on the hues of the collected materials, without any additional colorants being added. As a result, the color of the trays can vary, ranging from various shades of pink, brown, and green (ICA Gruppen, 2020).

In 2019 the largest retailer in UK, Tesco introduced a plastic-focused strategy named 4Rs standing for Remove, Reduce, Re-use, Recycle. It has published a list categorizing the packaging materials as red/orange/green similar to a traffic light system according to the recycling capabilities, infrastructure, and end-of-life outcomes in the UK. This list serves as a straightforward representation of the packaging types that Tesco aims to utilize. Tesco has actively demanded suppliers to eliminate all materials categorized as 'red' and has chosen not to stock new products containing such materials (Tesco, 2022). This decision is driven by the fact that 'red' materials are difficult for customers to recycle in the UK or deemed excessive packaging. PVC and Compostable/PLA and biodegradable plastics are part of this undesirable list. During 2021, 500 million pieces of nonessential plastic were identified and eliminated, mostly in the form of bags, cutlery, straw, lids that were replaced by paper alternatives. These measures have resulted in the reduction of this retailer’s annual packaging footprint by more than 6,000 tonnes.

5.3 Implications and limitations of the study

5.3.1 Implications for the company and the industry

According to the results of the evaluation conducted in this study, monoPP is the most environmental solution for the company to proceed in its growth in the market. This indicates an opportunity for the company to continue the launching and scaling up of that solution. The findings of this study suggest that a fiber-based solution and a monoPET solution are interesting possibilities for Micvac to pursue as well. However, some development trials are necessary to assess the feasibility of these options through a Micvac process before they can be added to the company's portfolio. In addition, it is expected that the advantage of PET as the only material approved for recycled content will be diminished with the upcoming legislation.
Since the highest growth of ready meals and chilled ready meals is seen and projected to be in Finland and Spain, it would be effective to focus the expanding market share strategy on these two countries. However, all other countries analysed in this study showed growth in recent years, so the category is promising for the actors who are involved in this supply chain and the industry as a whole.
The results highlighted that a biopolymer solution is not favorable in terms of decreasing the environmental impact, at least in the context of Sweden due to lack of industrial facilities treating compost or biodegradable waste. Based on the guidelines from FTI, it is foreseen that this direction will not change thereby making bioplastic packaging products not the optimal choice for the ready meals market.

5.3.2 Limitations of the study

The study's limitations encompass several factors. Firstly, the focus on Micvac technology as a case study may not be directly applicable to other companies or industries, requiring some adjustments when evaluating different packaging solutions in alternative technologies. These adjustments are particularly crucial for packaging attributes influencing food waste, as discussed in detail throughout the study. Furthermore, the proposed evaluation tool may not encompass all sustainability factors such as ethical or economical sustainability or provide an exhaustive assessment due to the time and resource constraints. Additionally, economic feasibility of the solutions and consumer perception of sustainable packaging options within Micvac technology was not specifically assesed in this study.

In principle, this evaluation study was an environmental one and due to time and resource constraints, it was outside of the scope of the project to verify the packaging solutions feasibility. Regardless, some aspects of the design challenges of the PET tray were mentioned which was not the case for a biopolymer tray.

Consequently, it is necessary to further ensure whether these solutions can withstand the Micvac treatment method and how would that affect their shelf-life compared to other packaging technologies. Despite the author's attempts to identify microwave-applicable trays that exist in the market, the suitability of the selected packaging for the Micvac technology needs to be certified by experimental tests and supported by real-life commercial examples in the future. This validation is particularly important for the MonoPET and biopolymer packaging options that were described in the study.

To have a comprehensive evaluation, the tool requires tangible data from different parts of the supply chain and that information is not always documented by the actors in the supply chain, particularly the suppliers of packaging materials. The data on the material carbon footprint resulted to be challenging to find and calculate, therefore they must be interpreted with caution. Identifying a microwaveable bioplastic solution and evaluating it the tool was also found to be difficult because there is a lack of information regarding the developments in the biopolymer industry. This reflects the real situation in the market since this industry sector is not as developed as conventional plastics yet. In contrast to its conventional equivalents, it is likely that much of the knowledge gap in the bioplastic value chain stems from the lack of available data in the market, owing to the relatively few years of activity.

Furthermore, the requirements of the food manufacturers and the retailers were deducted from interviews with a few of the companies which are operating in the ready meals market. The views of the specific collaborators in this project do not represent the views of every actor in the market, therefore the findings cannot be extrapolated to all the players in the market. Due to time and resource constrains, only actors from Sweden, Norway and Denmark were directly contacted, therefore the requirements might be slightly different if other companies from France, UK or Spain are included in the data collection process.

6 Conclusions

In this section, the study is concluded by answering the research question, and the author gives suggestions for further research in the future.

This study sheds light on the recent market trends in ready meals, in-pack pasteurization technology and recent progress in sustainability of microwave packaging materials. The research concludes by answering the research question formulated in the beginning of the study. The results of the evaluation tool show that a mono material PP solution is the most sustainable solution for the Micvac technology at the moment. This solution aligns with the requirements of the food manufacturers and retailers for a monomaterial option, emphasizing its value as fully recyclable packaging with flexible films expected to start being recycled in Sweden later this year. Since a monoPP solution is lighter that the current Micvac packaging, it conforms with the recent EU proposal compelling decrease of plastic waste by weight. Simultaneously, it would comply with upcoming EU legislation which would regulate recycled content in packaging for food contact. However, it is important to consider other solutions as well as they did not score significantly lower than the monoPP option. Other types of response could include actively road mapping potential future solutions in fiber-based packaging or a monoPET. Taken together, the results of the evaluation tool, the supply chain actors' requirements and the predicted legislative framework suggest that the company should proceed in the development of a monomaterial solution and depending on its viability, find ways to scale up its launch in the market. It is worth highlighting that to achieve significant advancements in environmental sustainability, it is essential for the actors within the supply chain to collaborate closely.

The innovative packaging materials mentioned in the overview of the research literature are interesting to pursue from a functionality perspective, but they are composed of combinations of different materials and therefore not suitable for recycling in the current circumstances. Even if future developments reduce the number of layers and components they are made of, it will take some undefined time to build separate streams for their collection in post-consumer waste. Therefore, despite their interesting technological properties, these innovative materials do not environmentally perform in the same rank as conventional solutions of polymers and fibers, deeming them undesirable from an environmental perspective.

All the markets where Micvac is operating show growth in ready meals and chilled ready meals categories with the highest growth reported in Finland and Spain.

The expectations from different angles and actors are unanimously projecting the introduction of a new EU regulation on approving and standardizing the recycled content of packaging materials for food contact. It is estimated that this introduction will change the landscape of the packaging materials supply and demand as more companies rush to incorporate more sustainable practices in their operations to solidify a “green” brand image and attract more customers.

6.1 Suggestions for further research

An interesting area of future research would be to investigate the application of the proposed evaluation tool in other packaging solutions for the Micvac portfolio, especially the thermoform. Some of the options can also be envisioned from the innovative materials which were elaborated on the literature review. The materials manufactured from nanotechnology sources are of particular interest. The further improvement of these innovations and growing awareness of their properties will guide the visualization of the future supply chain.

Regarding the proposed tool, it would be beneficial to continue developing the influence on food waste area by defining levels which are based on numerical data instead of relying on comparing solutions against a reference. This would decrease the bias and the effect of subjective opinions, thereby improving the accuracy of the tool results.

Another important research would be to evaluate the technological feasibility of the proposed solutions by utilizing various testing methods. Additionally, an area of interest would be the economic viability of implementing the specific packaging solutions mentioned in this study within Micvac technology. The design for developing microwave packaging and process efficiency should be further investigated. Sourcing availability of the solutions and the cost which it would have in the company is a perspective which would give the actors in the supply chain a comprehensive overview of sustainability not just from an environmental perspective, but also from an economical one.

It is also suggested to test the consumer behavior and acceptance of different sustainable packaging options regarding ready meals. This can provide valuable feedback in the design process of the future packaging, as it all comes down to consumer decisions. Despite a packaging being fully recyclable and having its own developed waste stream where the collection and recycling process is highly efficient, if the consumers do not discard the packaging in the proper waste bin, it will end up losing its value in an incinerator or a landfill. To avoid this situation, clear labeling of primary packaging content and engaging consumer awareness campaigns are recommended.

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Appendix A Project plan and outcome

A.1 Project plan and outcome

The project plan and the outcome are presented together in Figure A.1. The activities which followed the plan are depicted in purple color. When the project tasks were completed beyond the planned period, the extra period is represented in orange. If a project activity started later than it was planned, it is depicted in the lines pattern. Throughout the project, the overall time structure was maintained. However, the data collection phase took longer than anticipated due to limited availability of time from the supply chain actors. Nonetheless, parallel activities that did not depend on the data were carried out to prevent project delays. In summary, the project was effectively managed throughout the process, overcoming challenges as they arose, and allocating additional effort when necessary.

Project Planner

ACTIVITY / TASK	PROJECT PLAN START	PROJECT PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Identification of Micvac packaging characteristics	1	1	1	1	100%
Preparation of the methods for data collection	1	1	1	2	100%
Bibliography review of microwaveable materials	1	3	2	3	100%
Listing the pros and cons of packaging materials suitable for use in microwave	2	2	2	2	100%
Meeting with the supervisors	4	1	4	1	100%
Collecting market data on the production and usage of rigid and flexible plastics in several European markets	4	1	5	1	100%
Researching main trade organisations policies shaping the packaging materials required by the market	5	2	5	2	100%
Reviewing relevant EU regulations to plastic packaging & waste	5	1	5	2	100%
Conducting interviews with different stakeholders in Micvac's supply chain	4	2	5	4	100%
Meeting with the supervisors	6	1	6	1	100%
Selecting the final packaging solutions to evaluations	6	1	6	2	100%
Outlining the utilized tool with areas and criteria	8	1	8	2	100%
Tailoring the tool to Micvac - definition of new levels and criterion	8	2	8	3	100%
Calculating and inputting the gathered data in the tool	8	2	8	4	100%
Summarizing the results by condensing the performance of each packaging solution to one value	11	1	12	1	100%
Meeting with the supervisors	13	1	13	1	100%
Report writing process	12	6	12	7	100%
Preparing final presentation and poster	17	2	18	3	100%
Delivering final presentation and poster draft session	20	2	20	2	100%
Master thesis approval	22	2	22	2	100%

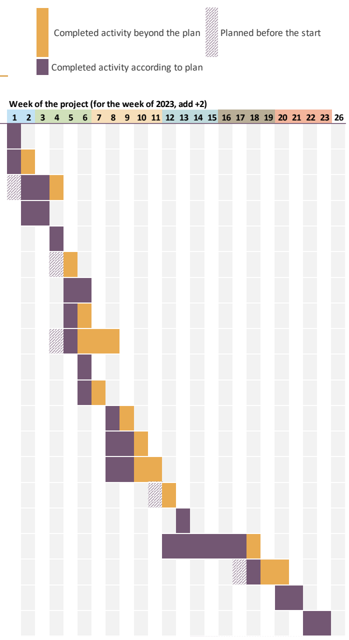

Figure A.1 Project plan and project outcome

Appendix B Data collection tools

B.1 Semi-structured interview guides

The purpose of the interviews was to acquire additional information regarding the environmental strategies of the actors engaged in the supply chain of ready meals produced through the Micvac technology. The gathered information was utilized for assessing similarities and differences to the results of the evaluation tool, thereby applying the insights to suggest recommendations to minimize the environmental impact of the company's packaging solutions.

B.1.1 Questionnaire for Packaging Developer at Dagab, Axfood related to the environmental strategy and the forecast of the retailer's market

1. Please tell me about your background and your current position in the company.

2. How are ready meals distributed from the food manufacturer to your stores? Do you have a particular transport company?

3. What would you say about the integration of sustainability in your packaging development? What is its impact on the decision-making process?

4. Can you tell me about your sustainability strategy? What is it called and can do you describe it briefly? How do you collaborate with your suppliers?

6. Which areas are you focusing on? What are your guiding principles to enable you to meet your goals and targets?

7. What are your targets and commitments regarding packaging?

8. What are the metrices/KPIs you are using to measure your advancement in the strategy?

9. Does your strategy help reduce food waste? How?

10. How do you perceive the use of recycled content in food packaging in the future? Will there be any use of recycled content and what stream it should come from?

11. What would you list as the main opportunities and challenges of your strategy?

12. Do you have specific guidelines for packaging design, for example a traffic light system?

B.1.2 Questionnaire for Senior Packaging Developer at Orkla Norge related to the environmental strategy of the company

1. Please tell me about your background and your current position in the company.

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

3. What would you say about the integration of sustainability in your packaging development process? What is its impact on the decision-making process? How do you collaborate with your suppliers?

4. Can you tell me about your sustainability strategy? What is it called and could you describe it briefly?

5. What are the drivers of this strategy? Does it encompass specific SDGs?

6. Which areas are you focusing on? What are your guiding principles to enable you to meet your goals and targets?

7. What are your targets and commitments, particularly regarding packaging?

8. What are the metrices/KPIs you are using to measure your advancement in the strategy?

9. Does your strategy help reduce food waste of your products? How?

10. Is circular packaging an ambition for you? If yes, what have you done to take it from a strategic perspective to an operational level?

11. How do you perceive the use of recycled content in food packaging in the future?

12. What would you list as the main opportunities and challenges of your strategy?

13. What aspects of current Micvac packaging design do you consider can be improved?

B.1.3 Questionnaire for Packaging Lead at Lantmännen Cerealia related to the environmental strategy of the company

1. Please tell me about your background and your current position in the company.

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

3. What is the sustainability impact on the decision-making process for packaging? How do you collaborate with your suppliers?

4. Can you tell me about your sustainability strategy? What is it called, and can you describe it briefly?

5. What are the drivers of this strategy? Does it encompass specific SDGs?

6. Which areas are you focusing on? What are your guiding principles to enable you to meet your goals and targets?

7. What are your targets and commitments, particularly regarding packaging?

8. What are the metrices/KPIs you are using to measure your advancement in the strategy?

9. Does your strategy help reduce food waste of your products? How?

10. Is circular packaging an ambition for you? If yes, what have you done to take it from a strategic perspective to an operational level?

11. How do you perceive the use of recycled content in food packaging in the future?

12. What would you list as the main opportunities and challenges of your strategy?

13. What aspects of current Micvac packaging design do you consider can be improved?

B.1.4 Questionnaire for Process & Product Specialists at Faerch Plast s.r.o related to the feasibility of a monoPET package

1. What is the material carbon footprint of the PET tray that you produce? Do you have data on their production impact?

2. I intend to analyze monomaterial packaging with all three components being PET. Do you think that is feasible?

3. My main interest in asking about PET is because I want to include recycled content, meaning rPET. Do you have information on what is the recycling rate of your PET trays?

4. I saw on your website your products have 70% recycled content. Does this encompass every PET product in your portfolio, or it is an average?

5. What is the weight of the PET tray? What are the other characteristics of a possible PET tray for Micvac?

6. Where is your production facility located?

7. What are the main challenges about developing a PET tray suitable for the Micvac process?

8. How is the tray transported to the food manufacturer? What mode of transport is used?

9. Which of the following can you certify that your trays are free of:

- PVC and chlorinated plastics

- Bisphenol A (the primary package)
- Does not contain engineered nanomaterials and not treated with preservatives or disinfectants (exception for hydrogen peroxide)
- No chemicals from SIN list are intentionally added into packaging?

B.2 Email questionnaire

B.2.1 Email questionnaire for Material specialist at FTI related to the recycling of rigid and flexible plastics

1. What are the recent recycling rates of some materials such as rigid PP, flexible PP, fibers in Sweden? Do you have data on the recycling rates of specific plastic fractions?

2. What is the number of recycling cycles a PP tray and a PET tray go through in Sweden at the moment?

B.2.2 Email questionnaire for Development Engineer at Svensk Plaståtervinning related to the recycling of rigid and flexible plastics

1. What is the number of recycling cycles that rigid PP, rigid PET go through on an average in Sweden?

2. I heard that flexible plastic (including flexible PP) will start to get recycled soon in Site 0 in Motala. When is the recycling of flexible plastic projected to begin?

3. When that happens how do you think it impacts the recycling process if a consumer puts a PP lid film inside a PP tray (the same material) andthem together in the bin? From a recycling perspective, do you see that there is any difference if the film and the tray are discarded separately? How about if the lid and the tray are two different materials?

Appendix C Modeling in Stackbuilder

C.1 Outbound transport packaging configuration

The configuration of the ready meals transport from the point of manufacturing to the warehouse and then retailer can be observed in the figures below. The primary packaging is represented by each packaging solution tray. The secondary packaging is represented by reusable half-size 120 red SRS crates used in Sweden with the following dimensions: outer length 400mm, outer width 300mm, outer height 148mm. The tertiary packaging is represented by a typical Euro pallet with normal dimensions 1200x800x144mm.

C.1.1 PP tray

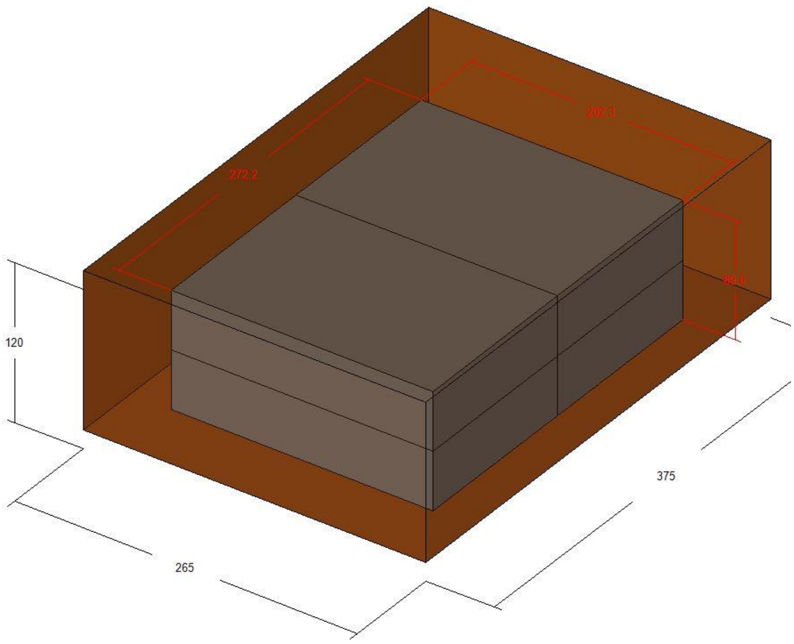

Figure C.1 Approximate configuration for ready meal PP trays in a 120 red SRS crate

C.1.2 Fiber tray

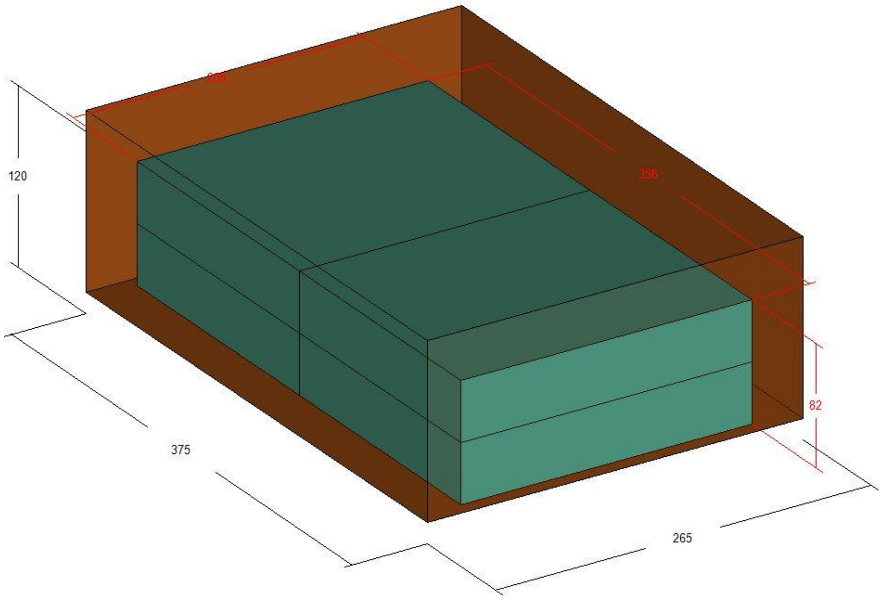

Figure C.2 Approximate configuration for ready meal fiber trays in a 120 red SRS crate

C.1.3 PET tray

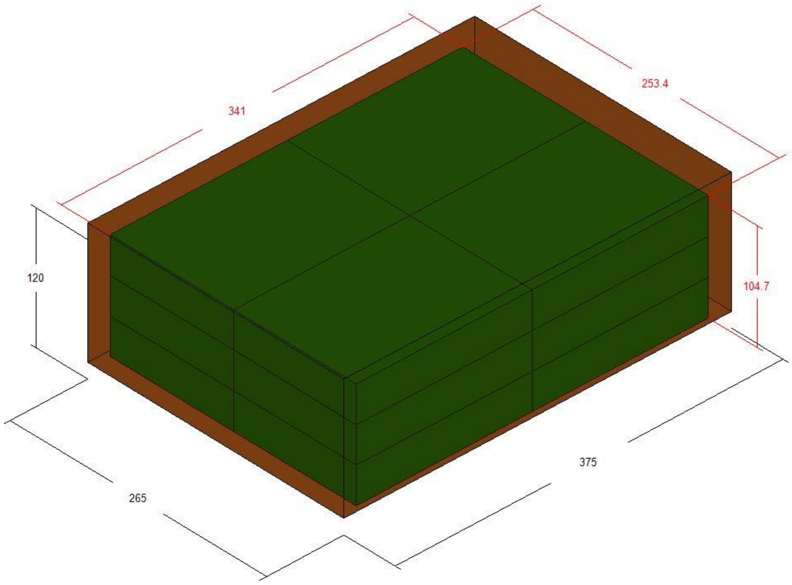

Figure C.3 Approximate configuration for ready meal PET trays in a 120 red SRS crate

C.1.4 Biopolymer tray

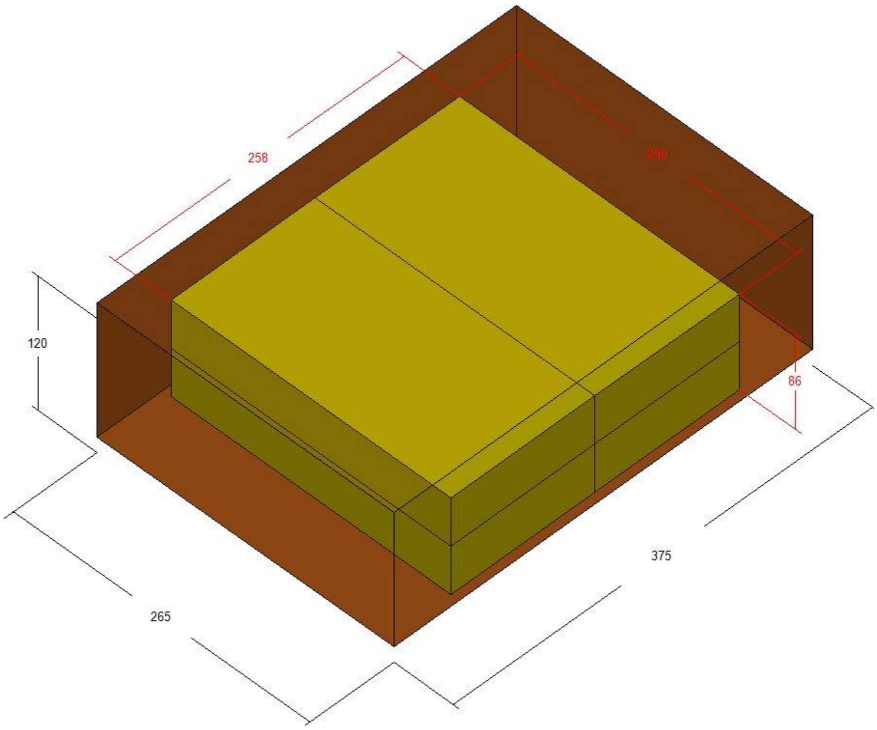

Figure C.4 Approximate configuration for biopolymer trays in a 120 red SRS crate

C.1.5 Secondary packaging configuration

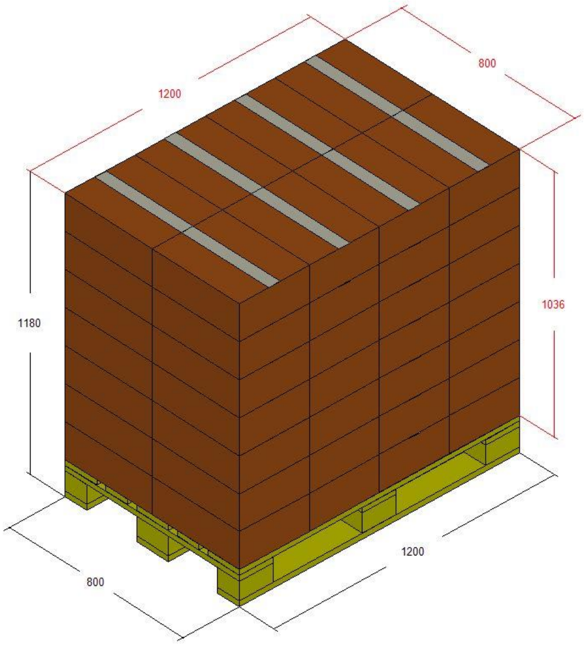

Figure C.5 Approximate configuration for ready meals 120 red SRS crates in a pallet

C.1.6 Tertiary packaging configuration

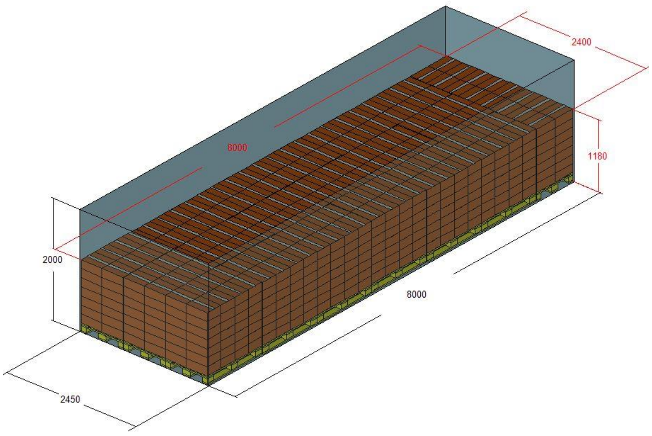

Figure C.5 Approximate configuration for ready meals pallets in a standard 7.5-12-ton truck

Appendix D Transportation routes

D.1 PET trays to Food manufacturer

Table D.1 Transportation route from PP trays Supplier to Food Manufacturer

Start location	***End location***	***Transportation mode***	***Distance***
Færch Plast s.r.o Techniků 535, Doubí, 463 12 Liberec, Czechia	Gooh AB, Snickarvägen 9, 153 35 Järna, Sweden	Truck with trailer 34-40t by road	1681km

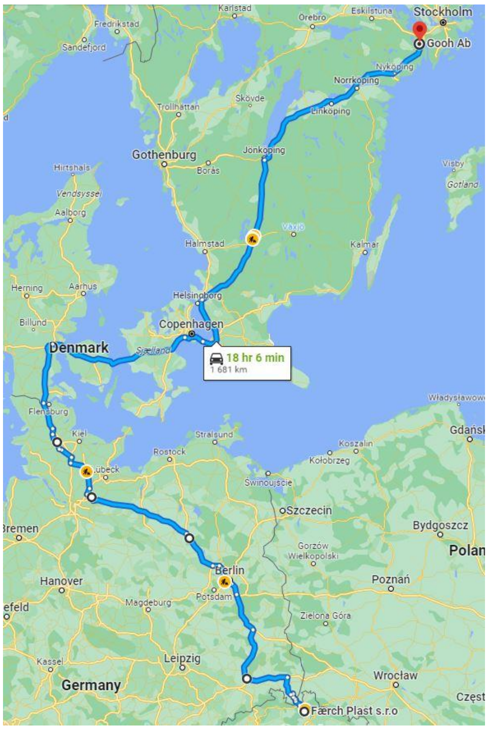

Figure D.1 Approximation on the tray transportation route from Faerch Plast s.r.o. to Gooh AB

D.2 PVC valves to Food manufacturer

D.2 Transportation route from PVC valves supplier to Food Manufacturer

Start location	***End location***	***Transportation mode***	***Distance***
Micvac AB Flöjelbergsgatan 10, 431 37 Mölndal, Sweden	Gooh AB, Snickarvägen 9, 153 35 Järna, Sweden	Rigid truck 7.5-12 t	426km

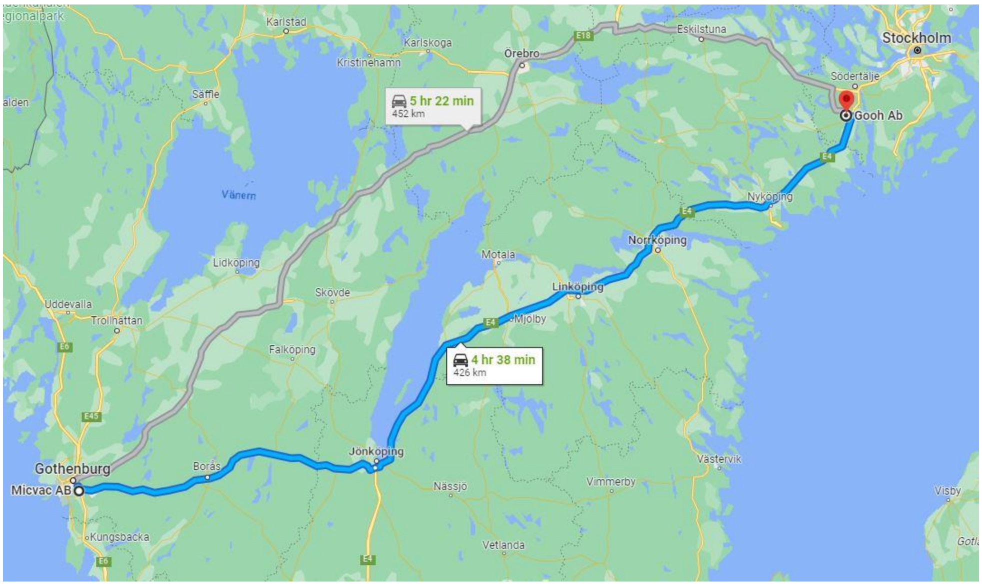

Figure D.2 Approximation on the valve transportation route from Micvac AB to Gooh AB

D.3 PET trays to Food manufacturer

Table D.3 Transportation route from PET trays Supplier to Food Manufacturer

Start location	*End location*	*Transportation mode*	*Distance*
Faerch A/S Rasmus Færchs Vej 1, 7500 Holstebro, Denmark	Gooh AB, Snickarvägen 9, 153 35 Järna, Sweden	Truck with trailer 34-40t by road	947km

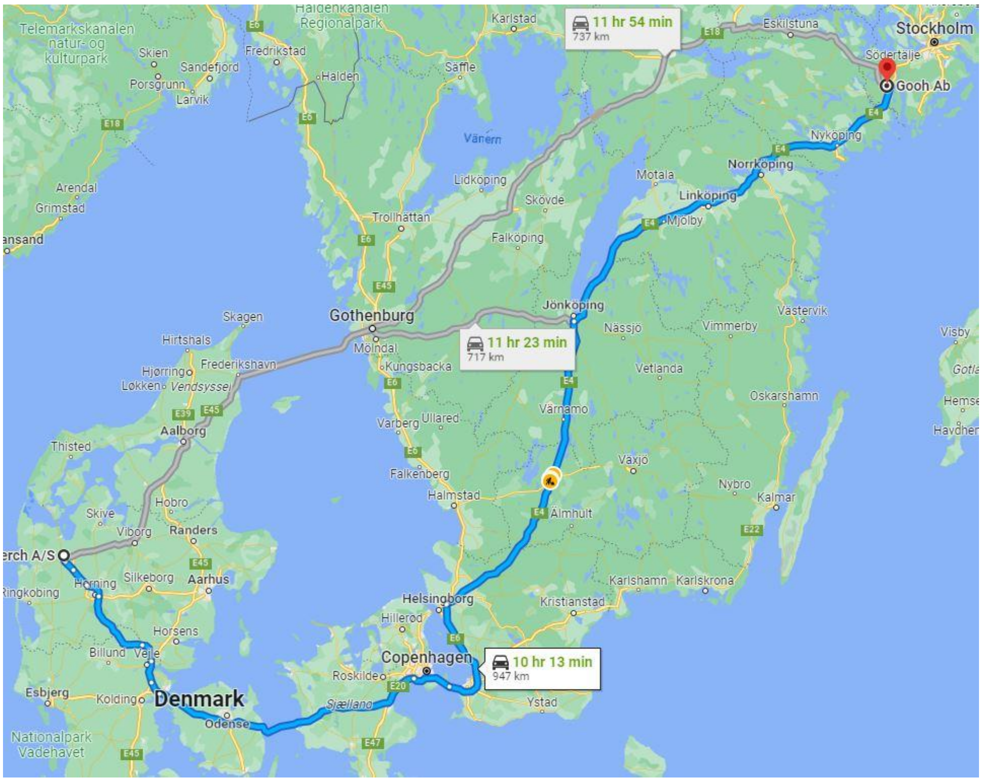

Figure D.3 Approximation on the tray transportation route from Faerch A/S to Gooh AB

D.4 Biopolymer trays to Food manufacturer

Table D.4 Transportation route from biopolymer trays Supplier to Food Manufacturer

Start location	*End location*	*Transportation mode*	*Distance*
Duni Poland Sp. z o.o, Syrenia 4, 61-017 Poznań, Poland	Gooh AB, Snickarvägen 9, 153 35 Järna, Sweden	Truck with trailer 34-40t by road	1600km

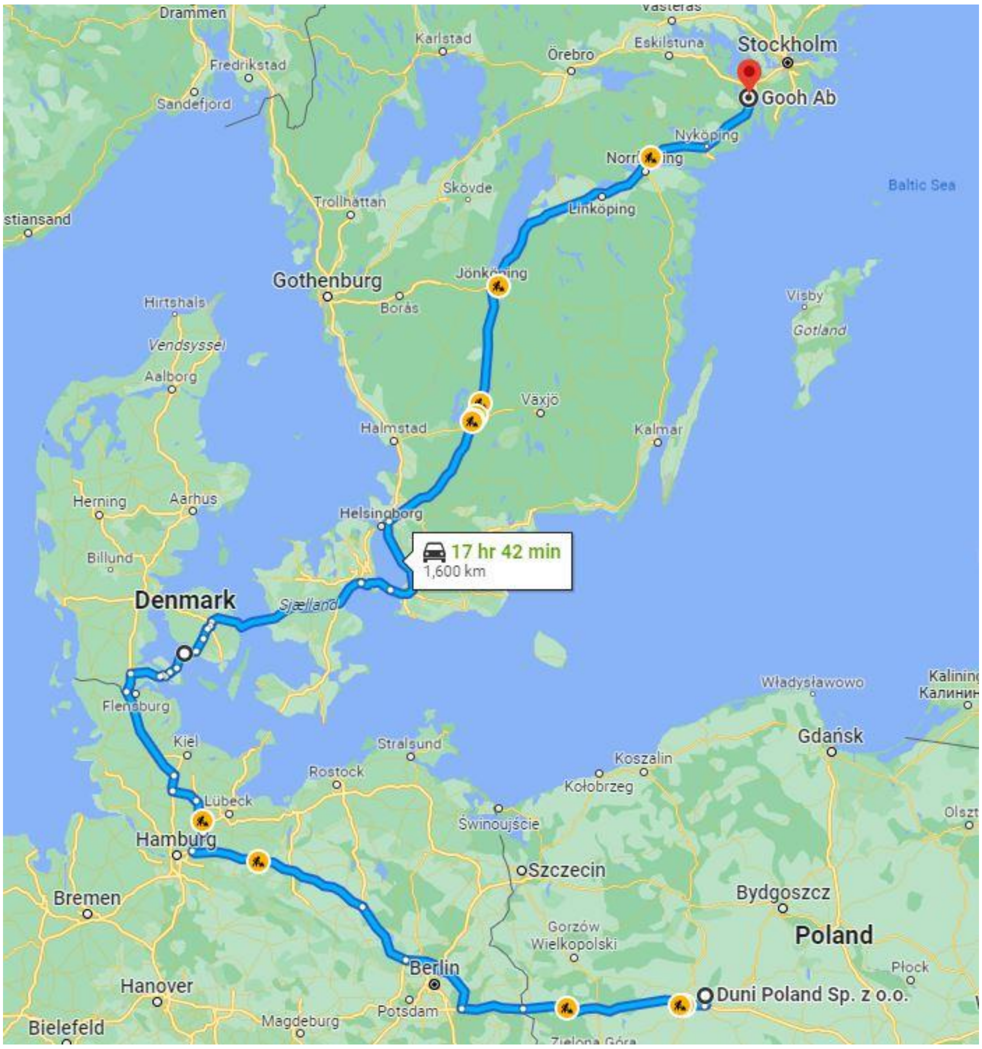

Figure D.3 Approximation on the tray transportation route from Duni Sp.z.o.o to Gooh AB

Appendix E Legislative framework

Table E.41 European legislations impacting the Micvac value chain

Legislation	***Content***
Directive on Packaging and Packaging Waste 94/62/EC	Sets essential requirements that all packaging placed on the EU Community market needs to comply with
- Amended by Directive (EU) 2018/852	General and specific recycling targets for different materials by 2025 and 2030
Regulation (EC) No 1935/2004	Materials and articles intended to come into contact with food
- Amended by Regulation (EU) 2019/1381	The transparency and sustainability of the EU risk assessment in the food chain
Regulation (EC) No. 1895/2005	The restriction of use of certain epoxy derivatives in materials and articles intended to come into contact with food
Regulation (EC) No 2023/2006	Good manufacturing practice for materials and articles intended to come into contact with food
Regulation (EC) No. 450/2009	Active and intelligent materials and articles intended to come into contact with food
Regulation (EU) No. 10/2011	Plastic materials and articles intended to come into contact with food
Regulation (EU) 2022/1616	Recycled plastic materials and articles intended to come into contact with foods
Proposal for the revision of the Directive on packaging and packaging waste (November 2022).	New rules and mandatory targets on packaging and packaging waste; clarifying the labels of bio-based, biodegradable, and compostable plastics

Appendix F Environmental evaluation tool results for each area

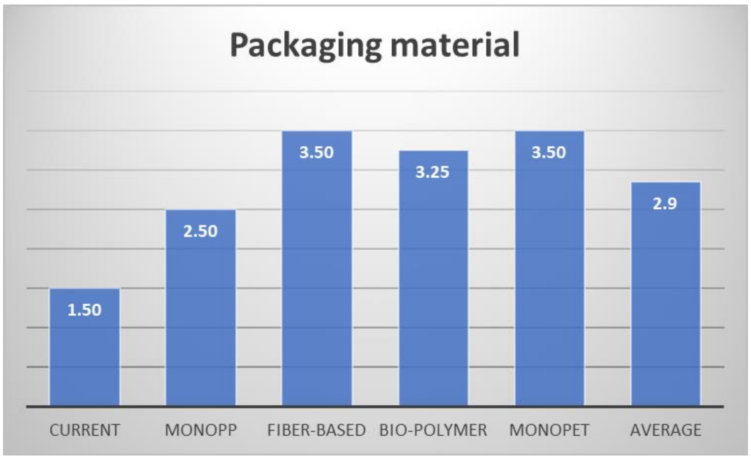

Figure F.1 Environmental performance of packaging solutions in the first assessment area

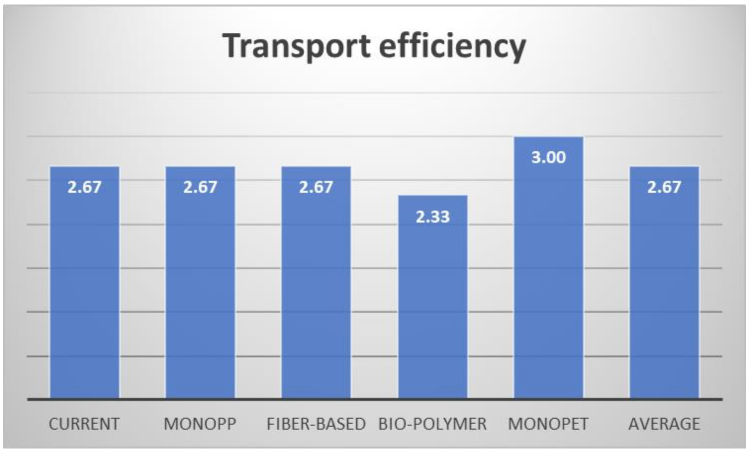

Figure F.2 Environmental performance of packaging solutions in the second assessment area

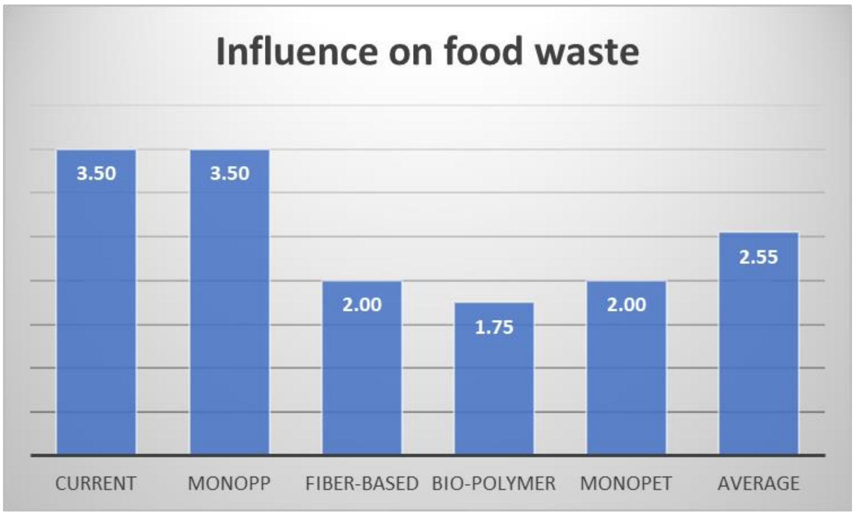

Figure F.3 Environmental performance of packaging solutions in the third assessment area

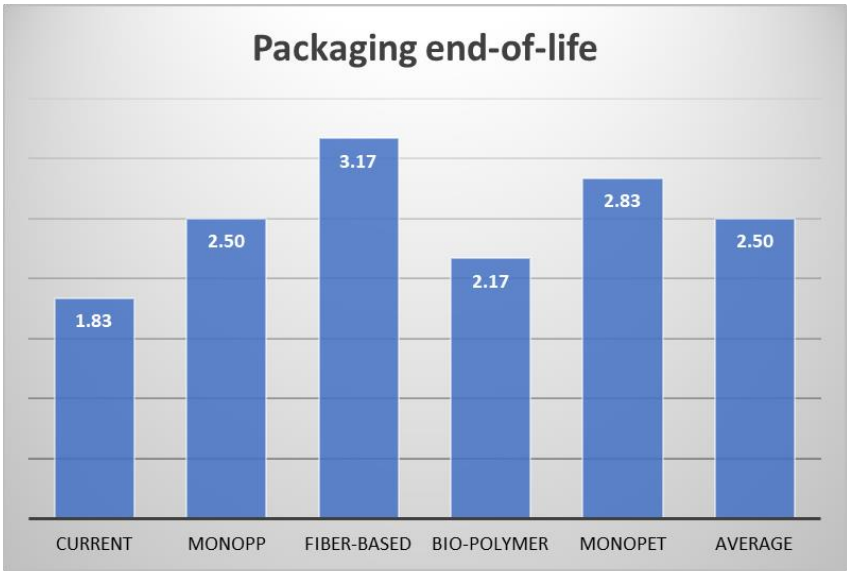

Figure F.4 Environmental performance of packaging solutions in the fourth assessment area