Reducing packaging waste in the meal delivery industry

A quantitative evaluation study on handling methods for the reuse of food containers

Master Thesis

Céline van Hooff

Delft University of Technology

TUDelft

Reducing packaging waste in the meal delivery industry

A quantitative evaluation study on handling methods for the reuse of food containers

by

Céline van Hooff

Faculty: Civil Engineering, TU Delft
Date: Wednesday 14th July, 2021

TU Delft

Graduation Committee

Chair
Prof.dr.ir. L.A. (Lóránt)Tavasszy
Full professor
Delft University of Technology
Faculty of Civil Engineering and Geosciences
Section: Transport and Planning
Room 4.10.1
Stevinweg 1, 2628 CN Delft

First supervisor
Dr. A.M. (Alp) Arslan
Postdoctoral Researcher
Delft University of Technology
Faculty of Technology, Policy, and Management
Section: Transport and Logistics
Room B3.290
Jaffalaan 5, 2628 BX Delft

Second supervisor
Dr. A. (Arjan) van Binsbergen
Delft University of Technology
Faculty of Civil Engineering and Geosciences
Section: Transport and Planning
Room 4.07
Stevinweg 1, 2628 CN Delft

Summary

Waste generation has become a major problem for society. Online food delivery services account for a large share of packaging waste. Policy-makers worldwide are introducing reduction measures to ban these packaging products from the market. Initiatives offering reusable food container services recently joined the delivery market, each having its own logistics network design. However, these initiatives still have a small market size, therefore we cannot conclude that the implementation of these initiatives on the market size of an existing meal delivery network is profitable and sustainable. From our literature review, we can conclude that no study has yet quantified the actual environmental and economical implications of container handling methods for the reuse of food containers in the meal delivery industry. This paper aims to fill this knowledge gap by evaluating different container handling methods for reuse by quantifying their impact on the environment and the profitability.

The literature review on the barriers for the adoption of reusable packaging shows that socio-psychological factors such as convenience and perceived positive environmental impact, play an important role. Besides that, financial incentive programs, such as cash for recyclables, have an impact on the short term. However, this effect disappears when the financial incentive is removed. Furthermore, the literature shows that an economic deposit system generally induces a negative reaction since consumers perceive it as a coercive rather than motivating system. In addition, the adoption of reusable concepts and initiatives for the reuse of food containers are investigated in the literature. This analysis shows that most of the current initiatives are mainly impacted by the customer return behavior. The market size of the reusable food container concepts are slowly growing, however, the literature shows that for the general public, the ‘feel-good-factor’ of sustainable packaging is not enough. Therefore, we identified more convenient alternatives for reusable food container networks and compared these to conventional systems. Such as including the driver in pick-up and delivery of a reusable food container from the customer to the restaurant.

Based on case studies of reusable initiatives that are currently on the market, we distinguish three reusable container handling methods: the passive method (the driver performs the return action), the active method (the customer controls the return action), and the hybrid method (both the driver as the customer can control the return action). Remark that the behavior of the drivers is fully controllable by a meal delivery platform in contrast to the behavior of the customers which can only be partly controlled. The optimal control action appears to be: take the used food container from a customer. Only drop a reusable food container at a restaurant if the next order is also in a reusable food container. To correct for food container shortages or skewed storage at restaurants, we defined two redistribution actions: restock and refill. Furthermore, we defined, based on desk research, different parameters such as the container lifespan, maximum capacity of the driver, the order frequency at restaurants, and the trip frequency of the driver. Additionally, we define scenarios based on variation in the percentage of customers and restaurants that reuse. Lastly, we determine the relative costs and emissions per reusable food container and transport cost and emission savings per redistribution event. These factors together form the basis for the simulation study. Next, we use numerical simulation in combination with a Monte Carlo analysis to estimate the economical- and environmental impact of integrating different types of reusable food container networks in the meal delivery industry.

We observe the following system behavior from our simulation study for each of the container handling methods:

- **Passive method.** As long as the total initial restaurant stocks are equal to the number of reusing customers and drivers, the minimum number storage per restaurant, and the food containers are approximately uniformly distributed over the restaurants, the system will always be in control and all stock levels will converge over time. Because from that moment, each time a driver serves a node, we will guarantee that the driver drops its stored food container, takes a food container from the same restaurant, and drops the food container at a customer where the driver picks up an used reusable food container from the customer.
- In the **hybrid method**, we have the same driver dynamics as for the passive method. However, since we also allow customers to return their food container to the reusable restaurant (which is randomly sampled), we cannot guarantee the stability of the total restaurant stock which we could guarantee by the passive method.
- In the **active method**, the system has become largely uncontrollable. The customers return their food containers to a random restaurant at a random time. Hereby, forcing many redistribution events to balance the restaurant stocks.

After validation of the system behavior, we can conclude that that for each of the container handling methods, emission- and cost savings can be realized compared to a system in which only disposable food containers are used. Even for situations in which only a small part of the customers and restaurants use reusable food containers. Moreover, the passive handling method outperforms the hybrid- and active container handling method, both economically and environmentally. We observe that the benefits are positively correlated with the customer and restaurant participation ratio. As all handling methods more or less realize equal environmental gains, the methods mainly differ in the economical performance.

Contents

1

Introduction

The outbreak of COVID-19 has large effects on the restaurant industry. Online meal delivery platforms facilitated restaurants to keep operating and enabled consumers to order prepared meals, COVID-19 accelerated the shift from restaurant dinners to ordering food online (Li et al., 2020). Data from the reservation system 'OpenTable' shows that due to lockdowns, sit-down traffic at restaurants decreased by 83% globally (Ivanova, 2020). Consequently, the number of users and revenue of online meal delivery services grew with 10% worldwide over the last year (Statista, 2020b). According to Statista (2020b), this growth is continuing worldwide with an annual factor of 6.4%. The global trend results in many countries having at least one major platform for meal delivery. The European market has a large potential for online meal delivery platforms, especially The Netherlands. According to FSIN (2020), the Dutch meal delivery sales increased by approximately 37 percent in 2020. The revenue is expected to show an annual growth rate of 7.5% in the coming years (Statista, 2020a). The meal delivery industry in cities is even growing faster as the number of inhabitants in urban areas is increasing (Buchholz, 2020; Nations et al., 2019).

Nevertheless, the meal delivery industry significantly contributes to environmental pollution that occurs from food packaging, production, and waste generation (Song et al., 2018; Yi et al., 2017; Li et al., 2020; Jia et al., 2018). Yearly 8 million tons of plastic material end up in the oceans worldwide (Thevenon et al., 2015; EU Commission, 2018). The takeaway industry is the largest contributor to this waste generation (Morales–Caselles et al., 2021). Only in Europe, take-away food generates approximately 20,000 tonnes of waste per year (Bûmerang, 2021). In addition, the demand for single-use, disposable food packaging soared globally due to its hygienic perception in the COVID-19 pandemic (Neo, 2020). Unfortunately, only 14% of the plastic packaging is collected for recycling and just 5% of it is successfully recycled into new plastic (Dauvergne, 2018; Hahladakis and Iacovidou, 2018).

The alarming growth of plastic pollution leads to action among organizations worldwide. According to Wilson et al. (2016), the United Nations calls policy and decision makers to take action on waste management. Packaging management is necessary within almost all industrial sectors (Bortolini et al., 2018). In 2019, the European Parliament approved a new law banning the top ten single use plastic items found on EU beaches (European Parliament, 2019). The ban will apply to plastic cotton buds, cutlery, plates, straws, drink stirrers, and balloon sticks (EU Commission, 2018). For food containers and drink cups, reduction measures should be introduced by member states. They can do so by ensuring that plastic products cannot be provided free of charge, setting national reduction targets, or making alternative products available at the point of sale. One of the reduction measures already introduced is the increase of taxes on the incineration of waste (Harmsen, 2021). Hereby, governments discourage single-use products and thereby stimulate the recycling or reuse of products since the price is much lower.

Consequently, the need occurs for online meal delivery platforms to consider alternatives for meal packaging. These alternatives should be beneficial both economically as environmentally.

1.1. Problem Statement

Online meal delivery platforms are growing worldwide. COVID-19 accelerates the shift from restaurant dinners to ordering food online. Nevertheless, the takeaway business model is currently the major source of plastic packaging waste generation. The alarming growth of plastic pollution leads to action among governments worldwide resulting in single-use plastic bans. A handful of start-ups offer reusable food container services. However, no online meal delivery platform has adopted such as service. The market size of these initiatives is therefore still small. There is no proof of concept on a larger scale. For this purpose, this study identifies, defines, and evaluates reusable food container handling methods in the meal delivery industry.

According to this background, the reminder of this paper is organized as follows. Section 2 revises literature on reusable systems, key success factors for reuse, and methodologies that are able to measure the environmental- and economical performance of packaging systems. This section is concluded with the definition of the research gap. Section 3 describes the identification of the conventional meal delivery system and potential concepts for reuse of food containers in this system based on case studies. In addition, system boundaries and the functional unit for environmental- and economical evaluation are identified. Section 4 considers the definition of reusable container handling methods and parameters. Based on this information, a simulation study is defined in Section 5, which also covers the evaluation and discussion of the simulation results. Furthermore, the limitations of the study are presented in this section. Given these outcomes, conclusions, recommendations, and future research suggestions are formulated in Section 6. The scientific paper of this report can be found in Appendix A.

1.2. Relevance

Scientific Relevance

The market for online meal delivery has grown rapidly over the past years (Statista, 2020a). Companies facilitating reusable food container packaging recently entered the meal delivery market. Since these initiatives are relatively new, not much has been written on their network design in the literature yet. Jia et al. (2018) underline the rapid increase of door-to-door cooked food deliveries resulting in environmental issues but concludes that empirical and analytical studies towards resolving these issues still deserve further investigation. This underlines the scientific relevance of the evaluation of different container handling methods.

Conversely, the environmental impact of food containers has been studied widely in the last couple of years. Gallego-Schmid et al. (2018, 2019); Accorsi et al. (2014, 2020) executed life cycle assessments (LCAs) on current food containers to evaluate the carbon footprint associated with the life cycle of packaging. The majority of the literature only focuses on the environmental aspect, whereas the study by Accorsi et al. (2014) assessed both the environmental as the economical impact of a food container. They conclude in their study on reusable packaging systems for a regional catering company that the reusable system was environmentally superior to the current single-use system, however it led to increased costs. This aligns with the remark by Coelho et al. (2020) suggesting that the overall cost of a reusable packaging system could be lower than that of single-use packaging, although a variety of factors influence the benefits. Accorsi et al. (2014) suggest further evaluation of packaging solutions and distribution system configuration (e.g., materials, vehicle routing, delivery frequency, shape, and dimensions of the packaging).

In conclusion, research on handling methods for the integration of reusable food containers is lacking. No study has yet quantified the actual environmental- and economical implications of different container handling methods for the reuse of food containers in the meal delivery industry. Therefore, this paper aims to fill the knowledge gap by analyzing different container handling methods by quantifying their impact on the environment and economic profitability.

Societal Relevance

Food packaging waste has become a major problem. Online meal delivery services account for the largest share of plastic packaging waste. If online meal delivery platforms could include reusable food container packaging in their services, it would have a large positive impact on the environment and is therefore beneficial for society. Additionally, there is a need for online meal delivery platforms to change to alternative food packaging than single-use products since the European Parliament is banning these items in the EU (European Parliament, 2019). Besides that, governments already started to increase taxes on waste incineration. Discouraging the disposal of single-use products. Thevenon et al. (2015) underline this by stating that support for research on the replacement of single-use plastics is necessary to prevent and reduce plastic pollution.

Up to now, we cannot conclude that the implementation of reusable food containers on a market size of an existing meal delivery network is profitable and sustainable. Since these concepts still need time to grow, there is a need for simulation models analyzing different container handling methods to quantify their impact on the environment and profitability. These analysis give actors (e.g., consumers, restaurants, reusable food container start-ups, online food platforms) in the meal delivery market, relevant insights into the environmental impact of reusable container systems. Besides that, the research aims to provide information on the business case of such systems by estimating the effect on costs.

Furthermore, almost all current reusable food container initiatives rely on the customers motivation to return the containers to a certain drop-off point. Other types of reusable container handling methods could be more convenient, such as including the driver in the return logistics of the containers. These concepts could have a higher chance of adoption among customers, which enlarges the societal impact. It is therefore important to investigate which factors are relevant for the adoption of reusable containers. This knowledge, in combination with the expected costs and emissions, helps online meal delivery platforms to understand the implications of the introduction of reusable food containers in their business.

1.3. Research Objective and Deliverables

We aim to evaluate the environmental- and economical performance of the introduction of reusable food containers in the meal delivery industry. Additionally, we investigate the potential adoption success of different reusable container handling methods. This results in better insights into the potential of various reusable container handling methods on a large scale instead of relying on the performance of the relatively small reusable container handling initiatives that currently exist. Thereby, we fill the knowledge gap on the performance of reusable food container networks in both academic literature as the industry.

1.4. Research Questions

To ensure that this research works towards a single goal, a research question is formulated which will be answered during this study:

What is the economical- and environmental impact of integrating reusable food containers in the meal delivery industry?

To be able to answer the the main research question, subquestions need to be answered. These structure the research problem and show the relevant aspects of the evaluation study.

1. **What are key factors for the adoption of reusable food containers by stakeholders in the meal delivery industry**

We take the following stakeholders into account: consumers, restaurants, drivers, and meal delivery platforms. Examples of relevant factor for the adoption of reusable concepts are customer behavior, return possibilities, and restocking policies.

2. **What are container handling methods for the integration of reusable food containers in the meal delivery industry?**

The meal delivery industry is defined as a network of multiple restaurants, drivers, customers, and an online meal delivery platform. Reusable food container systems provide the delivery of meals that are packed in reusable food containers. Besides that, it includes the return logistics to the restaurants and the process of washing to ensure that the food containers can be reused.

3. **What key performance metrics quantify the environmental- and economical impact of container handling methods for reusable food containers in the meal delivery industry?**

Dominant factors in the economical quantification are, for example, the costs for restocking and packaging. The environmental quantification includes, among other things, the emissions that are caused during the production, usage, and disposal of packaging. We will quantify the economical and environmental impact by the total extra costs and total carbon footprint of one meal order, for each of the container handling methods for different scenarios, respectively.

1.5. Methodology

To fulfill the research gap, we execute an evaluation study that consists of three consecutive research phases: identify, define, and evaluate. The methodology framework can be seen in Figure 1.1. The research phases can be seen in the rows. In each block, the research element is given. The bullet points show the methodology used to gain information about the research element.

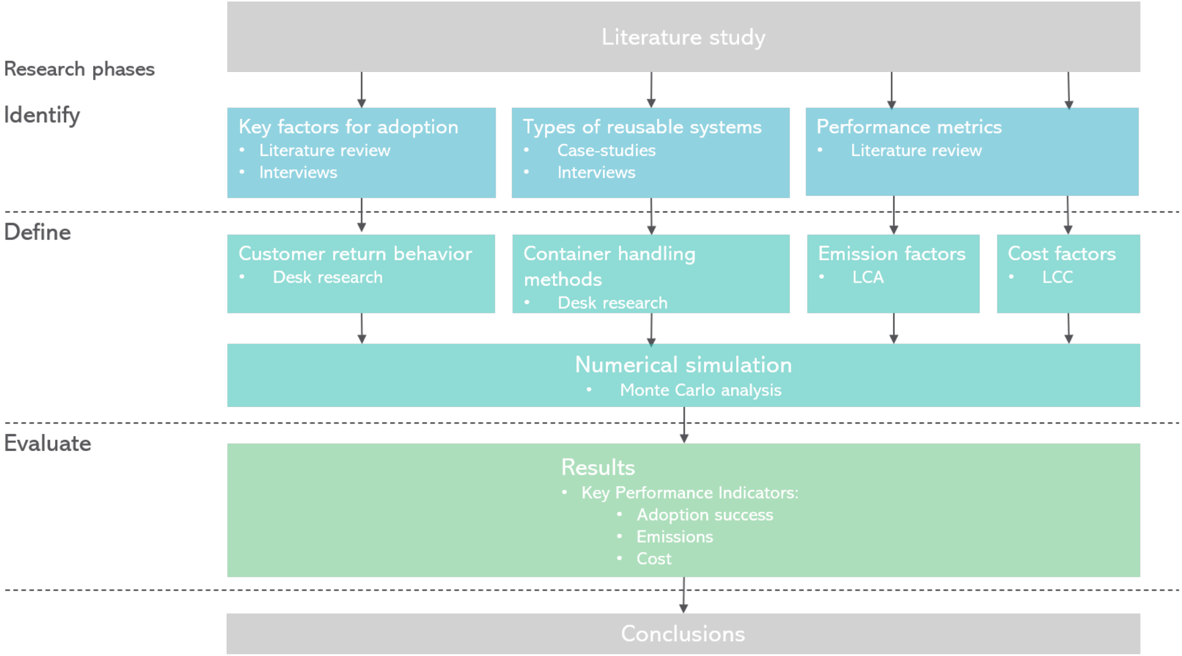


Figure 1.1: Methodology framework

Before executing the evaluation study, we gain an understanding of the existing research on logistics concepts for reusable systems, key success factors for reuse, and methodologies that are able to measure the environmental- and economical performance of packaging systems. Based on this literature study, a research gap is identified which is used as an input for the identification phase. The three different research phases can be described as follows:

1. **Identify:** in the first phase of the evaluation study we explore and identify the conventional meal delivery system and customer characteristics. Furthermore, case-studies among reusable packaging initiatives in the meal delivery industry are executed to gain insight in the innovative concepts that recently entered the market. Moreover, the scope for the economical- and environmental performance measurement is identified.
2. **Define:** in the second phase of the research study we define the system, container handling methods, and parameters. Besides that, we define the performance metrics used to quantify the economical- and environmental consequences of different container handling methods in multiple scenarios. The definition of these container handling methods are based on the case-studies in the previous research phase. Further details are defined based on desk research. The container handling methods together with a factor for customer return behavior and the defined emission- and cost factors, are used as an input for the numerical simulation study which is executed using a Monte Carlo analysis.
3. **Evaluate:** the last phase of the study focuses on the evaluation of the simulation study results which gives insight in the performance of the defined handling methods for the reuse of food containers. We evaluate the container handling methods based on three categories of key performance indicators: the adoption success, emissions and cost.

Based on the analysis of the results, we draw conclusions and formulate recommendations for future research and implementation.

2

Literature Review

Within this research, we aim to analyze different container handling methods for the integration of reusable food containers in meal delivery services. The organization of reusable containers in meal delivery broadly links to Green Supply Chain Management (GSCM) in the literature (Srivastava, 2007; Wang et al., 2011; Cascini et al., 2014; Tseng et al., 2019; Bortolini et al., 2018). According to the comprehensive literature review by Srivastava (2007), a distinction within GSCM can be made between two types of sustainable initiatives: green design of products or green operations. This research focuses on the latter while taking the available designs of reusable- and disposable food container products into account.

According to this background, the reminder of this literature review is organized as follows. First, literature on recyclable- and reusable systems in different industries are discussed in Section 2.1. Next, the key factors for the adoption of reusable food container systems are described in Section 2.2. Furthermore, techniques to evaluate the environmental and economical impact of systems are described in Section 2.3.1 and Section 2.3.2. We conclude this literature review with the description of the research gap in Section 2.4.

2.1. Reusable Packaging Systems

2.1.1. Success Factors of Reuse

We see two types of green developments in food container products: recyclable or reusable alternatives. Recycling food containers means turning the containers into raw materials which can be used again. An advantage of recycling is that there is no need for standardized product shapes. A diverse mixture of food containers consisting of similar material types can be recycled at once. Commonly known is the recycling of paper, which is centrally organized and facilitated by municipalities. Additionally, private companies provide more recycled programs, such as Nespresso for their coffee capsules. The aluminium material in the capsules is reused for the production of new capsules. This reduces the mining and production of aluminium, which is responsible for 86% of the environmental footprint of the capsules (Nespresso, 2021).

However, a large amount of energy is needed to transport, process, and reassemble recyclable materials (ClearanceSolutions, 2015). In the hierarchy of the circular economy a change from material recycling to product reuse is considered positive as more value is retained. Reuse of packaging therefore represents a major opportunity to retain functionality of the material and product and achieve potentially large reductions in material use and environmental impact (Coelho et al., 2020). Porter and Van Der Linde (1995, 2017) underline the competitive advantages by stating that investments in reusable systems can lead to resource savings, waste elimination and productivity improving.

Several companies have discovered that the reuse of packaging can also be commercially rewarding (Kroon and Vrijens, 1995). The more frequently reusable packaging can be used, the lower their cost per use. Loop (2020), an online delivery service of food in reusable packaging shows that their containers are viable for approximately 100 uses, so a $3 container would cost three cents per use. A plastic disposable container costs anywhere from 5 to 20 euro cents a piece. Improving the quality of reusable containers results in a longer lifespan which has a large positive impact on the cost and emissions per use.

Besides the lifespan of the reusable packaging, Jacobsen (2015) proposes in his study four other main drivers of profitability in packaging material reuse for companies. First of all, the number of avoided costs of purchasing new packaging materials for single-use packaging. Secondly, the firm's ability to reduce the cost of reverse transportation which is required for reuse. Additionally, the internal cost of handling, sorting, and cleaning packaging materials is relevant. Lastly, the firm's cost of disposing non-reusable materials. However, to be successful in all these aspects, a sufficient logistics system design and management is important. Meyer (1999); Rogers et al. (2012) underline the complexity of reverse logistic processes. Many companies are unable to handle the complex networking necessary to have an efficient reverse logistics process (Krumwiede and Sheu, 2002). It is therefore important to gather knowledge on the performance of different logistics systems for reuse.

Additional to the cost-related aspects, the ”green” image has become an important marketing element since customers increasingly expect companies to reduce their environmental footprint (Fleischmann et al., 2001). Besides that, research by Barnes et al. (2011a) shows additional willingness to pay for more sustainable packaging among consumers. Implementing sustainable packaging alternatives could therefore also be beneficial for online delivery platforms since they address a target group of sustainable customers. This results in a stronger position for competition on the market. However, Mahmoudi and Parviziomran (2020) highlight that reuse strategies also have been criticized by decision makers if there are not designed well since this could result in more required vehicles, added packaging weight, reverse logistics cost, and extra energy to clean the packaging.

Designing systems for the reuse of packaging products is something which is done for many years in different industries. However, these systems are not always sustained. Beer bottles have been successfully reused for several decades, due to high turnover rates, relative short transporting distances, and well-designed packaging systems (Mata and Costa, 1999). The key of this reuse success lays in the standardization of the beer bottle design which fosters the handling of the products (Gaines, 2012). Furthermore, due to standardization more actors within the network will use the same product resulting in higher product quantities, which is beneficial due to the economy of scale. This effect is enhanced by a growing sales market of the product. Resulting in advantages that arise due to the inverse relationship between per unit fixed costs and the processed quantity (Corporate Finance Institute, 2018). However, in the past decades, we have observed a trend away from standardized beer bottles since the design became part of the marketing strategy of beer companies. For the same reason, soft drinks and (spring) water distribution has shifted massively to disposable packaging products.

The trend of distinctive container designs can also be seen in takeaway packaging, with each restaurant using its own (personalized) packaging products. The customized packaging cannot be used for other restaurants in the network. This development makes it harder to benefit from the economy of scale when reusing food containers. Resulting in higher costs for the restaurants compared to disposable food containers (Accorsi et al., 2020). Making the disposable container option more attractive. This aligns with the findings by González-Torre et al. (2004), showing that factors such as packaging standardization level and the number of companies using the standardized packaging design, result in different environmental impacts and reverse logistics policies in European bottling and packaging companies. The economical and environmental trade-off between disposable- and reusable food containers in the meal delivery industry has not been studied before in the literature yet. Simulating such logistics concepts could prove the profitability and reduction of the environmental footprint, which is relevant information for the adoption of reusable containers by meal delivery platforms.

2.1.2. Logistic Approaches

A variety of possible design concepts for reusable container systems are proposed in literature (Kroon and Vrijens, 1995; Lützbauer, 1993; Savaskan et al., 2004). The basis of the concepts come from a study by Lützbauer (1993) in which three types of reusable packaging systems are proposed: switch pool systems, systems with return logistics, and systems without return logistics. If applied to the meal delivery industry, these types can be described as follows:

- **Switch pool systems:** A switch pool system specifically applies to delivery networks for individual restaurants. Each participant (restaurant, driver, customer) has its own share of food containers, for which the participant is responsible. Thus, cleaning, maintenance, and storage of containers are the responsibility of each pool-participant. A switch-pool system can be designed in two ways: sender-recipient or sender-carrier-recipient. In the former, the restaurant is responsible for managing the return flow of containers, while in the latter the driver is responsible for managing the return flow to the restaurant. In this case, an ownership switch occurs at every exchange of containers. When a filled food container is delivered to a customer, the customer should give the restaurant/driver the same number of empty containers in return.
- **Systems with return logistics:** In this type of system, the food containers are owned by a facilitating company. This organization is responsible for the return of containers after customers emptied and rinsed it. Furthermore, the facilitating company makes sure that the food containers are distributed over the restaurants after cleaning. This type of system applies to a delivery network with multiple restaurants. In this system, the customer bundles empty containers and stores them until a sufficient number of containers has accumulated for cost-effective collection. According to Hellström (2009), the logistics in this system could be designed based on a transfer or depot principle. In the former, the restaurants are fully responsible to track, manage, clean, and store the containers, while in the latter containers are maintained and stored in depots by the facilitating company. Which is also responsible for the collection and return of empty containers from the customers.
- **Systems without return logistics:** In this type of system, the food containers are all owned by the facilitating company. The restaurant rents the containers from them. The restaurant is responsible for all activities related to the containers, such as logistics, cleaning, control, maintenance, and storage. The restaurants return an amount of food containers to the company as soon as it no longer needs it.

Based on these different types of logistics systems, the product flow between restaurants and customers can be designed. Especially, the differences in the transfer or depot principle suggested by Hellström (2009) can have a large impact on the practical implication of the reusable system. In a transfer system, restaurants are responsible for cleaning and storing food containers. This results in transport distance in comparison with the depot principle, in which food containers are stored and cleaned in a central depot by the facilitating company. Nevertheless, the cleaning quality can more easily be guaranteed in a central depot than in a variety of restaurants. Mahmoudi and Parviziomran (2020) suggest to include a quality check in these systems. It is more reliable to check the container quality in a central location. Containers that meet the quality requirements are reused by restaurants. Damaged containers are transferred to the repair department of the facilitating company where they are repaired or disposed.

Which system a restaurant chooses depends on the type of goods, the quantities involved, and whether the restaurant has a return logistic system (Kroon and Vrijens, 1995). Besides that, the attractiveness of the offer by the facilitating company plays an important role. Furthermore, the scope of the system, the willingness to invest (both from the restaurant side as the customer side), the storage space available, the size of the restaurant's organization, and the acceptance in the market, influence the decision on the type of system. To the best of our knowledge, the majority of literature studies have considered a supply chain with a single sender (restaurant) and a single recipient (customer), while in practice mostly more complex supply chains are observed.

Currently, restaurants depend heavily on online food ordering platforms, such as Thuisbezorgd.nl, UberEats, and Deliveroo. The power of these networks has a major impact on the meal delivery industry. Most restaurants are small companies for which an investment in reusable packaging has an impact on their financial situation. Normally, individual restaurants do not take advantage of the scale since their quantities are relatively low compared to the whole market. Collaborating with a facilitating company that rents out reusable food containers is favorable. A driver network of online food platforms in combination with reusable packaging systems could have an impactful and profitable potential. However, evaluation studies on these logistic systems are lacking in literature so far.

2.2. Key Factors for the Adoption of Reusable Food Containers

Introducing systems for reusable food containers includes a wide variety of stakeholders which can be seen in Figure 2.1. The government agencies determine the laws and regulation for packaging usage. These stakeholders have a high level of power but are less interested in the specific implementation of reusable food containers in the meal delivery industry. The online meal delivery platform, restaurants, and customers are the most impactful stakeholders in the system. They have a high level of power and interest in the development of reusable food containers. Furthermore, the introduction of reusable food containers will lead to a system change for these stakeholders. Gaines (2012) highlight that institutional constraints, consumer preferences, and behaviors must be considered before the best path forward can be determined. We therefore investigate relevant factors for the adoption of a reusable container from the perspective of each of these actors in this section.

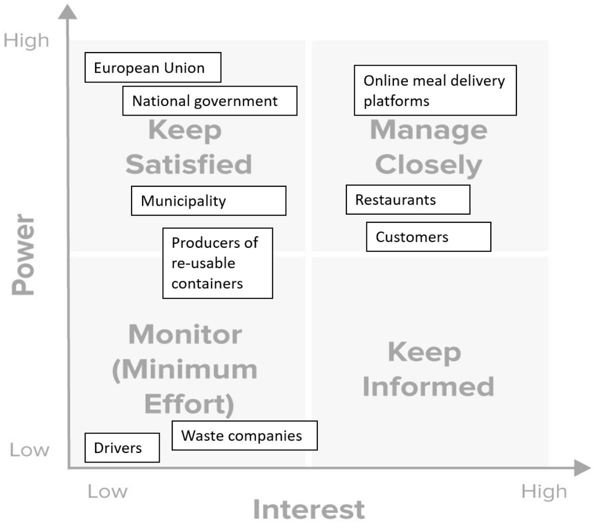


Figure 2.1: Actor field reusable food container packaging in the meal delivery industry in Europe

2.2.1. Meal Delivery Platform Perspective

For meal platforms, the key main barrier identified in the literature is the increased logistic complexity, requiring the reorganization of supply chains to ensure that food containers are available. Besides that, the return rates and turn-around time to prepare the package for a new cycle affect the system (Coelho et al., 2020). Deposits and refund systems induce customers to return food containers in good condition and in a timely manner. For example, Tyme gave $1 off new purchases when customers returned jars, which resulted in an 80% return rate (Tyme, 2020). Swapbox goes for another strategy by giving the customer 14 days to return the food containers. If the customer still has the food container after 14 days, their account is blocked and they pay a one euro late fee (SwapBox, 2021).

Furthermore, the upfront investments in reusable food containers are noted as a barrier (Coelho et al., 2020). Twede (1999) suggests that the capacity of the industry seeking for environmental friendly packaging, providing storage space (for empty containers), labor and space (to sort containers), and washing and repair, as the most important factor affecting the economic viability of these container types. Simulating the economical impact of such an investment gives relevant insight into the profitability of the concept of meal delivery platforms.

2.2.2. Restaurant Perspective

From a restaurant perspective, the operations management of reusable containers is one of the main concerns of companies who are willing to adopt reusable containers for their own business (Mahmoudi and Parviziomran, 2020). Next to cost and logistics complexity, product safety is an important concern for both meal delivery services as restaurants. Jetten et al. (1999) conclude that reuse of plastic food packaging does not significantly influence the food quality and safety. In further research, Jetten and De (2002) found that the characteristics of the plastic did not change significantly after repeated washing. However, for strongly flavored meals, the flavor may likely be carried over to the food packaging. Using professional dishwasher machines helps to solve this problem.

One of the key barriers for restaurants is the additional space and hygiene requirements for the storage of reusable food containers (Coelho et al., 2020). Furthermore, the more intensive usage of their dishwashers for food container cleaning may result in higher risks for maintenance and increased cleaning costs. Third-party companies, or the meal delivery platform itself, could take that risk from the restaurants' hands by facilitating the storage, cleaning, and transport of the reusable food containers. SwapBox, GoBox, and Sharepack are companies currently offering these services (SwapBox, 2021; GoBox, 2021; Bûmerang et al., 2021).

2.2.3. Customer Perspective

Whether a network for the reuse of food containers is successful or not depends strongly on adoption rates by customers and restaurants. Research by Grimes-Casey et al. (2007) showed that a reusable packaging system will depend on the willingness to return by customers. They found that, although refillable bottles seem to be more economical in the long run, the system can only be successful if the consumer's return rates are high. Consumers that dispose reusable bottles, or reduce their demand in response to the return incentive, drive the costs up and force the whole system to use disposables instead. It is therefore important to investigate how the customer market of the meal delivery industry looks like, which factors play an important role in customer decisions for the usage of reusable packaging, and what motivates them to reuse (Grimes-Casey et al., 2007). First, we describe the customer characteristics of online meal delivery platforms. Secondly, we identify socio-demographic, socio-psychological, and economic factors that are relevant for customer adoption.

Customer Characteristics

To gain a better understanding about the conventional meal delivery system and its customers, we execute user research. First, we will look into the different customer groups using meal delivery services. According to Garcia (2018) meal delivery adoption is very much related to age. Research by Zion et al. (2020) underline this by stating that 63% of U.S. people between 18 and 29 years old have used a multirestaurant delivery website or app service in the past 90 days. Followed by 51% for people between 30 and 44 years old, 29% for those between 45 and 60 years old, and just 14% for people of 60 years old and over. We see a similar type of distribution in the user base of DoorDash, one of the biggest online meal delivery platforms in the United States. People between 18-34 account for the largest order share of 42%, followed by people between 35-54 accounting for 36%. People of 55 years and older account for 22% of the meal orders at DoorDash (Bryan, 2021).

Research by Green (2016) splits up the younger category of people between 18-34 years old. Interestingly, the category of 18-24 orders on average 1.02 times per week, while the group of people between 25-34 years old orders 1.22 times per week. People between 35-44 order 0.81 times per week, 45-54 year-old people order 0.46 times per week, and people of 55 years and older order 0.23 times per week. From these studies, we learn that younger people are more used to ordering food at online meal platforms, especially the group of people between 25-34 years old.

Besides the distinction of customer groups by age, we could categorize customers by their order frequency. Research by Gilsenan (2018) shows that among a group of 1,500 takeaway meal delivery users in the U.K., 3% orders takeaway food every day or nearly every day, 13% orders 2-3 days a week and 26% orders once a week, 20% orders once every 2 weeks, 23% orders once a month and 15% orders less than once a month. This is in line with research by Garcia (2018) stating that 31% of the respondents ordered a meal for takeout or delivery from a restaurant once a week or more. 53% of the respondents ordered twice a month or less. In conclusion, it seems that frequent users order meals once a week or more, regular users once a month and infrequent users once in two months.

Socio-demographic Factors

An important adoption factor to consider is the willingness of reuse and recycling among different customer groups. Shen and Saijo (2008) state in their literature review that the relationship of environmental concern with various social characteristics has been explored by several researchers. SPC (2020) conclude that younger consumers have a higher Willingness to Pay (WTP) for recyclable products. This aligns with the age effect suggested by Liere and Dunlap (1980), which states that younger people tend to concern more about the environment than elders. According to Green (2016), millennial consumers increasingly show a conscious engagement with the food industry, how food is produced, and the way it is consumed. However, looking at general findings on sociodemographic, the results appear to be inconsistent (Saphores et al., 2012). Variables such as, gender, age, income and education, are statistically significant however their explanatory power tends to be small (Hornik et al., 1995). Therefore, we cannot assign any characteristics about the willingness of reuse to specific the customer groups. In general, irrespective of these socio-demographic factors, customers need to be highly motivated to engage in recycling behavior (Roca i Puigvert et al., 2020).

Socio-psychological Factors

Socio-psychological determinants play an important role in the reuse and recycling behavior of customers. A study by Ajzen (1991) developed a framework for this analysis called 'Theory of Planned Behavior'. The framework helps to understand the value-attitude-behavior link. Ajzen (1991) defined that behavioral achievements depend on three factors: the attitude of individuals towards the behavior; subjective norms that influence the intention to perform the activity; perceived ability to perform the task. The stronger the values of collectivism, perceived social desirability, and pressure associated with reuse and recycling, the more customers tend to recycle (Sorkun, 2018; Passafaro et al., 2019). Certain individuals use the belief that the government is responsible for collective problems caused by waste management to justify the inaction (Stern et al., 1985). Roca i Puigvert et al. (2020) conclude that the behavior, attitudes, and intentions towards reuse and recycling depend highly on the perceived convenience and efficacy of the new system as well as the values and subjective norms with which they are associated.

Zhang et al. (2016) analyzed the behavior of recycling under the 'Theory of Planned Behavior'. The study showed that when recycling facilities are so easily accessible that no additional effort is required to return packaging for reuse, the percentage of people using reusable packaging would significantly rise. This aligns with the results in Struk (2017) which showed that more people will separate and recycle waste if there is less distance to the waste collection site. According to Luyben and Bailey (1979), making recycling more convenient in terms of effort and required resources have a positive impact on the degree of recycling. Any perceived inconvenience could strongly influence and outweigh the attitudes about the long-run importance of recycling (Roca i Puigvert et al., 2020).

Furthermore, convenience affects the acceptance of reusable packaging systems by consumers (Coelho et al., 2020). When you give a customer the choice between the most convenient option and the most sustainable options, the convenient option wins (Devenyns, 2019). Return opportunities (e.g., in-store, pick-up) play an important role in customer convenience. According to a study by Saphores et al. (2006) the convenience and familiarity with recycling are important factors in waste management behavior. People living more than five miles away from the nearest drop-off recycling center are less likely to recycle. Familiarity with recycling concepts increases the willingness to recycle.

An innovative company named Loop, built their business based on convenience by playing into the consumer search for ease (Loop, 2020). Loop delivers everyday grocery products in reusable packaging to the customer in a reusable tote. When a product is used up, the customer puts it back into the tote and schedules a free pick-up, returns it to a pick-up point, or schedules a pick-up event with their next delivery. According to Devenyns (2019) the idea of fusing reusability with convenience has generated wide appeal. Loop (2020) reports a long waiting list for their services. This example shows that the ease or convenience of a service plays an important role in the participation of customers in networks with reusable food containers.

Furthermore, consumers are more likely to choose for a more environmentally friendly purchase if consumers believe that their environmental purchase would make a positive impact on the environment (Valor, 2008). Jain et al. (2013) conclude in their study that tallying environmental units (e.g., the number of ”trees needed to offset emissions” of customer consumed energy) to be more effective in cutting energy use than other information strategies, both short- and long-term. As such, green marketing is not just an environmental protection tool but also a successful marketing strategy (Yazdanifard and Mercy, 2011). Research by Agatz et al. (2021) on time slot choice for food delivery shows that green labels outperform price incentives leading to greater cost savings.

Providing correct information about the footprint of the packaging to the consumer is essential since research shows that most consumers have misconceptions on sustainability in general. For example, bioplastics are misinterpreted by consumers as being biodegradable in the environment, whereas most of the biodegradable polymers can only be decomposed in industrial systems under controlled conditions (Boz et al., 2020). This aligns with the results in Steenis et al. (2017) that show consumer opinions on sustainable packaging do not always align with the actual sustainability of a package determined in the Life Cycle Assessment (LCA). Metal and plastic-based materials were not considered as environmentally advantageous, whereas paper-based packaging was perceived as environmentally friendly. Coelho et al. (2020) suggest that consumers have limited understanding to distinguish and rate the impacts of packaging concepts. This highlights the importance of emphasizing the environmental impact of reusable food containers compared to other food container types to the customer.

Economic Factors
According to Agatz et al. (2021), three-quarters of the participants claimed willingness to pay up for environmental friendly products. This aligns with results in Barnes et al. (2011b), which demonstrates an increase in the consumer’s willingness to pay for more environmentally friendly food containers. However, Coelho et al. (2020) suggest that for the general public, the ’feel-good factor’ of sustainable packaging is not enough. Hence, a financial incentive may be important to change consumers to switch to reusable packaging systems. van Birgelen et al. (2009) show that ecological packaging could create brand switching, while taste and price characteristics must be fulfilled. Interestingly, several studies based on field experiments show that listing environmental information can more effectively elicit conservation behavior than offering nothing more than financial information.

Financial incentive programs such as cash for recyclables, lotteries, and prizes on recycling behavior could have a positive impact on the amount of recycled waste (Struk, 2017). The financial incentive of lotteries is also introduced in the COVID-19 vaccine strategy by governments worldwide. ”Vax and you’re in Schumaker (2021)”. It results in higher turnout rates among a wider diversity of groups than without this incentive. However, the encountered effect of economic incentives does not persist for a long period. The effect disappears when the financial incentives are removed (Luyben and Bailey, 1979). Besides these incentive programs, deposit systems could be introduced in which the consumers pays money for a certain product and receives a refund when returning the product. According to Roca i Puigvert et al. (2020) the economic deposit system generally induces a negative reaction. Consumers perceive it as a coercive rather than motivating system. They expressed that, due to the obligatory nature of the economic deposit, they felt victimized. The system would force them to assume further efforts and responsibilities. A deposit scheme could induce a reduced sens of environmental responsibility which would cause citizens to dispose of the rest of the waste improperly (Roca i Puigvert et al., 2020).

2.3. System Performance Metrics

To evaluate the environmental- and economical performance of packaging systems, several assessment methods are used in literature. Most of these methods take the life cycle of the packaging product as a basis of the assessment. This includes the production, transport, use, and disposal of the product. Section 2.3.1 and Section 2.3.2 describe the existing literature on life cycle performance measurements on both environmental as economical aspects.

2.3.1. Life Cycle Assessments

While it is intuitively plausible that reusable food containers are environmentally better than their single-use counterparts, a limited number of studies have yet quantified the actual environmental implications of different takeaway food containers and how they perform compared with their reusable alternatives (Gallego-Schmid et al., 2019). Tsiliyannis (2005) showed that factors such as annual reuse frequency, lifetime, maximum number of reuse trips, amount of packaging present in the market, annual production, reuse rate and consumer discard rate affect the environmental impact of reusable packaging systems.

An international standardized methodology used to quantify the environmental impact related to goods and services is the Life Cycle Assessment (ISO 14040 ff) (European Commision, 2015). According to Molina-Besch et al. (2019), the LCA appears to be a useful method for performing a complete analysis of the environmental impact of food packaging systems. However, methodologies to apply impact assessments differ within literature. According to Accorsi et al. (2014), there is no evidence of a single best practice for assessment. Table 2.1 summarizes a selection of applied assessment methods dealing with food packaging in literature. From this literature study, we can conclude that most of the impact assessments are executed by using software.

Table 2.1: Overview of impact assessment methods applied in literature

Author and publication date	Functional unit categories	LCA Software tool
Arunan and Crawford (2021)	Food packaging for the range of common cuisines delivered by OFDS	PIQET Software: GHG emissions
Amienyo and Azapagic (2016)	Beer: glass bottles, aluminium cans, steel cans	GaBi 4.3 LCA Software: CML 2001
Gallego-Schmid et al. (2018)	Plastic and glass reusable food containers	GaBi 6.5 LCA Software: CML 2001
Gallego-Schmid et al. (2019)	Four most commonly used food containers	Gabi 6.5 LCA Software: CML 2001
Accorsi et al. (2014)	Single-use and reusable crates for food catering	Carbon footprint
Singh et al. (2006)	Reusable plastic containers and display-ready corrugated containers for the packaging of fresh fruits and vegetables	Energy consumption: solid waste production, carbon footprint

Many packaging LCAs concentrate on the comparison of disposable packaging materials (Arunan and Crawford, 2021; Gallego-Schmid et al., 2019). Another frequently used topic in packaging LCAs is the comparison between single-use packaging and returnable packaging systems (Gallego-Schmid et al., 2018; Frauenhofer Institut, 1993; Accorsi et al., 2014). LCA findings by Gallego-Schmid et al. (2018) reveal that the glass container has 12%-16% higher impacts than the reusable plastic container and should have 1.3-3.5 times longer lifespan to equal the environmental footprint of the plastic containers. In the last years, several authors have criticized LCAs on food packaging. They argue that the influence of food waste and logistical efficiency should also be included (Silvenius et al., 2014).

Further research by Gallego-Schmid et al. (2019) executes a LCA of the most commonly used takeaway containers: aluminium, extruded polystyrene (EPS) and polypropylene (PP). EPS containers are the best option among the three due to the lower material and electricity requirements in their manufacture. The EPS is also the best option compared to reusable takeaway PP containers, unless these are reused 3-39 times. These LCA findings show clearly that single-use plastic containers are not necessarily the worst option for the environment. However, EPS containers are currently not recycled and therefore cannot be considered a sustainable option. This example shows the need for the inclusion of a LCA in the comparison of different packaging alternatives.

2.3.2. Life Cycle Costing

Besides the environmental impact, we are interested in the costs of different reusable systems. Reusable packaging can be a profitable investment or a costly mistake (Twede and Clarke, 2005). The overall cost of a reusable packaging system could be lower than that of single-use packaging, although a variety of factors influence the benefits (Coelho et al., 2020). Several literature studies explored the factors that effect the economic cost of reusable packaging. Mollenkopf et al. (2005) found that some factors such as the size of reusable containers, average daily volume of the product to be transported, delivery distance, cycle time, total number of units per container (pack quantity), and fluctuation in peak volume can affect the costs of reusable containers. Accorsi et al. (2014) add to this, factors such as containers' service life, washing rate, waste disposal treatment, as well as network geography. All these factors have impact on the whole life cycle of the product.

Accorsi et al. (2020) concluded in their study on reusable plastic containers (RPC) for a regional catering company that the reusable system was environmentally superior to the current single-use system, however it led to increased costs. An important note within this research is that the unpredictability and influence of several parameters such as RPC lifespan, disposal treatment, and network distribution profoundly affect both the environmental and economic analysis, potentially leading to different conclusions (Accorsi et al., 2020). Hence, the need for further research on different network distributions integrating reusable food containers in the meal delivery industry occurs.

A commonly used tool to measure the cost of products over its life cycle is called the Life Cycle Cost (LCC) methodology. More specifically, the environmental LCC, since this methodology is based on the same system boundaries and functional units as those of LCA, addressing the complete life cycle. In general, the environmental LCC aims at comparing the life cycle costs of alternatives. According to Hunkeler et al. (2008), the LCA and LCC analysis can be seen as complementary. Figure 2.2, shows the connection of LCA elements to LCC elements. The cost elements that are directly derived from an LCA are written in bold italics. The elements just written in italics can indirectly be derived from the life cycle inventory data.

	Cost for product manufacturer	**Cost for product user**
Production	***Materials**** ***Energy*** *Machines, plants* *Labor* ***Waste management*** ***Emission controls*** ***Transports*** Marketing activities	Acquisition
Use	*Maintenance and repair (warranty)* *Liability* *Infrastructure*	***Transport*** *Storage* ***Materials*** ***Energy*** *Maintenance and repair* *Infrastructure*
End of life	***Waste collection, and disassembly/ recycling/disposal if take-back schemes or the like exist***	***Waste collection, and disassembly or recycling or disposal***

Figure 2.2: Connection of LCA elements with costs in LCC from Hunkeler et al. (2008)

How these factors effect the costs strongly depends on the design and management of the reusable system. According to a study by Twede and Clarke (2005), the operational cost can become a challenge if the logistics of containers are not well managed. Twede and Clarke (2005) showed that a strong channel leader with cost-saving incentives is required to manage the system. This entity should manage and monitor the use of the equipment over the complete life cycle span. McKerrow (1996) adds to this that the channel leader should have authority and responsibility. The quality and reconditioning standards of the equipment should be the responsibility of the channel leader. Furthermore, the channel leader should manage and control the collection process aiming to minimize cost and maximize availability. It does so by minimizing the collection process operations of empty containers, maximizing the containers' utilization, and satisfying the requirements and preferences of restaurants (McKerrow, 1996).

Inefficient allocation and ineffective tracking increase the number of containers needed in a system, and thus, the total cost of the system (Twede and Clarke, 2005). Mollenkopf et al. (2005) showed that reusable containers are more economically justifiable if larger containers are involved and the average daily volume of products to be transported is high, while single-use containers are more economically practical when delivery distance, cycle time, pack quantity and/or fluctuations in peak volume increase. Twede and Clarke (2005) found that the following supply chain factors favor reusable packaging systems: short supply chain (in time); short shipping distance or network for repositioning; efficient sorting, cleaning, and tracking systems; industry consortia for standardization.

2.4. Research Gap

From our literature review, we can conclude that there is a large potential for reusable systems to have a positive effect on the profitability and sustainability of a company. However, the literature shows that most companies are unable to handle the complex networking necessary for an efficient reusable system. Additionally, if the reusable system is not designed well, it could require more vehicles, added packaging weight, reverse logistics cost, and extra energy to clean the packaging. Therefore, it is important to gain knowledge on the design and performance of multiple logistics system concepts. However, the economical and environmental trade-off between disposable- and reusable food containers in the meal delivery industry has not been studied before in literature.

Currently, research on reusable packaging systems mainly focuses on supply chains with a facilitating company that manages the reusable packaging system on behalf of a group of restaurants. While in practice, restaurants depend heavily on online meal delivery platforms. A driver network of online food platforms in combination with reusable packaging systems could have an impactful and profitable potential. However, evaluation studies on these logistic systems are lacking in the literature so far.

Furthermore, this literature review discussed the key factors for the adoption of reusable food containers. The most important factor for the customer is the convenience of product. Especially, the return action for reuse of the product is important. In the case of restaurants, the guarantee of product safety and enough storage space is relevant. Online meal delivery platforms aim for high profitability of their business. Sustainability is becoming more important for customers, introducing reusable food containers could lead to competition advantages in the highly competitive meal delivery industry. The adoption factors for each of the stakeholders are taken into account to determine the success factors for different reusable container handling methods. This has not been done in the literature before.

In addition, this literature review examined different methods for environmental- and economical performance. The 'Life Cycle Assessment' (LCA) is an international standardized method to measure the environmental impact of packaging products. The scope of this assessment forms the base for the 'Life Cycle Costing' (LCC) methodology, which expresses the economical cost of the packaging system. The LCA by Gallego-Schmid et al. (2018) is used as a base for the environmental impact of reusable-, and disposable food containers. Furthermore, cost elements from LCC's in the literature could be a useful starting point for the economical assessment.

3

System Identification

In this section, we explore and identify the conventional meal delivery system. In addition, we perform case studies among eleven reusable food container initiatives in Section 3.1. Furthermore, we identify the steps for reuse in a conventional meal delivery system in Section 3.1.3. Additionally, the system boundaries for economical- and environmental performance measurement are identified in Section 3.2.

3.1. Meal Delivery Systems

To understand the container handling methods for reusable food containers, we identify the stakeholders, process steps, and user characteristics in the conventional meal delivery system in Section 3.1.1. In addition, we identify innovative food container handling concepts for reuse in Section 3.1.2. Moreover, we identify in Section 3.1.3 possible process steps in reusable meal delivery systems.

3.1.1. Conventional System

As can be seen in Figure 3.1 there exist four different stakeholder groups in the process of meal delivery. The following steps can be distinguished in the conventional process of meal delivery:

1. The customer places an order at the online food delivery platform.
2. The online meal delivery platform assigns the order to the selected restaurant. Besides that, the order is assigned to a driver.
3. The restaurant prepares the meal and packs it in a disposable food container.
4. The driver receives the order from the restaurant and delivers it to the customer.
5. After consumption the customer disposes the single-use container.

Besides these steps for delivery, the online meal delivery platform works closely together with the connected restaurants to promote and provide menu options to the customers. Furthermore, customers and restaurants could provide comments and feedback to the online meal delivery platform.

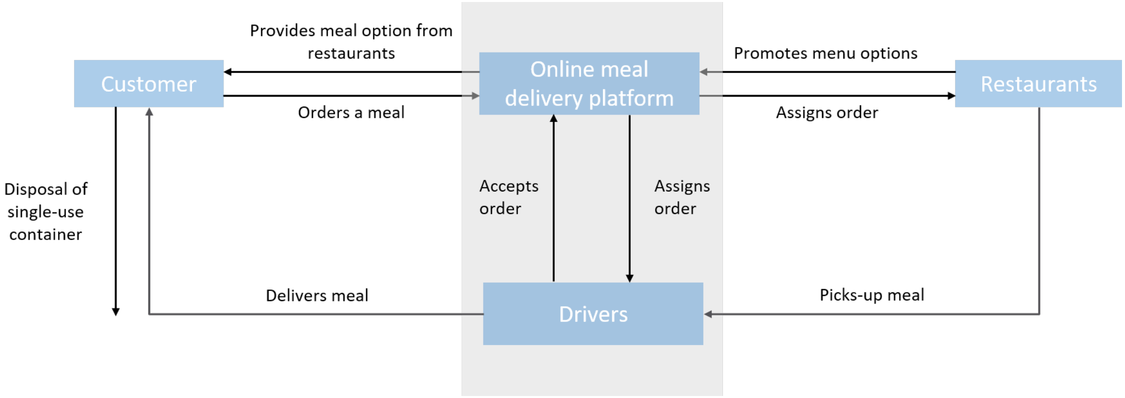


Figure 3.1: Functions and process steps associated to a reusable network for meal delivery

3.1.2. Reusable Container Handling Innovations

With the increase of takeaway food orders, the number of companies providing reusable transit packaging has been growing (Coelho et al., 2020). Desk result on reusable container handling initiatives result in the companies listed in Table 3.1.

All these initiatives have a common goal: creating a network for reusable food packaging. However, they differ in their size and market approach. For example, ReCircle (2019) is currently one of the biggest operators among these examples. The company has over more than 250 restaurants connected to their reusable food container network in Switzerland. Deliverzero (2021) integrated their reusable food container service with its own online meal delivery platform. While most other initiatives depend on existing online delivery platforms and just focus on facilitating reusable food containers to restaurants and its customers.

Furthermore, the concepts differ in their supply chain network designs. The design of these networks can be divided into three categories: forward logistics, reverse logistics, and recycling logistics. An overview of the different logistic components per reusable concept is given in Table 3.1. The different concepts within these categories can be explained as follows:

- **Forward logistics.** This type of logistics refers to the process of consumption of reusable food containers. This can either be done by purchasing the food container physically at the restaurant or by ordering food online and having the food delivered in a reusable food container. Deliverzero (2021) focuses on the online meal delivery market and therefore mostly provides their containers in combination with the delivery of an order made at restaurants connected to their platform. While EcoBox (2021a); Returnr (2021); Tiffin (2021) mostly focus on the take-away market in which customers buy their food in reusable food containers physically at the restaurants.
- **Reverse logistics.** After the customer used the food containers, there are different options for the return of the containers. Deliverzero (2021); Bûmerang et al. (2021) enable the customer to return their food containers at the next order to the driver. Most other concepts facilitate the return of containers to the restaurant connected to the network. Additionally, GoBox (2021); Bûmerang et al. (2021); SwapBox (2021) use retail locations like supermarkets as drop points for food containers. Shared Packaging (2020) even offers a transport service, apart from the driver, that picks up food containers from the customers.
- **Recycling logistics.** Most concepts explicitly ask customers to rinse food containers at their homes. A difference in recycling logistics can be seen in the cleaning location. Deliverzero (2021); ReCircle (2019); Returnr (2021); Tiffin (2021) arranged that the restaurants clean the containers themselves at their washing facilities. Initiatives such as Bûmerang (2021); EcoBox (2021b); GoBox (2021); Ozarka (2021); Bûmerang et al. (2021); Shared Packaging (2020); SwapBox (2021) created special washing facilities.

Table 3.1: Overview of reusable takeaway food container concepts and their supply chain network design. The listening of initiatives are just examples and do not cover the totality of reusable food container initiatives.

	Forward logistics		Reverse logistics				Recycling logistics	
Recycling initiatives	Customer receives the food container at the restaurant.	Deliverer delivers ordered food container at the customer.	Customer returns the food container to any restaurant connected to the reusable network.	Customer returns the food container to a drop site e.g. retail location.	Deliverer collects the used container from the customer at the next order.	Deliverer collects the used container at the customer by appointment.	The container is cleaned by the restaurant	The container is cleaned at a cleaning facility
Deliverzero		x	x		x		x	
Bûmerang	x	x	x					x
EcoBox	x		x					x
GoBox	x	x	x	x				x
Ozarka	x	x	x		x			x
reCircle	x	x	x				x	
Returnr	x		x				x	
Shared packaging		x				x		x
Sharepack		x	x	x	x			x
Tiffin	x		x				x	
SwapBox	x	x	x	x				x

From the industry, we can see some first concepts that are trying to collaborate with large online platforms. For example, customers at Takeaway, UberEats or Deliveroo are able to order their food in a SwapBox if the restaurant is connected to the network of SwapBox (2021). However, this currently depends heavily on the customer knowledge of the concept since the opportunity to order food in a SwapBox is not mentioned at the platforms' websites. A customer should include their special wish for meal delivery in a SwapBox in the 'Notes to the restaurant'. This is not user-friendly. Furthermore, besides Deliverzero (2021), all initiatives depend on the customers' willingness to return since the customer has to return their containers to a drop-off point or any restaurant in the system.

3.1.3. Reusable System

To facilitate reusable food containers, several extra process steps are required. These steps are illustrated in black arrows in Figure 3.2. We shortly discuss each of these steps in this section. We further define the different container handling methods in Section 4.2.

The online meal delivery platform owns the containers and distributes them over the restaurants. The platform keeps track of the inventory levels of reusable containers at restaurants and is also responsible for the restock of containers. The restaurant provides reusable food containers to their customers. The following steps can be distinguished in the process of meal delivery including reusable containers:

1. The customer orders a meal in a reusable food container at the online meal delivery platform.
2. After the usual steps for the delivery are executed, the steps for reuse are added to the process. A system could consist of either one of these options or a combination.
    (a) The customer returns the reusable food container itself, to any restaurant providing reusable containers.
    (b) A driver picks the reusable food container up at the next meal order of the customer. Next, the driver returns the reusable food container to any restaurant providing reusable containers.
3. The restaurant cleans the returned reusable food containers. After which they are ready to be used again.

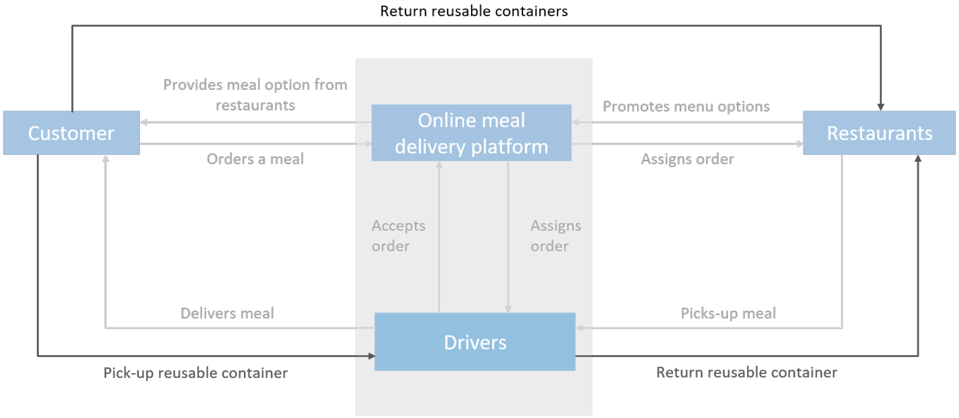


Figure 3.2: Function and process steps associated to a reusable network for meal delivery

3.2. System Boundaries

In this section, we identify the boundaries of the system for our environmental- and economical assessment. Based on these, we define a functional unit.

Food packaging serves the following functions: product protection, product use, product promotion, and facilitation of recycling (Arunan and Crawford, 2021). Specifically for meal delivery services, significant negative environmental effects have been suggested to occur from food packaging production and waste generation (Yi et al., 2017; Song et al., 2018). Not surprisingly, the environmental impact of packaging is frequently studied within the literature (Accorsi et al., 2020). The environmental impact of polypropylene (PP) single use containers has been studied by Gallego-Schmid et al. (2019). The impact of reusable PP containers has been assessed in a previous study by the same authors Gallego-Schmid et al. (2018). We use these studies as a basis for our environmental assessment.

A commonly used methodology to determine the environmental impact of packaging is called the Life Cycle Assessment (LCA). Several studies (Gallego-Schmid et al., 2018, 2019; Accorsi et al., 2020) executed LCAs on current food containers to evaluate the carbon footprint associated with the life cycle of the packaging. As described in Section 2.3.2, the Life Cycle Cost assessment uses the same system scope as the LCA. In this paper, we focus on the LCA of reusable- and disposable food containers. Therefore, we distinguish two different life cycles. One for single-use food containers and another for reusable food containers (Figure 3.3).

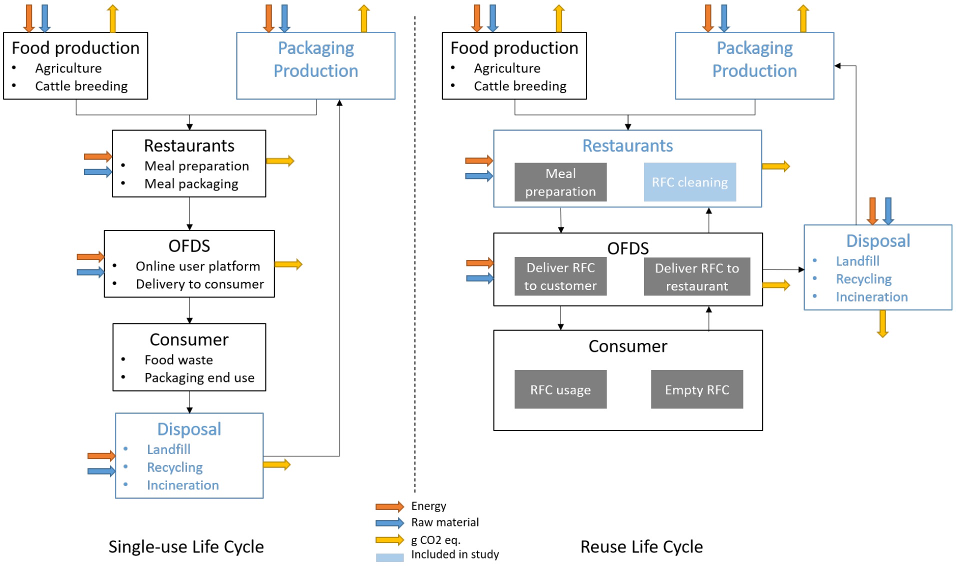


Figure 3.3: Scope of the LCA. On the left side: single-use packaging life cycle. On the right side: reusable packaging life cycle

The text boxes marked in blue in Figure 3.3 are included in the LCC and LCA. The energy and raw material flows are visualized with orange and blue arrows. The yellow arrow shows the emission flow. The following system barriers are taken into account for the LCA and LCC:

- Because food containers are used for a wide variety of meals, it is hard to estimate and include the food waste in the LCA. Therefore, we analyze the impact of a packaging system instead of including an analysis on food products.
- The scope of the LCA includes activities associated with the production, usage, and disposal of food containers. The usage of single-use containers is considered to not have any impact since the packaging is disposed after usage. For reusable food containers, cleaning is considered.
- We exclude the delivery to the customer since this is similar for both food container types.
- We consider refill- and restock events for both the LCA as the LCC.

Functional Unit

The functional unit considered is defined as the production and disposal of a food container storing a meal for one person. An average food container contains 670 ml according to fieldwork and information provided by manufacturers (Gallego-Schmid et al., 2019). The three mostly used takeaway containers are: aluminium-, extruded polystyrene (EPS), and polypropylene (PP) containers (Marsh and Bugusu, 2007). Cardboard- and paper food containers are less commonly used for 'wet' food (e.g., served with a sauce). These types are therefore not included in the study. EPS and aluminum containers cannot be cleaned in the dishwasher.

According to Plastic Packaging Facts (2019), PP is the most used material for food containers. This aligns with our multicase study, in which polypropylene is the mostly used material for reusable food containers (Table B.1). Additionally, Gallego-Schmid et al. (2018) showed that out of the 40 best-selling food saver brands considered, 90% of the food savers are made of polypropylene. The big advantage of PP is that it has one of the lowest densities among commodity plastics, and this results in money savings due to their low handling weight for manufacturers. On top of that, the high temperature resistance makes PP particularly applicable for food containment (Hisham A. Maddah, 2016). Customers that are environmentally conscious could reuse the PP containers. However, to make single-use PP containers comparable to reusable food containers, we assume that the PP containers are disposed after their usage in case of single-usage. Often a silicone rubber is used as part of the lid to ensure tight closure. We therefore consider polypropylene and silicone rubber as a functional unit of the reusable food containers.

4

System Definition

Based on the identification of the meal delivery system and its potential for reuse in Section 3, we define a system for further evaluation of reusable container handling methods. In Section 4.1 we first describe our system, after which we define in Section 4.2 the different container handling methods we will consider. In Section 4.3 we derive the parameters of our model. In Section 4.4 we define the performance metrics used to evaluate the system.

4.1. System Description

In this section, we will define our system and simulation model. In Section 4.1.1, we explain the different elements of the system. Next, we define the restock and refill events used to redistribute containers over the restaurant nodes that reuse in Section 4.1.2. At last, in Section 4.1.3 we describe the different input and output factors of the system.

4.1.1. System Elements

The system is described by a graph on which drivers move to transport food containers from one node to the other. In this section, we define each of the system elements. We first introduce the graph, after which we define the food containers and drivers, and their dynamics.

Graph

The meal delivery network for a single service region is represented by a complete graph $G = (N, E)$, where N is a set of nodes and E is the set of edges connecting nodes in N. Each node is connected to every other node by undirected edges. The node and edge characteristics can be described as follows:

- **Nodes:** the set of nodes consists of two subsets: the subset of restaurants (N^R), and the subsets of customers (N^C) for which holds: $N = N^R \cup N^C$. For these two subsets, the following holds:
    - **Restaurant Nodes:** Take n_R as the number of restaurants ($|N^R|$) in the meal delivery system. Two types of restaurants are distinguished, (i) restaurants offering reusable containers, denoted by set N^R_r, and (ii) restaurants without reusable containers, denoted by set N^R_{nr}.

      Reusing restaurant nodes have the possibility to deliver meal orders in reusable food containers and disposable food containers, whereas non-reusing restaurant nodes will only use disposable food containers to deliver their meals. Note that a reusing restaurant will only use reusable food containers if the ordering customer demands its meal in a reusable food container. Otherwise, the reusing restaurant will use a disposable to deliver the ordered food. Let α be the ratio of the restaurants offering reusable containers among all restaurants in the system; i.e., $\alpha = \frac{|N^R_r|}{n_R}$.

      Let us define the average number of orders ordered at a restaurant per day as ORDER_FREQ_REST. We assume no difference in restaurant popularity, the ORDER_FREQ_REST is equal and constant for all restaurants. For each order, a restaurant is randomly sampled from the set of all restaurants with equal probability per restaurant, i.e., we assume a uniform sampling distribution. Note that this implies that the choice of a restaurant does not depend on whether or not a customer wants its food delivered in a reusable package. The customer preference for food container type is only taken into account after restaurant sampling.

We define a minimum required stock of reusable food containers per reusing restaurant. If the stock is below this level, it will trigger an action to fill its stock. The minimum required stock level of each restaurant is defined as MIN_PACK_LEVEL.

Take p_{init} as the initial number of reusable containers each reusable restaurant has in stock at time zero.

- **Customer Nodes:** Take n_c as the number of customers ($|N^C|$) in the meal delivery system. Two types of restaurants are distinguished (i) customers that demand for reusable containers, denoted by set N_r^C, and (ii) customers that demand for non-reusable food containers, denoted by set N_{nr}^C.

  Per time step, the customer that places an order is randomly sampled from a distribution based on order-frequency data obtained from 'Takeaway.com' (see Section 4.5.2). The restaurant at which this order is placed is uniformly sampled from the set of restaurants (N^R).

  Each customer node starts the simulation with zero containers in stock. Over time, the customer can develop a stock of multiple containers.

  Reusing customer nodes always choose for reusable food containers if the restaurant offers these. Whereas the non-reusable customers always demand their orders in disposable food containers. Let β be the ratio of the customers that demand for reusable food containers among all customers in the system; i.e., $\beta = \frac{|N_r^C|}{n_C}$.

  A customer can be allowed to return a reusable food container to a reusable restaurant by itself. The return behavior of a customer is defined by: the number of days after which the customer will start to return a food container is defined as CUST_RETURN_PACK_THRES; after this number of days, the chance of return is given by CUST_RETURN_PACK_CHANCE. The restaurant to which the customer returns its reusable food container is sampled uniformly from N_r^R.

The total number of nodes of the graph is given by $n = n_R + n_C$. There is no geographical distance included in the system, i.e., we do not consider the nodes to have a specific location.

- **Edges:** The set of edges is denoted by E. We assume all nodes to be connected to each other, i.e., our graph is fully connected. As we do not consider any location information for the nodes, the edges do not have travel time characteristics. In our discrete simulations, we will assume that every edge can be traveled to in one time step.

Food Containers

Food containers function as packaging for the meals that are ordered by customers and produced by restaurants. The food container characteristics are described as follows:

- A reusable food container can only be used a fixed number of times before it is discarded. The maximum number of uses is defined as the parameter: LIFESPAN.
- The container size is standardized. There is one type of disposable food container and one type of reusable food container.

Drivers

The number of drivers is defined as d. Drivers move on the graph to fulfill the transport of orders from restaurant nodes to customer nodes. The routes are assumed to be given. Besides that, drivers can play a role in the return logistics of reusable food containers to the reusable restaurant nodes. The characteristics of the drivers can be described as follows:

- All drivers move in sync. A time step is defined as one delivery trip of a driver. Each time step every driver moves from a restaurant node to a customer and back to a restaurant.
- The average number of trips a driver can execute in one day is defined as the TRIP_FREQ_DRIVER.
- The driver has the possibility to store reusable food containers. The maximum number of containers a driver can take in storage is defined as the MAX_PACK_CAP.

Overview of System Elements

In this Section we give an overview of all system elements. Table 4.1 shows for each system element the related parameters. More details on these parameters are given in Section 4.3.

Table 4.1: Overview of the system parameter per system element.

System Element	Parameter Name	Parameter Description
Restaurant Node	n_r	Number of restaurant nodes
	α	Percentage of restaurant nodes that reuse
	ORDER_FREQ_REST	The average order frequency at each restaurant node
	MIN_PACK_LEVEL	Minimal required reusable containers in stock at restaurant nodes
	p_{init}	The initial number of reusable containers in stock at reusable restaurant nodes at start of the simulation
Customer Node	n_c	Number of customer nodes
	β	Percentage of customer nodes that reuses
	CUST_RETURN_PACK_THRES	Threshold value for the number of days after which order receiving from which there is a chance of container returnment by the customer
	CUST_RETURN_PACK_CHANCE	Chance of a reusable customer for returning its used food container to any reusable restaurant in the system
Food Containers	LIFESPAN	The number of uses for which the reusable food container is expected to work properly
Drivers	d	Number of drivers in the system
	MAX_PACK_CAP	Maximum storage capacity of reusable food containers for each driver
	TRIP_FREQ_DRIVER	Average number of trips per day per driver

4.1.2. Container Redistribution Methods

In general, a redistribution action is triggered when the number of reusable food containers in stock at any reusable restaurant node gets below the required stock level. We reconfigure the reusable food containers by redistributing them over all reusable restaurant nodes (restock event), and if necessary by adding new packages to all reusable restaurant nodes (refill event). Both are well-known stock management actions. However, it is important to clarify the two actions specific for our simulation in this section.

Restock Event

The left side of Figure 4.1 shows a potential situation of the system in which the reusable container stock at the reusable restaurant nodes has become skewed. In this time step where a restock event is triggered, we sum the reusable container stocks from all reusable restaurant nodes and divide these over all reusable restaurant nodes. This can be seen in the right graph of Figure 4.1. The costs and emissions for a restock activity are further defined in Section 4.4.

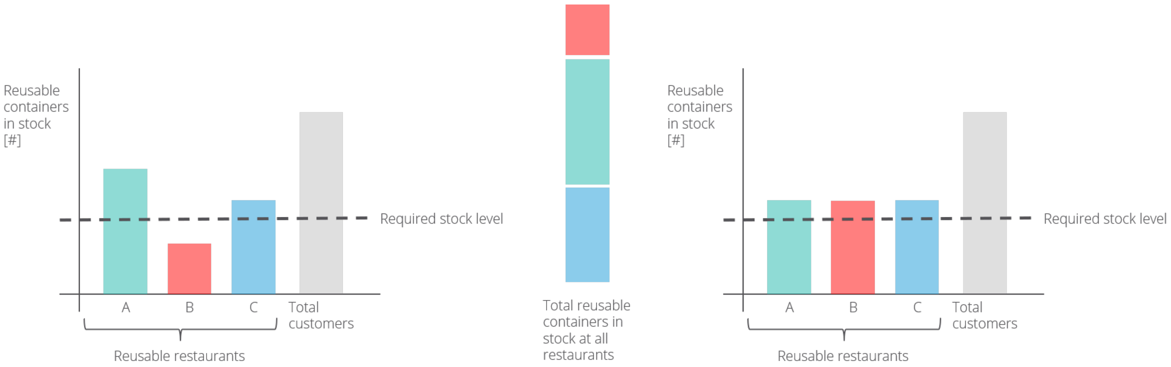


Figure 4.1: Restock event. Left side: situation that triggers a restock event. Middle: sum of container stocks of all reusable restaurants. Right side: situation after restock event

Refill Event

It could be that the total number of reusable food containers in stock of restaurants is too small to reach the minimal required stock level after a restock event. This is shown in the left graph in Figure 4.2. In this case, a refill of reusable containers at reusable restaurant nodes is required. In the time step where this occurs, we refill the stock of reusable containers at each reusable restaurant to the level of p_{init}. The costs and emissions for a refill event are further defined in Section 4.4.

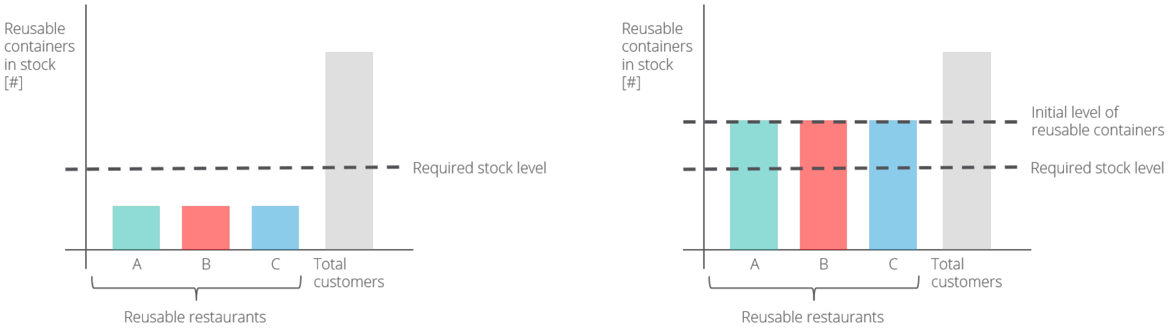


Figure 4.2: Refill event. Left side: situation in which the stock levels after restock are not enough to reach the required stock level. Right side: the stock levels are refilled with reusable container to equal the initial level of reusable containers at each reusable restaurant node.

4.1.3. System Input-output

Now that we have defined the system elements and the redistribution actions, let us look at the in- and outputs of the system. An abstraction of the system can be seen in Figure 4.3. We will explain each of the elements in this section.

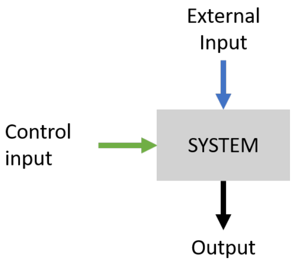


Figure 4.3: Input-output model of the system

The factors in this system, which can be described as follows:

- **External input:** These input factors are assumed to be given and fixed. There are two types of external input factors which play a role in the system depending on the container handling method (see Section 4.2). These external input factors can be described as follows:
  - **Routing.** Is defined as the route that each driver takes to pick up an order from a restaurant and deliver these to a customer.
  - **Intrinsic customer return behavior.** The willingness of customers to return reusable food containers to restaurants is defined by the number of days (CUST_RETURN_PACK_THRES) after order receivement after which there is a chance (CUST_RETURN_PACK_CHANCE) that the customer returns their food container to any reusable restaurant in the system.
- **Control input:** These are the input factors by which we can control the system. There are three types of control input factors which play a role in the system regarding the container handling method (see Section 4.2) The factors can be described as follows:
  - **Container redistribution.** As explained in Section 4.1.2, there are two methods for the redistribution of reusable food containers over the reusable restaurant nodes. The minimal number of reusable containers in stock (MIN_PACK_LEVEL), triggers these redistribution events. Varying this value results in different system dynamics.
  - **Driver storage policy.** A driver has the possibility to take a number of reusable food containers in storage (MAX_PACK_CAP) and to return these containers to reusable restaurant nodes. Dependent on the number of reusable containers at a customer and the driver's free storage capacity, the driver takes a number of reusable food containers in storage. The driver dropping control rule is defined as: the driver can only return reusable containers to a reusable restaurant node if the next order that he picks up at this restaurant is an order in a reusable food container.
  - **Incentives for customer return behavior.** Customer return behavior could be influenced by different customer incentives such as: deposit systems, discount on the next purchase, or drop-off points that are closer to the customer. These could impact the number of days (CUST_RETURN_PACK_THRES) after order receivement from which there is a chance (CUST_RETURN_PACK_CHANCE) that the customer returns their food container to any reusable restaurant in the system.
- **Output:** We assume that our system is fully measurable, i.e., we can measure the trips, the number of food containers, customers, restaurants and drivers, etc. Based on these measurements, we calculate two performance metrics, which are the outputs of the system:
  - **Costs.** The economical performance of the system is defined as the cost of the food container (per use) and the redistribution events in euros.
  - **Emissions.** The environmental performance of the system is defined as the emissions of the food containers (per use) and redistribution events, in kg CO_2 equivalent.

4.2. Container Handling Methods

Based on the literature review and the multi-case study, we define the container handling methods for our evaluation study. To define our methods, we will look from perspective of the customer and distinguish three types of handling methods. We explain each method based on the control factors that impact the system dynamics, which were introduced in Section 4.1.3. Furthermore, an example of a potential network configuration is explained for each handling method to show the potential transport flows in the system. We focus on a situation in which all customer nodes and restaurant nodes reuse. In general, remember that the meal delivery routes for drivers are assumed as given. We do not influence or change anything about the routing of the drivers.

4.2.1. Active

In a meal delivery system where we use the active container handling method, only customers actively return the reusable food container(s) to any restaurant connected to the reusable food container network.

Figure 4.4, shows a conceptualization of the system. We assume that the delivery operations between restaurants and customers are organized efficiently. As we let the customers actively return their reusable food containers, we need to control the incentives for customer return behavior inputs. For example, the introduction of deposits or fines for too late returnment of reusable food containers. In our system, these kinds of incentives can impact the CUST_RETURN_PACK_THRES i.e., the number of days after which their is a CUST_RETURN_PACK_CHANCE that the customer returns its reusable food container.

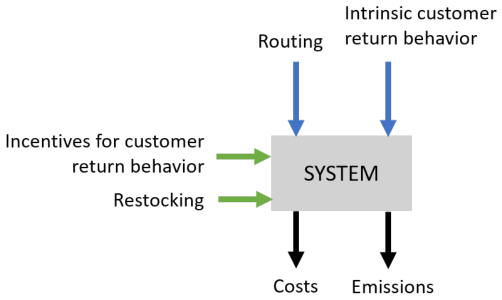


Figure 4.4: System abstraction regarding the active container handling method

Example Network Configuration

Figure 4.5 shows an example of the network situation in which an active container handling method is applied. The driver starts at restaurant one (red node) and serves customer one (blue node). The driver returns to restaurant one to pick up a new order for customer two. After delivery, the driver goes to restaurant two to pick up an order for customer three. The customer returns the food container to any restaurant in the system that provides reusable containers. In this example, customers one, two, and three return their containers to a random restaurant.

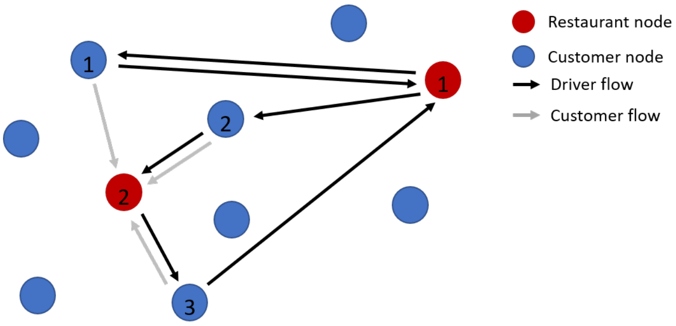


Figure 4.5: Active handling method for reusable food containers

As one can see, in the active case, we cannot control to which restaurant a reusable food container is returned, as the customer randomly selects a restaurant. Therefore, we expect to have variation in the restaurant stocks. Furthermore, we cannot control from which reusable restaurant a food container is taken, as the routes of the drivers are assumed to be given. Thereby, the reusable food container stocks are uncontrollable.

4.2.2. Passive

In a reusable system with passive container handling, the driver has a storage capacity in which containers from the customer can be stored. The driver checks at each delivery if the customer has any containers in stock. If the driver has enough free space in his own storage, he takes the container with him. The driver only drops the container at a reusable restaurant if the order that he picks up at that restaurant is an order in a reusable food container.

In Figure 4.6 we can see that the route of the driver is again given. The customer is not included in the return logistics of the reusable food containers and therefore excluded from the factors that influence the system dynamics. The only control input in the passive system is the driver storage policy,

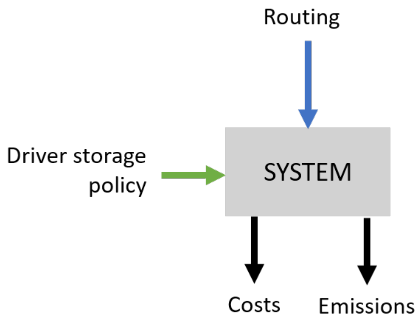


Figure 4.6: System abstraction regarding the passive container handling method

Network Configuration Example

We assume the system is in a steady state, such that each customer has one reusable container in stock. The driver flow can be described as follows: the driver starts at restaurant node one where he receives the order for customer one in a reusable food container. After the delivery of the order at customer node one, the driver receives a used reusable food container from the customer. The driver returns it to restaurant node one where picks up the next order for customer node two, and so on. The routing of the driver remains the same as in the active approach. However, the customer could remain passive since he/she does not have to return the container to any reusable restaurant itself.

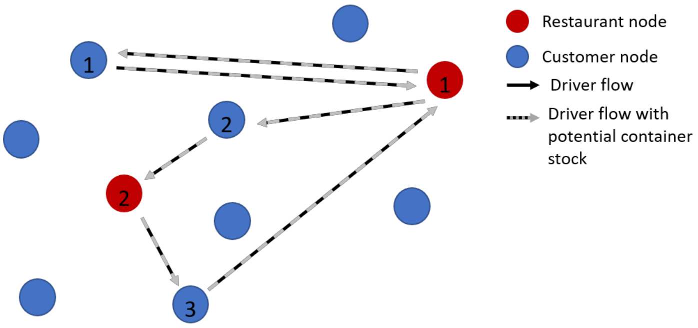


Figure 4.7: Passive handling method for reusable food containers

4.2.3. Hybrid

The hybrid handling method combines the active- and passive handling methods. A customer could return the container to any reusable restaurant in the system or the driver picks up a used container from the customer.

The factors that impact the system dynamics are also a combination of the factors for the active handling method and passive method. Note that in comparison with the passive handling method, the hybrid handling method includes the partly uncontrollable return of the customers.

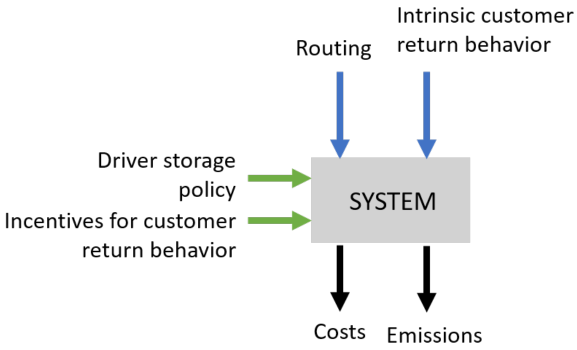


Figure 4.8: System abstraction regarding the hybrid container handling method

Network Configuration Example

In Figure 4.9, we see that both the driver as the customer has the possibility to return reusable food containers to reusable restaurants.

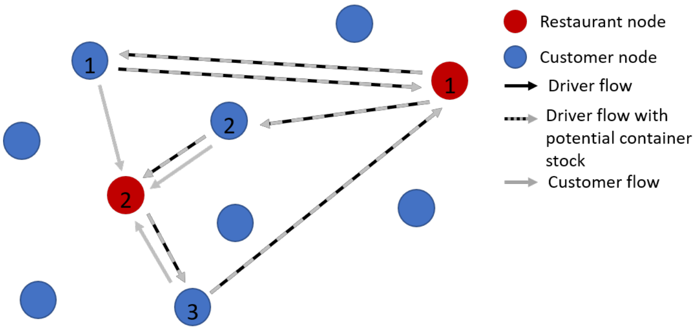


Figure 4.9: Hybrid handling method for reusable food containers

4.3. Parameters

In this section, we derive the parameters used in the simulation model. First, the constant parameters are described in Section 4.3.1. Next, the variable parameters are described in section 4.3.2. Lastly, different combinations of variable parameters, called scenarios, investigated in the numerical simulation study are introduced in Section 4.3.3.

4.3.1. Constant

The constant parameters have the same value for each simulation. They can be described as follows:

- **LIFESPAN:** Lifespan of reusable food containers. The lifespan of the containers differs among companies within the case study from Section 3.1.2. We choose a conservative value of 200 uses as the lifespan of the reusable food containers in this system. In Section 5.3, we analyze the sensitivity of this parameter.
- **n_r and n_c:** Total number of restaurant nodes and customer nodes in the system. Since meal delivery platforms have their main business in cities, we take a customer/restaurant ratio which is similar to large cities. According to CBS (2020), there are 10 restaurants per 1000 inhabitants in urban areas such as Amsterdam. Since an online meal delivery platform has a greater range, and the computation time increases when we increase the number of customers, we assume a total of 500 customer nodes and 10 restaurant nodes.
- **MAX_PACK_CAP:** Maximum food container storage capacity of the driver. We choose a conservative amount of one food container since the bags used for delivery are relatively small.
- **ORDER_FREQ_REST:** Average order frequency per restaurant per day. The average order frequency is based on data from ”Takeaway.com”. According to their annual year report 2020, there were 12,000 restaurants connected to their network. Approximately 49 million orders were placed at these restaurants in one year (Just Eat Takeaway, 2021). We therefore assume twelve orders per day at each restaurant node in our system.
- **MIN_PACK_LEVEL:** Minimal number of reusable containers in stock reusable restaurants. Since we expect on average 12 orders at each restaurant per day and assume that each refill/restock event takes one day, we define this variable as twelve.
- **TRIP_FREQ_DRIVER:** Average number of trips per day per driver. We assume that each driver works six hours a day and is able to execute two deliveries per hour. We define this variable as twelve.
- **CUST_RETURN_PACK_THRES:** Number of days after which there is a chance that the customer returns its reusable food container. We assume three days as the intrinsic customer return behavior. In Section 5.3, we analyze the sensitivity of this parameter.
- **CUST_RETURN_PACK_CHANCE:** Chance that a customer returns its food container after CUST _RETURN_PACK_THRES. We assume that three days after order receiving, there is each day, 5% chance that the customer brings back its container to any reusable restaurant in the system. In Section 5.3, we analyze the sensitivity of this parameter.

4.3.2. Variables

Variable parameters differ for each scenario but hold the same value for that scenario. They are defined as follows:

- **α and β:** Since reusable food container systems are not widely applied in the meal delivery industry, we do not have any information about the percentage of customers and restaurants that reuse (α and β). We therefore differ the percentages of reusable customers and restaurants resulting in scenarios (see Section 4.3.3).
- ***d*:** Number of drivers. The number of drivers differs by the number of restaurants in the system (n_r). Besides that, the order frequency (ORDER_FREQ_REST) and the trip frequency of a driver per day (TRIP_FREQ_DRIVER) has an impact on the required number of drivers. The number of drivers in the system is determined by Equation 4.1.

$$d = \frac{n_r * ORDER\_FREQ\_REST}{TRIP\_FREQ\_DRIVER} \tag{4.1}$$

- $\boldsymbol{p_{init}}$: Initial number of food containers. The number of food containers that is in stock at the beginning of the simulation differs by the number of reusable restaurants (N_r^R) and customers (N_r^C). Besides that, other variables related to container stock such as the number of drivers (d) and minimal required level of food containers in stock (MIN_PACK_LEVEL) play a role. This results in Equation 4.2.

$$p_{init} = \frac{N_r^C + d}{(N_r^R)} + MIN\_PACK\_LEVEL + d + 1 \tag{4.2}$$

4.3.3. Scenarios

To understand the system dynamics of each of the container handling methods, we differ the percentage of reusable customer- and restaurant nodes for each scenario. At the start, we select which nodes in the system will demand or provide reusable food containers. This selection remains constant over the simulation time. The following scenarios are defined:

Table 4.2: Scenario overview

Scenario	Percentage of customers that reuses [%]	Percentage of restaurants that reuses [%]
1	100	100
2.1	100	40
2.2	100	20
3.1	50	100
3.2	25	100
4.1	50	40
4.2	25	20

4.4. Performance Metrics

In this section, we define the environmental- and economical cost factors and their assumptions. First, we look at the different aspects that impact the environmental assessment of food containers and redistribution events in Section 4.4.1. Based on this assessment, we define in Section 4.4.1 the environmental performance measure. Next, we look at the different aspects that impact the economical performance in Section 4.4.3. Based on this assessment, we define in Section 4.4.4 the economical performance measure.

4.4.1. Environmental Assessment

In this section, we define the different environmental factors that impact the environmental cost of a single-use food container and a reusable food container. Besides that, we quantify the environmental impact of food container redistribution. The functional unit considered is defined as the production and disposal of a food container storing a meal for one person. The environmental performance of different processes in the life cycle of a food container are discussed below.

Production

Both the PP single-use container as the PP reusable container are mostly produced in China Suwanmanee et al. (2013). Therefore the Chinese electricity grid mix has been used as the energy source for the production of the containers. Based on primary production data from a major producer of these containers, Gallego-Schmid et al. (2019) found that the extrusion and thermoforming cost in the case of single-use PP containers 170 joules. In the case of reusable food containers, these production stages cost 764 joules.

Transport

The transport of raw materials is also included in the LCA by Gallego-Schmid et al. (2019). After production, the containers are shipped from China to Europe by a transoceanic tanker. Next, the containers are shipped to Munich, the central geographical location of Europe. From this point, the containers are shipped to retailers. Lastly, transport for waste treatment is considered. A distance of 50 kilometers to the landfilling facilities is assumed and 100 kilometers to an incineration/recycling site. All in all, these transport steps take 700 kg*km for single-use PP containers and 3109 kg*km for reusable food containers. The difference lays in the weight differences between the container types. Single-use containers weigh 31.5 grams and reusable containers 132.8 grams (Gallego-Schmid et al., 2019).

Use

The usage of single-use PP containers is considered to not have any impact. Since the packaging is disposed after usage. In the case of reusable food containers, cleaning is considered. To ensure the product quality, we assume that the containers are cleaned in a dishwasher machine. This takes approximately 58 joules.

End-of-life Waste Management

The waste generated can be handled by different methodologies. According to Eurostat (2018), the PP packaging treatment methods are as follows within the EU27: 42% recycling, 40% landfilling, 12% backfilling and 6% incineration. Recycling is defined as the recovery of products by which materials are reprocessed which could be used again (Eurostat, 2014). Landfill is the deposit of waste into or onto land (Eurostat, 2013). This type of waste treatment is most harmful to the environment. EU rules therefore aim to limit the amount of waste sent to landfill. Backfilling contains a recovery operation in which suitable waste is used for reclamation purposes in excavated areas (Eurostat, 2019). Another methodology is to incinerate waste to extract energy. Different scenarios could be introduced to simulate the effect of different waste treatment strategies in the future. Currently, we assume, based on Gallego-Schmid et al. (2019), that 11% of the waste is recycled, 44% incinerated and 45% landfilled.

According to Harnoto (2013); Gallego-Schmid et al. (2018) reusable PP containers can, on average, be reused 43 times before dispose. However, the usage behavior has a strong impact on the containers' life cycle. The same impact can be seen in the beer industry. According to Van Doorsselaer and Lox (1999), the breakage rate of glass bottles has a large impact on the justification of reusable packaging. If the breakage rate remains below 5%, using reusable glass bottles can be environmentally and economically justifiable.

Table 4.3: Life cycle inventory data for single-use and

Life Cycle Stage	Polypropylene single-use container	Polypropylene reusable container
Raw materials [g]		
Polypropylene	32	133
Silicone	-	9
Production [J]		
Extrusion: electricity	58	258
Thermoforming: electricity	113	506
*Transport [kg*km]*	700	3109
Use [J]	-	58
End-of-life waste management [g]		
Recycling: plastics	3	14
Incineration: plastics	14	58
Landfilling: plastics	14	69

The environmental impacts have been calculated by Gallego-Schmid et al. (2019), following the CML 2001 (Althaus et al., 2010). An overview of all input data can be seen in Table 4.3. Since this research mainly focuses on the global warming potential (GWP) of the products, we express the environmental footprint in g CO_2 equivalent. The GWP for single-use and reusable food containers can be seen in Table 4.4. We apply the concept of 'transition point' to define where the system of reusable containers starts to perform better than the single-use containers (Ligthart and Foundation, 2007). It can be seen that the reusable PP containers should be used at least 5 times to balance out the GWP of single-use PP containers. Another factor that should be included in the environmental assessment are the emissions caused by reusable food container cleaning. Based on the study by Gallego-Schmid et al. (2019), we assume that 12 g CO_2 equivalent is emitted due to cleaning. This is defined as the parameter EMISSION_CLEANING.

Table 4.4: Environmental impact of a single-use container and reusable container made of PP.

Impact	Polypropylene single-use container	Polypropylene reusable container
GWP (g CO_2 eq.)	151	673

From the environmental assessment, we conclude that 151 g CO_2 equivalent is caused by the production and disposal of single-use food containers. Which is defined as the environmental factor EMISSION_DISPOSABLE. Furthermore, we conclude that the emissions caused by the production, usage, and disposable of a reusable food container is 673 g CO_2 equivalent. Which is defined as the environmental factor EMISSION_REUSABLE. Since a reusable food container can be used multiple times, we should use the emissions per use, based on its expected lifespan, as measure. The emission for a reusable food container per use is shown in Equation 4.3

$$EMISSION\_REUSABLE\_USE = \frac{EMISSION\_REUSE}{LIFESPAN} + EMISSION\_CLEANING \quad (4.3)$$

We will only take the emissions per use into account, i.e. we only measure the effective usage emissions. Note that, in total their will be more food containers in the system. However, it is not reasonable to count for the emissions of unused goods in advance. Following the line of thought of depreciation of goods, the emissions should only be counted relative to the decrease of value, the number of future usages, of a reusable food container.

Container Redistribution

Container redistribution is performed by a Light Electrical Vehicle (LEV). We assume that the LEV is similar to the LOADSTER (Citkar, 2021). For the quantification of the environmental performance, we also look at the emissions emitted during the lifecycle. According to Hall and Lutsey (2018), the life cycle emission of an electric vehicle in the European Union equals 125 g CO_2 equivalent per kilometer. According to Zhou et al. (2020), the average travel distance to a restaurant in an urban area equals 2.5 kilometers (AVG_DIST_REST). The TRANSPORT_DISTANCE is defined in Equation 4.4.

$$TRANSPORT\_DISTANCE = AVG\_DIST\_REST * (N_r^R + 1) \quad (4.4)$$

The required kWh per restock is defined in Equation 4.5.

$$KWH\_PER\_RESTOCK = TRANSPORT\_DISTANCE * KWH\_PER\_KM \quad (4.5)$$

According to Eurostat (2020), the emissions per kWh in the European Union are equal to 275 g CO_2 equivalent (EMISSION_KWH).

4.4.2. Environmental Performance Measure

Based on the environmental assessment, we include the following emission factors in our system:

- **RELATIV_EMISSION_USE** is defined as emissions caused by the production, usage, and disposal of a reusable food container relative to the emissions of a disposable food container. The emissions caused by a reusable food container are described by Equation 4.3. The relative emissions are derived from Equation 4.6.

$$RELATIV\_EMISSION\_USE = EMISSION\_REUSE - EMISSION\_DISP \quad (4.6)$$

- **TOTAL_EMISSION_RESTOCK** is defined as the total emission caused by transport for the redistribution of reusable containers. Equation 4.7 shows the formula used to derive the redistribution emissions. The emissions for a restock event are equal to the emissions caused by a refill event.

$$TOTAL\_EMISSION\_RESTOCK = KWH\_PER\_RESTOCK * EMISSION\_KWH \quad (4.7)$$

4.4.3. Economical Assessment

The economical assessment focuses on the same aspects as the LCA: packaging and redistribution transport. First, we discuss the container cost. Next, we define which factors play a role in the determination of the redistribution cost.

Container Costs

Based on a comparative commodity research for reusable- and disposable containers, we estimated the cost for each container in euros. For each container category, we took three different offered products and compared the prices with each other. An overview of the cost per container can be seen in Table B.2. Based on this comparative commodity research, we define COST_REUSABLE as €1.92, and COST_DISPOSABLE as €0.05.

Redistribution Costs

The cost for redistribution consists of labor cost and transport cost. We first define the labor cost. According to Picnic (2021), the salary of a driver is equal to €10.69 per hour. We assume that the handling time per restaurant equals 10 minutes (HANDLING_TIME_PER_RESTAURANT). The total handling time can be derived from Equation 4.8.

$$TOTAL\_HANDLING\_TIME = HANDLING\_TIME\_PER\_RESTAURANT * (N_r^R) \tag{4.8}$$

The labor costs are derived from Equation 4.9.

$$LABOR\_COST = LABOR\_PER\_HOUR * TOTAL\_LABOR\_TIME \tag{4.9}$$

According to Citkar (2021), the cost for fuel and vehicle investment per kilometer equals €0.36 per kilometer. The transport distance for redistribution can be derived from Equation 4.4. The total transport cost can be derived from Equation 4.10.

$$TRANSPORT\_COST = TRANSPORT\_DISTANCE * COST\_PER\_KM \tag{4.10}$$

4.4.4. Economical Performance Measure

Based on the environmental assessment in Section 4.4.3, we include the following emission factors in our system:

- **RELATIV_COST_PER_USE** cost of a reusable food container relative to the cost of a disposable food container. The parameter value can be derived from Equation 4.11.

  $$RELATIV\_COST\_PER\_USE = \frac{COST\_REUSABLE}{LIFESPAN} - COST\_DISPOSABLE \tag{4.11}$$

  It is important to notice that we do not add the fixed investment cost per food container to the total cost. We include this investment cost in the RELATIV_COST_PER_USE as the depreciation cost. We assume that the value of the reusable food containers remains the same over time. The online meal delivery platform can always receive their investment costs when selling these reusable food containers. Therefore, it does not impact the system performance.
- **TOTAL_COST_PER_RESTOCK** is defined as the transportation cost for redistribution events (refill or restock). The parameter value can be derived from Equation 4.12.

  $$TOTAL\_COST\_PER\_RESTOCK = LABOR\_COST + TRANSPORT\_COST \tag{4.12}$$

4.5. Simulation

We use a numerical simulation study to investigate the economical- and environmental performance of the container handling methods in Section 4.2. First, we define in Section 4.5.1 the algorithms used to implement the system dynamics, after which we describe the customer sampling methodology in Section 4.5.2.

4.5.1. Algorithms

The simulation model is written in Python, the code can be seen in *GITHUB - reusable_food_container _network*. A detailed explanation can be found in the README file. The algorithms explained in this section are a simplification of the simulation model. We present the algorithms per handling method. The functions used in the algorithms are explained after the description of the algorithms.

Algorithm Passive Handling Method

Algorithm 1: RUN Passive Approach

```
while $t \leq T$ do
    for each Driver in Drivers do
        SAMPLE_RESTAURANT();
        SAMPLE_CUSTOMER($t$);
        if Sampled_Restaurant uses reusable packages and Sampled_Customer uses
          reusable packages then
            DROP_PACKAGES_AT(Driver, Sampled_Restaurant, Stored_Packages_Driver);
            TAKE_PACKAGES_FROM(Driver, Sampled_Restaurant, $1$);
            DROP_PACKAGES_AT(Driver, Sampled_Customer, $1$);
        if Stored_Packages_Customer $> 0$ at $t - 1$ then
            TAKE_PACKAGES_FROM(Driver, Sampled_Customer,
              Stored_Packages_Customer);
        if $t = T$ then
            SAMPLE_RESTAURANT();
            DROP_PACKAGES_AT(Driver, Sampled_Restaurant, Stored_Packages_Driver);
    if CHECK_NEED_FOR_REFILL() then
        REFILL()
```

Algorithm Active Handling Method

Algorithm 2: RUN Active Approach

```
while $t \leq T$ do
    for each Driver in Drivers do
        SAMPLE_RESTAURANT();
        SAMPLE_CUSTOMER($t$);
        if Sampled_Restaurant uses reusable packages and Sampled_Customer uses
          reusable packages then
            TAKE_PACKAGES_FROM(Driver, Sampled_Restaurant, $1$);
            DROP_PACKAGES_AT(Driver, Sampled_Customer, $1$);
    for each Reusing_Cust_Node in Reusing_Cust_Nodes do
        if Stored_Packages_Customer $> 0$ at $t - 1$ and
          RAND_UNI() $>$ CUST_RETURN_CHANCE then
            SAMPLE_RESTAURANT();
            MOVE_PACKAGES_FROM(Reusing_Cust_Nodes, Sampled_Restaurant,
              Stored_Packages_Customer);
    if CHECK_NEED_FOR_REFILL() then
        REFILL()
```

Algorithm Hybrid Handling Method

Algorithm 3: RUN Hybrid Approach

```
while $t \leq T$ do
    for each Driver in Drivers do
        SAMPLE_RESTAURANT();
        SAMPLE_CUSTOMER($t$);
        if Sampled_Restaurant uses reusable packages and Sampled_Customer uses
          reusable packages then
            DROP_PACKAGES_AT(Driver, Sampled_Restaurant, Stored_Packages_Driver);
            TAKE_PACKAGES_FROM(Driver, Sampled_Restaurant, $1$);
            DROP_PACKAGES_AT(Driver, Sampled_Customer, $1$);
        if Stored_Packages_Customer $> 0$ at $t - 1$ then
            TAKE_PACKAGES_FROM(Driver, Sampled_Customer,
              Stored_Packages_Customer);
        if $t = T$ then
            SAMPLE_RESTAURANT();
            DROP_PACKAGES_AT(Driver, Sampled_Restaurant, Stored_Packages_Driver);
    for each Reusing_Cust_Node in Reusing_Cust_Nodes do
        if Stored_Packages_Customer $> 0$ at $t - 1$ and
          RAND_UNI() $>$ CUST_RETURN_CHANCE then
            SAMPLE_RESTAURANT();
            MOVE_PACKAGES_FROM(Reusing_Cust_Nodes, Sampled_Restaurant,
              Stored_Packages_Customer);
    if CHECK_NEED_FOR_REFILL() then
        REFILL()
```

Explanation of the functions:

- SAMPLE_RESTAURANT(): sample one restaurant node from the set of restaurant nodes with equal probability per element, i.e., using a uniform distribution. The sampled restaurant is assigned to the *Sampled_Restaurant* variable. A specific restaurant node can be sampled multiple times per time step, i.e., we sample with replacement.
- SAMPLE_CUSTOMER(*t*): sample one customer from the set of customer nodes using the order frequency distribution based on ”Takeaway.com” data (see Section 4.5.2). The sampled customer is assigned to the *Sampled_Customer* variable. A customer node can only be sampled once per time step, i.e., we sample without replacement. This implies that a customer can only order once per time step.
- DROP_PACKAGES_AT(*Driver, Node, Number of Packages*): The ’Driver’ object drops ’Number of Packages’ amount of reusable food containers from its storage at ’node’.
- TAKE_PACKAGES_FROM(*Driver, Node, 1*): The ’Driver’ object takes one reusable food container (meal order) from ’Node’.
- CHECK_NEED_FOR_REFILL(): check for each reusable restaurant if its stock level of reusable food containers is below MIN_PACK_LEVEL.
- REFILL(): A refill action is performed. All reusable food containers at the restaurant nodes are equally distributed over the reusable restaurant nodes. If the number of reusable food containers at any of the reusable restaurant nodes is still below the MIN_PACK_LEVEL we refill the number of containers at all reusable restaurant nodes to the initial number of reusable food containers in the system p_{init}.
- MOVE_PACK_FROM(*From Node, To Node, Number of Packages*): ’Number of Packages’ amount of reusable food container in storage at ’From Node’ is moved to ’To Node’.

4.5.2. Customer Sampling

We use anonymized, real world data about the order frequencies of customers ordering via 'Takeaway.com' in Amsterdam, to determine the order frequency of customers. To do so, we first derive a density function from the order data (left side of Figure 4.10). From the data we can see that more than a halve of 110,200 customers orders once in 199 days. The most 'loyal customer' orders over 130 times in 199 days.

From the probability density function, we derive a cumulative distribution function (right side of Figure 4.10. On the y-axis, we define the probability of the order frequencies. For each customer node, we sample a random number from a uniform distribution in which the probability of each number is equal. Next, we compare this random number to the cumulative customer share values. This results in an order frequency. This methodology of generating samples from a probability distribution is called inverse transform sampling (Burch, 2012). We determine the probability that a node is served by normalizing the order frequency of each node to the total sampled order frequency.

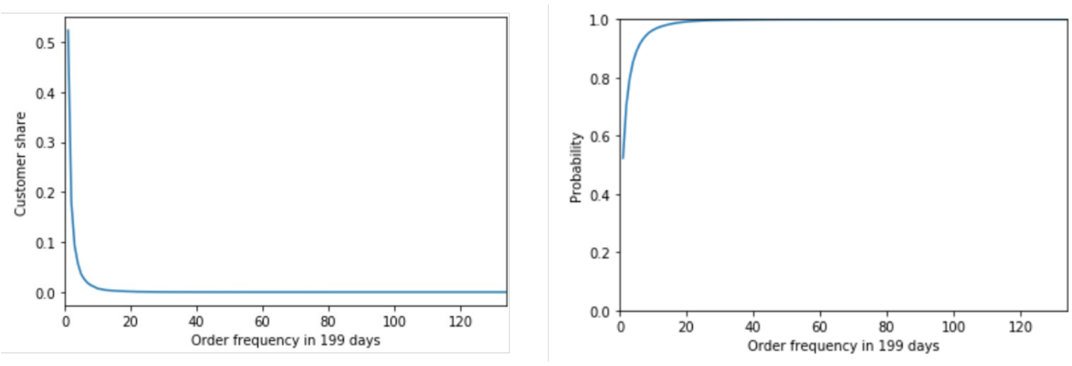


Figure 4.10: Order frequency meals customer 'Takeaway.com'. Left: Probability density function. Right: Cumulative distribution function

5

System Evaluation

In this chapter, we evaluate the different container handling methods using the results from our simulation study, which we defined in Chapter 4. First, we verify and validate the results of our simulation model in Section 5.1 and Section 5.2. Secondly, we analyze the experimental simulation results regarding the economical and environmental performance in Section 5.4. Last, we evaluate the adoption success of the different container handling concepts for each of the stakeholders in Section 5.5.

5.1. Model Verification

In this section, we verify that our simulation model is constructed properly, i.e., that the container handling methods and performance metrics are correctly implemented in our simulation study. We formulate our expectations and verify these with simulation results.

5.1.1. Container Dynamics

Redistribution of Containers

We expect the total number of containers to remain stable over time if no refill event occurs. In case of a refill event, the total number of containers in the system increases in one timestep.

Figure 5.4 shows a time series graph in which refills are executed. The total number of reusable food containers in the time series graph is shown as a horizontal dotted line. Redistribution events are shown by a dotted vertical line. The dotted horizontal line shows an increase of reusable food containers in the system in case of a refill event.

Container Stocks

Figure 5.5 shows a time series in which the customer stock level (blue line), the total restaurant stock level (green line), and the driver stock level (yellow line) can be seen. We expect that a decrease of food container stock at restaurants results in an increase of the customer- or driver stock.

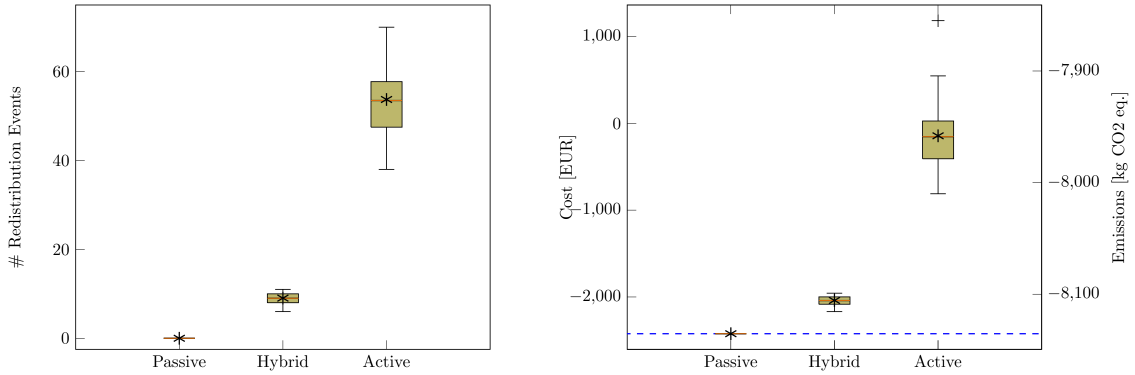
The time series in Figure 5.5 show results that align with our expectations. When the restaurant stock level (green line) decreases, the customer stock level (blue line) and the driver stock level (yellow line) increase.

5.1.2. Performance Measures

Economical Measures

In general, redistribution actions are approximately 1,000 times more expensive than the relative cost of one reusable food container. Since the exact redistribution costs depend on the length of the redistribution trip, the exact costs per restock differ per scenario, as the number of reusing restaurants differs per scenario. The high distribution costs are mainly due to the high labor costs. When the economical impact of a redistribution action is high, we expect container handling methods that require redistribution actions to result in higher total cost than the one with less redistribution actions.

The box plot in Figure 5.1a shows the number of redistribution events, Figure 5.1b shows costs and emissions per container handling method. Since the number of reusable container usages is equal for each of the container handling methods, the blue dotted line shows the cost/emission for these food container usages. The additional cost and emissions shown above the blue line are the result of redistribution events. From these figures, we see that the active handling method requires more redistribution events and is therefore more expensive. Since the total redistribution costs for scenario 1 are equal to €42, and approximately 60 redistribution events are required for the active handling method, we expect an increase in cost of approximately €2500 compared to a situation in which there are no redistribution events. The results align with the difference between the cost savings of the passive container handling method (€2500), and the cost savings of the active container handling method which are equal to zero.



(a) Redistribution events per container handling method

(b) Emission and cost per container handling method

Figure 5.1: Results scenario 1. The blue dotted line shows the cost/emission for these food container usages. The additional cost and emissions shown above the blue line are the result of redistribution events.

5.1.3. Environmental Measure

The usage of each reusable container saves 0.136 kg CO_2 equivalent. Each kilometer driven by the Light Electrical Vehicle emits 0.125 kg CO_2 equivalent. Since the number of uses in each of the container handling methods is the same in scenario 1, we expect redistribution events to cause differences in the emission savings per container handling method. For scenario one, the redistribution emissions equal 3.3 kg CO_2 equivalent. Because there are approximately 60 redistribution events required in the active container handling method. We expect a difference of 200 kg CO_2 equivalent in the emission savings between the passive container handling method and the active container handling method.

The box plot in Figure 5.1b shows the total emission per container handling method. The results align with the difference between the savings in emissions of the passive container handling method (-8140 kg CO_2 equivalent), and the cost savings of the active container handling method (-7945 kg CO_2 equivalent).

5.2. Model Validations

In this section, we validate the observed system behavior by our expectations. First, we evaluate the system dynamics for each of the container handling methods over time in Section 5.2.1. Secondly, we validate the existence of a warm-up period and steady state in Section 5.2.2. In Section 5.2.3 we conclude our validation study.

5.2.1. Behavior Prediction Handling Methods

We validate the results of the simulation model by evaluating the system dynamics over time. We first define our expectation and validate this with the time series graph. We only choose to evaluate scenarios 1 (all customers reuse, all restaurants reuse) and 4 (some customers reuse, some restaurants reuse), which were defined in Section 4.3.3, as both include the extreme behavior in the model. If the time series show the correct behavior for these situations, we expect the simulations to behave properly for the other scenarios. Furthermore, we validate the existence of a warm-up and steady state period of the system behavior.

Stock Level Behavior Scenario 1

We expect the following stock dynamics in scenario 1 for each of the container handling methods:

- **Passive:** In case of the passive container handling method, the stocks of reusable customers and drivers (both of size 1) need to be filled. As soon as all reusable customers have been served, all stock levels remain stable. Since from that moment, each time a driver serves a node, we will guarantee that the driver drops its stored food container, takes a food container from the same restaurant, and drops the food container at a customer where the driver picks up a used reusable food container from the customer. Finally, the system will become completely stable. Since we sample each time step randomly which customer to serve, we expect the system to move exponentially to the steady state. Because the chance of sampling a customer which does not have a food container yet in the start is much larger than when customers already have a food container at home.

- **Hybrid:** In the hybrid method, we have the same dynamics as for the passive method. However, since we allow customers to return their food container to a reusable restaurant (which is randomly sampled), we cannot guarantee the stability that we could guarantee for the passive method. The returning of the food containers by the customers can be seen as a disturbance in our system. Moreover, we cannot control this disturbance since on top of the direct disturbance of the customer, the random returnment of the customer also impacts the action of the driver. In the passive case, we guarantee (after convergence) that if a driver picks a reusable food container from a restaurant, it also drops one. Because we cannot guarantee that a delivery action to a reusable customer (after convergence) always results in the event in which a driver can take the used reusable container from a customer. We cannot guarantee anymore that a driver always drops a food container at a restaurant if he will pick one.

  The only thing we can do is hope that among all reusable restaurants, the stocks level out over time. We cannot control anything as for all uncontrollable systems in reality we will always reach instability. In this case, a stock level lower than the desired stock level is expected. Therefore, we assume the food container stock levels to converge nicely to fixed levels, but keep oscillating and at some point trigger a redistribution event.

  Note that however, we still control one thing: the number of food containers at a customer never becomes larger than one. Since a driver will always take the food container if its available. Therefore, we guarantee that only restock are necessary. In other words, the total stock level at restaurants is enough to restock all restaurants.

- **Active:** For the active method, the system has become completely uncontrollable. The customers return their food containers to a random restaurant at a random time. Both the possible accumulation of food containers at customers as the accumulation of food containers at restaurants, will result in skewed and overall lower stock levels at restaurants, due to the random choice of return location. This triggers much more restocks than for the other two handling methods. On top of that, due to the possible accumulation of food containers at customers, we expect that refills need to occur. Therefore, the total food containers in the system increase.

The validation of each of the container handling methods for scenario 1 can be described as follows:

- **Passive:** The simulation results in Figure 5.2 align with our expectation. After a relative short period of time, the stock levels of customers and restaurants converge to a steady state system. At that time step, all customers have 1 container in stock since the total customer stock equals 500 reusable food containers and the total number of customers equals 500 as well.

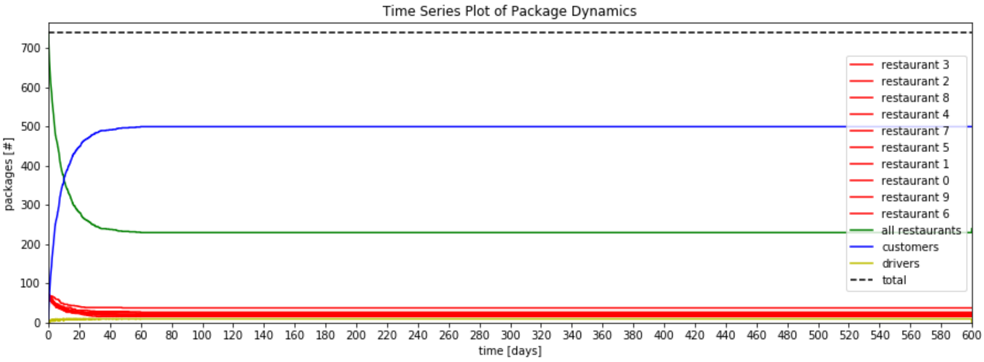


Figure 5.2: Time Series Graph Scenario 1 Passive container handling method

- **Hybrid:** The simulation results in Figure 5.3 align with our expectation. As expected, in contrast to the passive handling method, the hybrid method does require restock events after convergence due to the random food container returnment by customers.

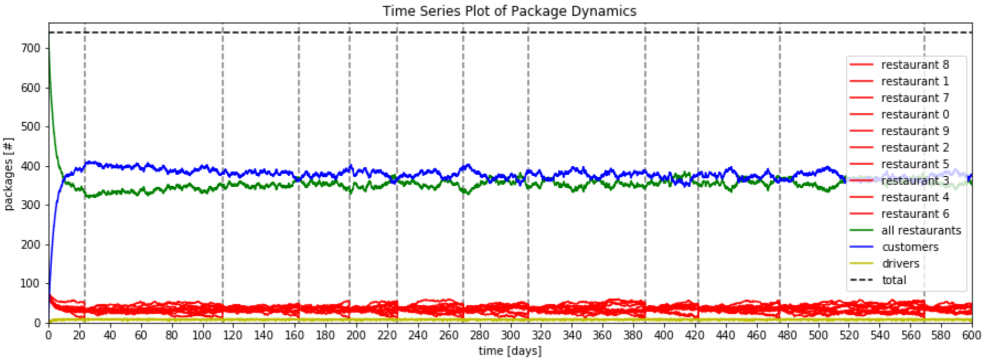


Figure 5.3: Time Series Graph Scenario 1 Hybrid container handling method

- **Active:** The simulation results in Figure 5.4 align with our expectation. The total number of reusable containers in the stock of customers increases significantly in the warm-up phase of approximately 40 days. This is due to the fact that there is a number of days after which there is chance of 5% that the customer returns its food container. Furthermore, the customer returns its reusable food container to a randomly picked reusable restaurant. Therefore, we observe even more restock events for the active approach then for the hybrid approach.

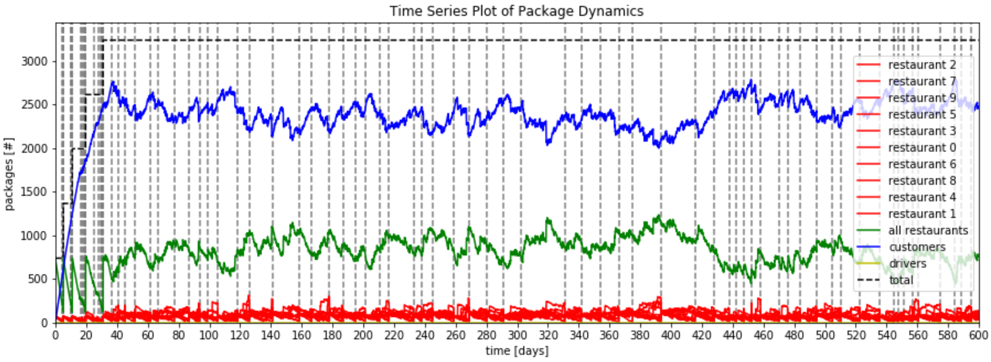


Figure 5.4: Time Series Graph Scenario 1 Active container handling method

Stock Level Behavior Scenario 4.2

In scenario 4.2, 25% of the customers reuses and 20% of the restaurants reuses. We expect the following stock dynamics for each of the container handling methods:

- **Passive:** We expect the same type of behavior as in scenario 1: a straight line after the warm-up phase in which each customer eventually has one container in stock. From that moment, the driver always brings a container to a node and receives one to take with him. The stock level will reach a steady state. The number of orders in the system depends on the average order frequency at restaurants. This is a fixed number for each restaurant. Because there are only two reusable restaurants instead of 10 reusable restaurants as in scenario 1, we expect a longer warm-up phase. Two reusable restaurant nodes result in fewer orders and therefore driver movement in the system. It takes more time steps before each customer has one reusable container at home.
- **Hybrid:** Since there are only two reusable restaurants in the system, the chance of returning a container to a reusable restaurant which is in need of a reusable container is greater than for scenario 1 in which there are more options for return among the ten reusable restaurants. We therefore expect less redistribution events than in scenario one. The possibility of reusable food container returnment by the driver makes sure that enough reusable food containers remain in the stock of the reusable restaurants.
- **Active:** We expect a refill event in the warm-up phase to overcome the fact that their is a chance of container returnment by the customer three days after the order receivement. We expect less variety in the stock levels of the two reusable restaurants than in scenario 1 where there are ten reusable restaurants.

The validation of each of the container handling methods for scenario 4.2 can be described as follows:

- **Passive:** The simulation results in the time series graph in Figure 5.5 align with our expectation. The system behavior reaches a steady state after all customers have one reusable container in stock. The warm-up period is indeed longer than in scenario 1 due to fewer reusable restaurants and therefore fewer orders per timestep.

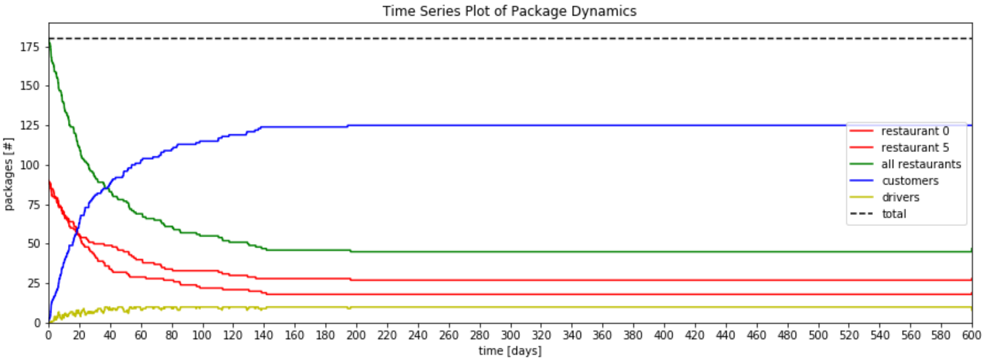


Figure 5.5: Time Series Graph Scenario 4.2 Passive container handling method

- **Hybrid:** The simulation results in Figure 5.6 show the system behavior that we expect. The stock levels of the reusable restaurants differ but not as much as in scenario 1.

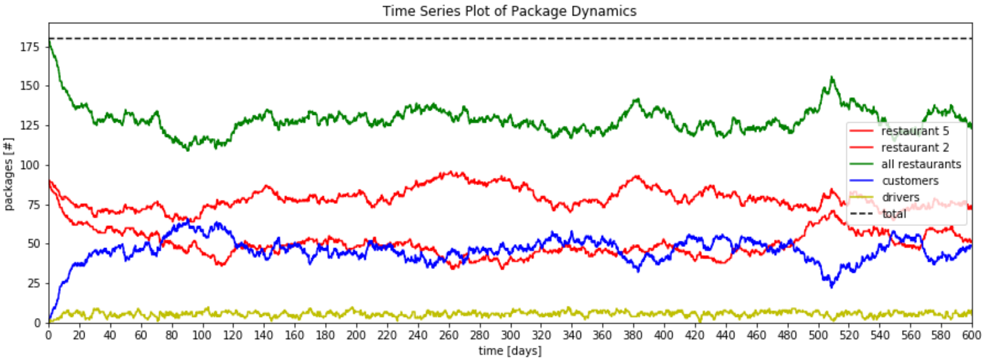


Figure 5.6: Time Series Graph Scenario 4.2 Hybrid container handling method

- **Active:** The simulation results in Figure 5.7 reflects the system behavior as we expected. A refill event occurs in the warm-up phase to overcome the fact that there is a chance of container returnment by the customer three days after the order receivement. After the warm-up period, the system remains relatively stable due to the fact that there is less variation in stock levels when there are only two reusable restaurants in the system.

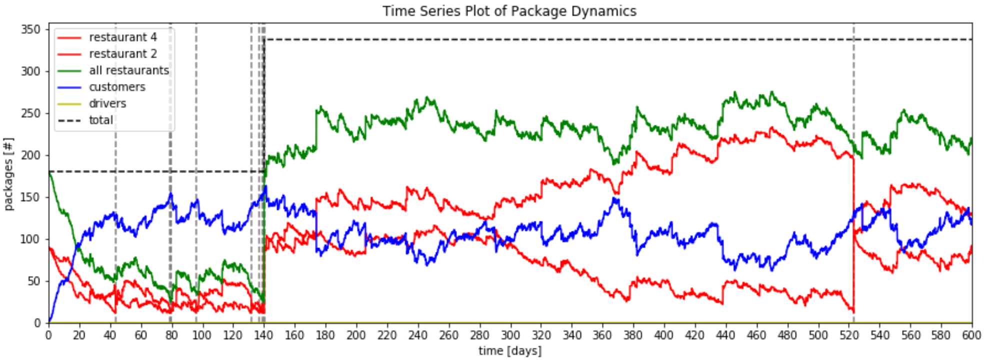


Figure 5.7: Time Series Graph Scenario 4.2 Active container handling method

5.2.2. Behavior Prediction Warm-up Period vs. Steady State

Since the simulation starts with all reusable food containers in stock of reusable restaurant nodes, we expect a warm-up phase in which all reusable customers receive an order. The stock levels of reusable customer nodes increases. The stock levels of reusable restaurant nodes will decrease. When all reusable customer nodes have at least one container in stock, we expect the system to become in a steady state. We expect the behavior of the system to differ between the warm-up period and the steady state. We therefore exclude the warm-up period from the system performance measurements.

To validate our expectation, we use the time series graphs of scenario 1 and scenario 3.1 (50% of the customers reuse, 100% of the restaurants reuse). Because, we expect the warm-up period to only depend on the number of customers.

- **Passive:** The stock levels of customers and restaurants converge to a steady state when all customers have one container in stock. This behavior can be seen in Figure 5.2 and in Figure 5.8 below. We conclude that there is a different system behavior in the warm-up period compared to the steady state.

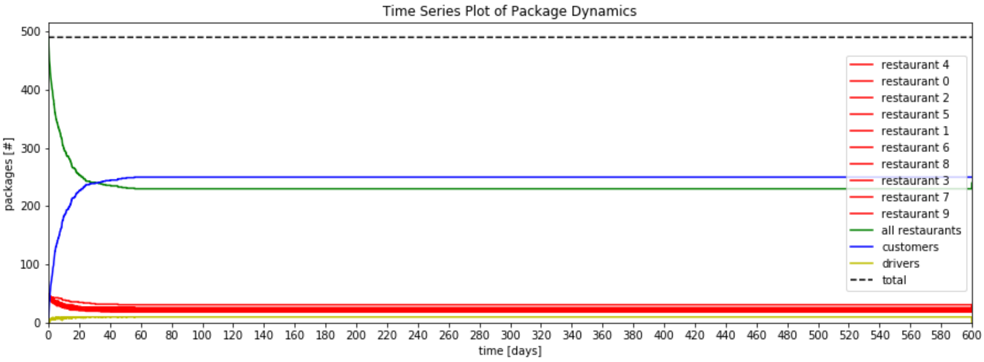


Figure 5.8: Time Series Graph Scenario 3.1 Passive container handling method

- **Hybrid:** We see an increase of containers in stock by customers in the warm-up period. This is mainly due to the fact that it takes three days before there is a chance of reusable container return by reusable customers. Eventually, this results in a steady state. The system behavior can be seen in Figure 5.3 and in Figure 5.9. We conclude that there is a different system behavior in the warm-up period compared to the steady state. Moreover, in contrast to the passive handling method, the steady state dynamics show still oscillations in stock levels.

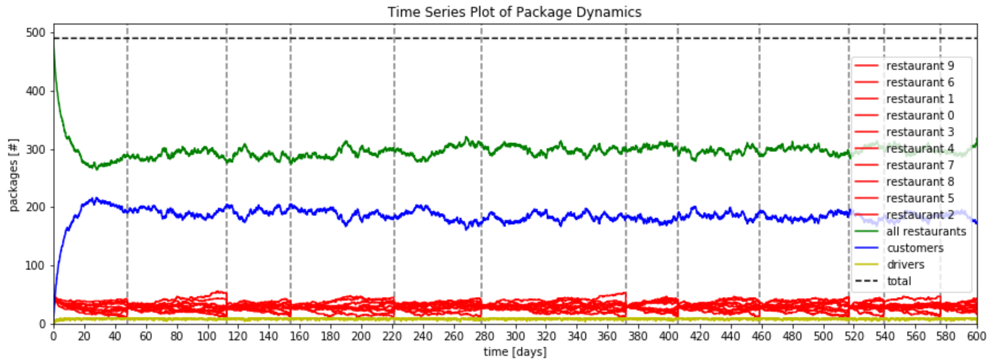


Figure 5.9: Time Series Graph Scenario 3.1 Hybrid container handling method

- **Active:** The active container handling method requires multiple refill events in the warm-up period of the simulation. Since the customers only start to return the food containers after some time, and with some chance, it will take longer to reach the steady state of the system. The fact that driver returnment is excluded contributes to this. The system behavior can be seen in Figure 5.4 and in Figure 5.10. After high peaks in food containers at the customer, we observe a relatively stable behavior of the system. However, this behavior is still much more unstable than for the passive and hybrid methods. Nonetheless, we will speak of a warm-up period and a steady state of the system, as the dynamics clearly differ.

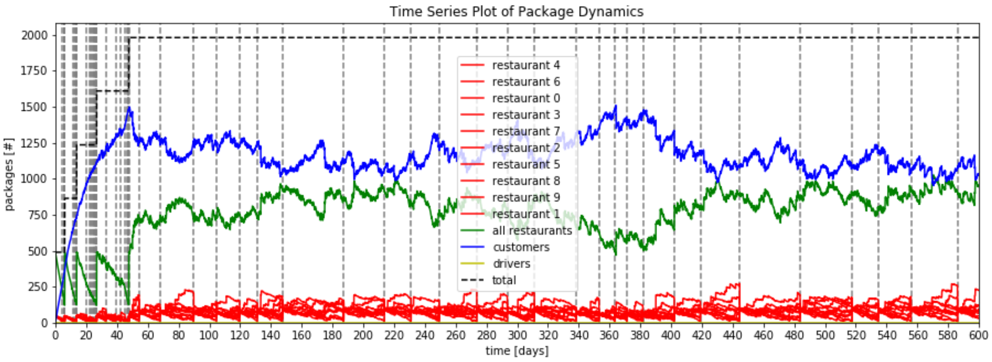


Figure 5.10: Time Series Graph Scenario 3.1 Active container handling method

The validation of the warm-up period for each of the scenarios and handling methods provides us with relevant information on the period for a pilot project. A short pilot period implies that the system will behave as in the warm-up period. As shown in this Section, this system behavior in the warm-up period is not representative for the steady-state performance of the system. We therefore advise to initialize a pilot project for a time span longer than the warm-up period.

5.2.3. Conclusion

All in all, the validation of the dynamics over time and the warm-up period shows that the system behaves as we expect it to be. We therefore conclude that the simulation study is a good representation of the different handling methods for reusable food containers in the meal delivery industry as defined in Section 4.2. Furthermore, the validation of a warm-up period and steady state prove our assumption to evaluate the system performance in the steady-state.

5.3. Sensitivity Analysis

In the sensitivity analysis, we investigate the influence of model parameters on model outcomes in a systematic way. We choose to analyze the sensitivity of the CUSTOMER_RETURN_CHANCE, CUSTOMER_RETURN_THRES and the LIFESPAN.

5.3.1. Customer Return Parameters

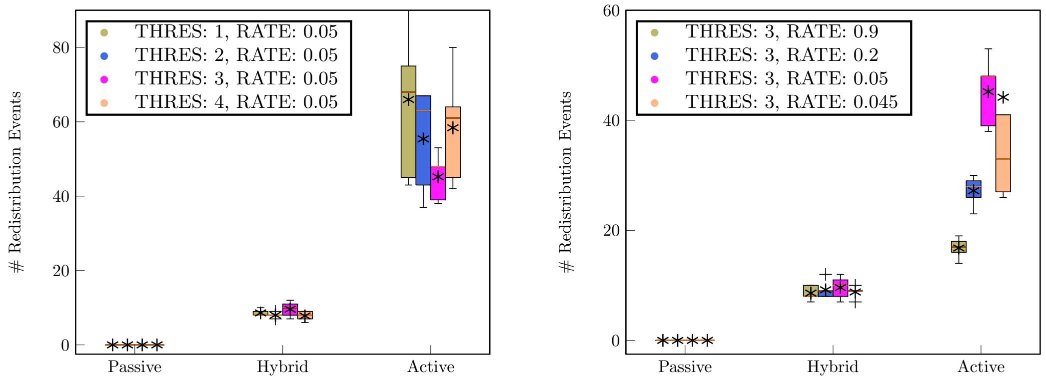
The CUSTOMER_RETURN_CHANCE and CUSTOMER_RETURN_THRES parameters determine the customer return action. The variation of CUSTOMER_RETURN_THRES and/or CUSTOMER_RETURN _CHANCE does not have impact on the number of redistribution events for the passive handling method since customers are not allowed to return containers. For the hybrid container handling method, we expect that decreasing the CUSTOMER_RETURN_THRES, and increasing the CUSTOMER_RETURN _CHANCE results in a less controllable system, since customers return their food containers randomly, drivers cannot control the return action as they did for the passive handling method. The hybrid system becomes similar to a system with an active container handling method. For such a system, we expect the following system behavior:

- The higher the number of days after which there is a chance of a customer return action (CUSTOMER_RETURN_THRES), the higher the number of redistribution events. Because customers keep the reusable food containers for a longer time in stock.
- The higher the chance of a customer return action CUSTOMER_RETURN_CHANCE, the lower the number of redistribution events, because each time step the chance of returnment by a customer is higher, therefore the customer stock decreases and the stock of restaurants increases.

In Figure 5.11a, we can see the effect of variation in CUSTOMER_RETURN_THRES. It seems that this parameter does not have a large effect on the number of redistribution events. The graph shows that CUSTOMER_RETURN_THRES variation results in the same range of redistribution events. Therefore, we cannot conclude any significant effect of variation in CUSTOMER_RETURN_THRES on the number of redistribution events.

In Figure 5.11b, we can see the effect of variation in CUSTOMER_RETURN_CHANCE. The results align with our expectations. The higher the CUSTOMER_RETURN_CHANCE, the lower the number of redistribution events. Nevertheless, we see that the lowest CUSTOMER_RETURN_CHANCE of 4.5% chance of food container returnment per day, results in less redistribution events than for a larger CUSTOMER_RETURN_CHANCE of 5%. We expect that the low CUSTOMER_RETURN_CHANCE results in higher customer stock and therefore low restaurant stock. This probably triggers a refill event in the beginning of the simulation run. Resulting in more food containers in the system. Varying stocks have less impact on the number of redistribution events.

Figure 5.12 shows the sensitivity analysis results of varying both CUSTOMER_RETURN_THRES as CUSTOMER_RETURN_CHANCE. The results look similar to the results in Figure 5.11b in which we vary the CUSTOMER_RETURN_CHANCE. Therefore, we can conclude that the a variation in CUSTOMER_RETURN_CHANCE has the largest impact on the number of redistribution events.



(a) Variation in CUSTOMER_RETURN_THRES

(b) Variation in CUSTOMER_RETURN_CHANCE

Figure 5.11: Results sensitivity analysis customer return parameters

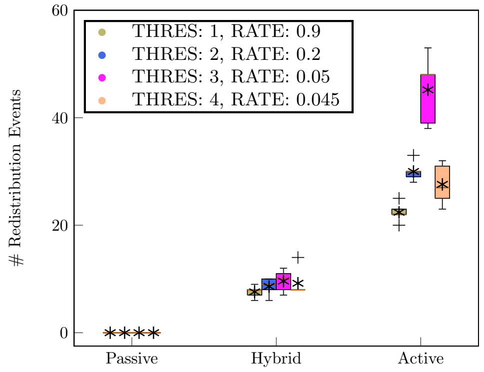
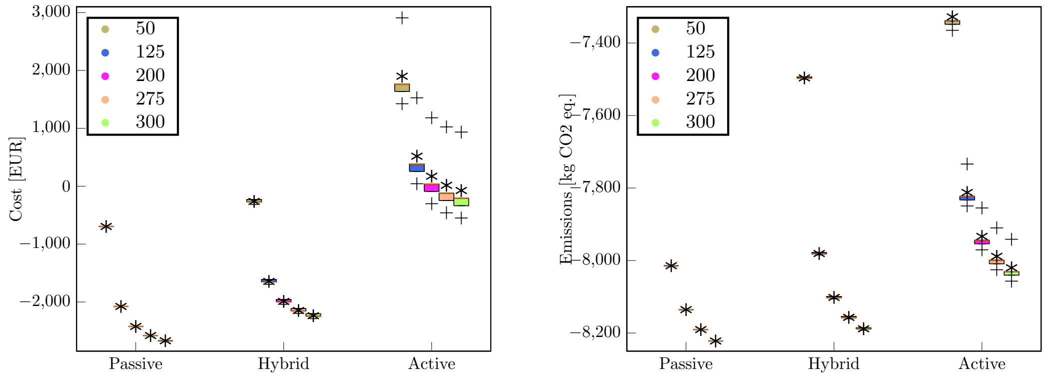


Figure 5.12: Variation in CUSTOMER_RETURN_THRES and CUSTOMER_RETURN_CHANCE

5.3.2. Lifespan Parameter

We expect that an increase of the lifespan decreases the total cost and emission per container handling method since the cost/emission per use decreases.



(a) Variation in lifespan impact on cost

(b) Variation in lifespan impact on emissions

Figure 5.13: Results sensitivity analysis lifespan

Figure 5.13a shows the effect of variation in lifespan on the total cost per container handling method. We can conclude that increasing the lifespan of a food container increases the number of uses per container and therefore decreases the total cost. Figure 5.13b shows the results of variation in lifespan on the total emissions. We can conclude that increasing the lifespan of a food container increases the number of uses per container and therefore decreases the total emissions.

5.4. Experimental results

In this section, we present the experimental results per scenario. We compare the different container handling methods on their environmental and economic performance. For a detail analysis of the results for each scenario see Appendix C. We evaluate the simulation with an equal number of reusable container usages in the steady state of the system. Based on the evaluation of the results in this section, Table 5.1 shows an overview of the experimental results. The green marked numbers show the best results and the red marked numbers show the worst result among the three different container handling methods.

Table 5.1: Overview experimental results

		Passive	Hybrid	Active
Scenario 1	Redistribution events [#]	0	9	53
	Usage costs [€/order]	-0.04	-0.03	0.00
	Emissions [kg CO2 equivalent/order]	-0.1356	-0.1351	-0.1326
	Investment cost [€/order]	0.02	0.02	0.10
Scenario 2.1	Redistribution events [#]	0	1	3
	Usage costs [€/order]	-0.04	-0.04	-0.04
	Emissions [kg CO2 equivalent/order]	-0.1335	-0.1334	-0.1333
	Investment cost [€/order]	0.05	0.05	0.14
Scenario 2.2	Redistribution events [#]	0	0	0
	Usage costs [€/order]	-0.04	-0.04	-0.04
	Emissions [kg CO2 equivalent/order]	-0.1336	-0.1336	-0.1336
	Investment cost [€/order]	0.09	0.09	0.17
Scenario 3.1	Redistribution events [#]	0	8	42
	Usage costs [€/order]	-0.02	-0.01	-0.01
	Emissions [kg CO2 equivalent/order]	-0.0552	-0.0548	-0.0531
	Investment cost [€/order]	0.02	0.02	0.06
Scenario 3.2	Redistribution events [#]	0	6	42
	Usage costs [€/order]	-0.01	0.00	0.02
	Emissions [kg CO2 equivalent/order]	-0.0257	-0.0254	-0.0237
	Investment cost [€/order]	0.01	0.01	0.03
Scenario 4.1	Redistribution events [#]	0	1	13
	Usage costs [€/order]	-0.02	-0.02	-0.01
	Emissions [kg CO2 equivalent/order]	-0.0582	-0.0581	-0.0574
	Investment cost [€/order]	0.03	0.03	0.08
Scenario 4.2	Redistribution events [#]	0	1	13
	Usage costs [€/order]	-0.01	-0.01	-0.01
	Emissions [kg CO2 equivalent/order]	-0.0350	-0.0317	-0.0313
	Investment cost [€/order]	0.03	0.03	0.05

Based on the outcomes of our simulation study, we can draw the following conclusions:

- We see that the active container handling approach results in the highest number of redistribution events, while the passive and hybrid container handling methods require almost no redistribution actions (see Figure 5.1b). This is a result of the uncontrollability of the random return action by customers in the active handling method. The difference in cost between these methods becomes smaller when the number of reusable restaurants in the system is smaller. In such a scenario (see Figure C.6b), the chance that a container is returned to a restaurant that is in need of a reusable container is larger than for more reusable restaurants. The number of redistribution events decreases resulting in lower cost.
- Since the redistribution is executed by a Light Electrical Vehicles, a relative small amount of emissions is emitted. The redistribution events have a smaller impact on the total emissions than on the total cost. The number of reusable orders dominates the total emissions. Since these are equal for each of the container handling methods, we see that the shape of the graph depends on the number of redistribution events. Therefore, the environmental impact of the active container handling method is larger than the hybrid method which is larger than the passive method (see Figures 5.1b).
- We can conclude that the passive container handling method performs best economically and environmentally. In scenario 1, we see that the passive handling method saves 0.04 euro cent per order compared to no savings for the active handling method.
- Higher customer stocks result in more reusable food containers in the system, which increases the investment cost. From Figure 5.14, we see that the active container handling method requires overall the the highest investment cost. In Figure 5.14, we see that scenario 1 requires the most food containers and scenario 4 the least. From this we conclude that the number of reusable restaurants and customers effects the number of reusable orders in the system and therefore the total number of required food containers.

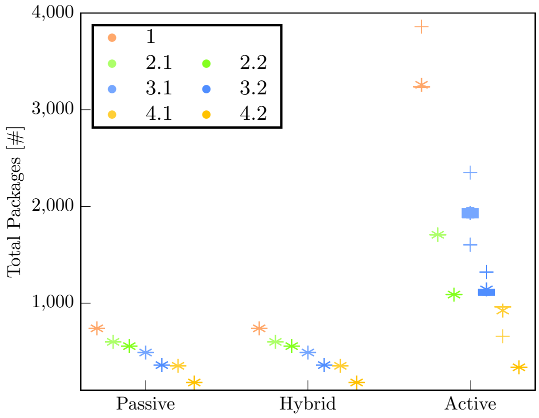


Figure 5.14: Total number of packages per scenario per container handling method

- According to our sensitivity analysis, increasing the lifespan results in lower cost and emissions. Furthermore, the CUSTOMER_RETURN_CHANCE has the largest impact on the customer return action compared to CUSTOMER_RETURN_THRES.

5.5. Discussion

In this section, we discuss the different reusable container handling methods on their adoption potential for its stakeholders. We base our review on the experimental results presented in Section 5.4. Besides that, we take the success factors for adoption into account, which are described in Section 2.2.

The main success factor from the perspective of restaurants and meal delivery platforms is the economic profitability of a reusable container handling method. Based on the results related to the economical performance in Section 5.4, we can conclude that all types of container handling methods result in cost savings. The passive container handling method saves the most costs and emissions. Restaurants and meal delivery platforms acknowledge the positive marketing potential of environmental friendly packaging products. This could be beneficial in the competition for customers in the meal delivery market where there is a high level of competition.

However, without customer adoption of reusable food containers, there will be less demand for the reusable packaging service. Restaurants and meal delivery services will not see the option for reusable packaging as beneficial compared to a disposable packaging system. It is therefore important to take the customer adoption factors into account.

As described in Section 2.2.3, the convenience of a reusable product is of major importance for customer adoption. In the passive handling method, the customer does not have to take the container to a reusable restaurant. He just has to hand over his food container at the next order to the driver. This is a convenient action for the frequent customer. In the meantime, the customer stores the reusable food container at home. This could be less convenient for users that rarely order, since the food container is stored at home for a longer period of time.

In the active container handling method, customers return the containers to any reusable restaurant in the system. Less distance to the collection points at the restaurant means more convenience for the customer to return. Since geographical distances are not included in the simulation model, we cannot see the effect of distance. Furthermore, adding container drop-off locations at shopping- or public transport locations could increase the return convenience since customers visit these places frequently. This increases the customers motivation to return the reusable food container. Customers that order less frequently could prefer the active container handling method. However, handing over a used reusable food container to a driver at the next order is expected to be the most convenient option for the vast majority of customers.

The hybrid container handling method provides a combination of the two return options. The customer can choose which return option is most convenient in his situation. However, the random returnment of containers to any reusable restaurant in the system results in more variance in the restaurant stocks. Resulting in more redistribution events which are more costly. Nevertheless, we expect an increase of customer adoption if there is a choice between two return options. Which could result in more demand for reusable food containers, which will lead to emission- and cost savings.

5.6. Limitations

Some limitations of the study should be considered

- We expect the reusable container return option to the driver to be the most convenient return action for the customer, since the customer does not have to travel to any drop-off location. However, this is just a hypothesis which is not customer preference data.
- Currently, the driver only drops a reusable food container at a reusable restaurant if the next order is also in a reusable food container. Future research could include different control actions. For example, the driver drops its food containers at reusable restaurants with low stock levels.
- The restaurant popularity is equal for all restaurants in the current simulation model. However, one could assume that some restaurants receive more orders than others. The chance for sampling these restaurants should increase.
- In our current simulation model, we sample, independently from the customers' food container preferences, a restaurant from the set of both reusable- as non-reusable restaurants. This is based on the idea that a customer first selects a restaurant based on its meal preferences. Whether the meal is served in a reusable food container or not is a consequence of the type of restaurant that is sampled. In future research, the customers' food container preferences could play a distinctive role in the selection of restaurants from which a meal order is sampled.

6

Concluding Remarks

In this chapter, we describe the conclusions from this research in Section 6.1. Furthermore, the scientific contributions are suggested in Section 6.2. Next, we propose practical recommendations from the study in Section 6.3. We end this chapter with suggestions for future research in Section 6.4.

6.1. Conclusions

According to our literature review in Section 2, no study has yet quantified the actual environmental and economical impact of different reusable container handling methods in the meal delivery industry. Therefore, this study focused on the main research question: *What is the economical- and environmental impact of integrating reusable food containers in the meal delivery industry?* We defined subquestions to structure the research problem and show the relevant aspects of the evaluation study. The following section discusses and answers each of the subquestions.

1. *What are key factors for the adoption of reusable food containers by stakeholders in the meal delivery industry?*

The following key factors increase the adoption of reusable food containers by customers:

- Familiarity with recycling concepts.
- Strong values of collectivism, perceived social desirability, and pressure associated with reuse and recycling.
- Convenient return options.
- Recycling facilities that are easily accessible, i.e., no additional effort is required to return packaging for reuse. For example, less distance to the drop-off locations.

The following key factors are relevant for the adoption of reusable food containers by restaurants:

- Next to cost and logistics complexity, product safety is an important concern. This could impact the quality of the meal service for a restaurant.
- Additional space and hygiene requirements for the storage of reusable food containers.
- Higher risks for maintenance and increased cleaning costs caused by intensive usage of their own dishwashers for food container cleaning.

The following key factors are relevant for the adoption of reusable food containers by online meal delivery platforms:

- Economic viability. The meal delivery platforms strive to be profitable. The financial aspect of the business case for the introduction of reusable food containers is therefore very relevant. For the general public, the 'feel-good factor' of sustainable packaging is not enough. It should also be a financial attractive alternative for disposable food containers.

- Sustainable image. The ”green” image has become an important marketing element since customers increasingly expect companies to reduce their environmental footprint. Implementing sustainable packaging alternatives could therefore also be beneficial for online delivery platforms since they address a target group of sustainable customers. This could result in a stronger position for competition on the market.

2. *What are container handling methods for the integration of reusable food containers in the meal delivery industry?*

Based on case studies of reusable initiatives that are currently on the market, we distinguish three reusable container handling methods: the passive method (the driver performs the return action), the active method (the customer controls the return action), and the hybrid method (both the driver as the customer can control the return action). Remark that the behavior of the drivers is fully controllable by a meal delivery platform in contrast to the behavior of the customers which can only be partly controlled. The optimal control action appears to be: take the used food container from a customer. Only drop a reusable food container at a restaurant if the next order is also in a reusable food container.

3. *What key performance metrics quantify the environmental- and economical impact of the logistic concepts for reusable food containers in the meal delivery industry?*

The environmental performance of different food container handling methods are defined as emissions in kg CO_2 equivalent. These factors are derived from a Life Cycle Assessment. We reported two performance metrics to quantify the environmental impact of container handling methods:

- Saved emissions per reusable food container: is defined as the emissions caused by the production, usage, and disposal of a reusable food container relative to the emissions of a disposable food container.
- Transport emissions: are defined as the total emission caused by transport for the redistribution of reusable containers.

The economical performance of different food container handling methods are defined as cost in euros. These factors are derived from a Life Cycle Costing analysis. We reported two performance metrics to quantify the economical impact of container handling methods:

- Saved cost per reusable food container: cost of a reusable food container relative to the cost of a disposable food container.
- Transport cost: is defined as the transportation cost for redistribution events (refill or restock).

Main Research Question
Based on the answer of these subquestions, we quantified the economical- and environmental performance of these container handling methods using a simulation study. We observe the following system behavior from our simulation study for each of the container handling methods:

- **Passive method.** As long as the total initial restaurant stocks are equal to the number of reusing customers and drivers, the minimum number storage per restaurant, and the food containers are approximately uniformly distributed over the restaurants, the system will always be in control and all stock levels will converge over time. Because from that moment, each time a driver serves a node, we will guarantee that the driver drops its stored food container, takes a food container from the same restaurant, and drops the food container at a customer where the driver picks up an used reusable food container from the customer.
- In the **hybrid method**, we have the same driver dynamics as for the passive method. However, since we also allow customers to return their food container to the reusable restaurant (which is randomly sampled), we cannot guarantee the stability of the total restaurant stock which we could guarantee by the passive method.
- In the **active method**, the system has become largely uncontrollable. The customers return their food containers to a random restaurant at a random time. Hereby, forcing many redistribution events to balance the restaurant stocks.

After validation of the system behavior, we can conclude that that for each of the container handling methods, emission- and cost savings can be realized compared to a system in which only disposable food containers are used. Even for situations in which only a small part of the customers and restaurants use reusable food containers. Moreover, the passive handling method outperforms the hybrid- and active container handling method, both economically and environmentally. We observe that the benefits are positively correlated with the customer and restaurant participation ratio. As all handling methods more or less realize equal environmental gains, the methods mainly differ in the economical performance.

6.2. Scientific Contributions

This study has contributed to our understanding of the environmental- and economical effects of three different reusable container handling methods, particularly in the meal delivery industry. Almost all existing food container studies mainly focus on the environmental quantification of different food container types, such as those by Arunan and Crawford (2021); Gallego-Schmid et al. (2018, 2019). However, these studies only focus on the performance of the packaging product itself. Hellström (2009) suggests the transfer container handling approach on which we base our system. However, the study only identifies the design of the network, it does not evaluate the performance. This study provides the first insight into the economical- and environmental performance of different container handling methods for both disposable as reusable food containers.

We used a life cycle assessment and life cycle costing approach in combination with a simulation study to evaluate the environmental- and economical effects of packaging materials for different container handling methods. The methods used can be replicated for any meal delivery network. To obtain comparable and universal results on the environmental- and economical performance of different container handling methods in the meal delivery industry, it is suggested that, where feasible, studies use one approach across different spatial scales. The results obtained in this study provide further knowledge on the potential emissions and cost of disposable- and reusable food containers within the meal delivery industry. Which can be used to inform online meal delivery platforms about the implementation consequences of reusable food containers. Furthermore, insights on the potential of reusable food containers can be useful for decision makers relating to their policy on banning single-use food containers.

6.3. Recommendations

Since our study is based on a simulation study, we recommend to start a pilot project to evaluate the expected environmental- and economical performance which follow from our study. The following practical recommendations for the pilot study are defined:

- In our evaluation study, we assume a lifespan of 200 uses for reusable food containers. We recommend to track the number of uses for each reusable food container in a pilot project. Hereby, a more reliable estimation can be made for the lifespan of a reusable food container implying the investment cost.
- In our evaluation study, we see that the active handling method requires much more reusable food containers in the system, since customers randomly return their food container after some time, to a random restaurant in the system. We expect the total customer container stock to increase. However, it is relevant to research the return behavior of customers in a pilot since it has a large impact on the number of reusable containers in the system.
- As explained in section 5.2.2, their exist different system behavior in the warm-up period and the steady state of the system for each type of handling method. Therefore, we recommend to plan a pilot project longer than the warm-up phase. The system then performs in a steady state which is more controllable than the warm-up period. We observe that fewer redistribution methods are needed in the steady state of the system for each of the handling methods. Therefore, the expected cost and emissions for transportation will be lower than in the warm-up phase.
- Another recommendation for the design of a pilot project is to start with a small group of reusable customers and a restaurant in which each customer starts with a reusable food container at home. In the case of passive- and hybrid container handling methods, this directly results in a steady state of the system. Resulting in time savings for insights into the expected performance of the system on the long term.

6.4. Future Research

Being the first evaluation study on the economical- and environmental performance of reusable food container integration in the meal delivery industry, there are many areas in which this research can be expanded:

- The current model assumes reusable container cleaning and storage at restaurants connected to the reusable container network. This is defined by Hellström (2009) as the transfer approach. We choose this approach since it results in the most efficient transport of reusable food containers compared to a system where drop-off locations or a central hub for cleaning and storage is chosen (depot approach (Hellström, 2009)). Besides that, we expect the depot approach to result in higher storage costs since one should invest in a central depot cleaning facility. Further research can investigate the differences in the economical- and environmental performance between the transfer approach and the depot approach.
- Furthermore, we expect that putting the cleaning responsibility on the restaurants could result in a lower or less reliable cleaning quality of the reusable food containers. At least, the online meal delivery platform has less control over the cleaning process than when the platform has its own cleaning facility in a central depot. This could increase the quality of the reusable food container service. This important adoption aspect could be a relevant subject to a survey among restaurants in the meal delivery industry.
- Because in our current system the reusable food containers are owned by the online meal delivery platform but used by restaurants and customers, it is relevant to research different tracking technologies for managing food container inventory at different locations. Mahmoudi and Parviziomran (2020) identifies five types of tracking technologies: barcode, passive radio-frequency identification (RFID), active RFID, Wi-Fi, and global positioning system (GPS). Which one is most applicable for reusable food container usage in the meal delivery industry provides insight into relevant practicalities for implementation.

Bibliography

R. Accorsi, A. Cascini, S. Cholette, R. Manzini, and C. Mora. Economic and environmental assessment of reusable plastic containers: A food catering supply chain case study. *International Journal of Production Economics*, 152:88–101, 2014. ISSN 09255273. doi: 10.1016/j.ijpe.2013.12.014.

R. Accorsi, G. Baruffaldi, and R. Manzini. A closed-loop packaging network design model to foster infinitely reusable and recyclable containers in food industry. *Sustainable Production and Consumption*, 24:48–61, 2020. ISSN 23525509. doi: 10.1016/j.spc.2020.06.014. URL `https://doi.org/10.1016/j.spc.2020.06.014`.

N. Agatz, Y. Fan, and D. Stam. The Impact of Green Labels on Time Slot Choice and Operational Sustainability. *Production and Operations Management*, page poms.13368, 2 2021. ISSN 1059-1478. doi: 10.1111/poms.13368. URL `https://onlinelibrary.wiley.com/doi/10.1111/poms.13368`.

I. Ajzen. The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, 50 (2):179–211, 12 1991. ISSN 07495978. doi: 10.1016/0749-5978(91)90020-T.

H.-j. Althaus, M. Margni, and M. Goedkoop. CML 2001, 2010. URL `http://www.gabi-software.com/support/gabi/gabi-5-lcia-documentation/life-cycle-impact-assessment-lcia-methods/cml-2001/http://www.gabi-software.com/support/gabi/gabi-lcia-documentation/cml-2001/`.

Amazon. Fullstar (12 Pack) Food Storage Containers with Lids - Black Plastic Food Containers with Lids - Plastic Containers with Lids - Airtight Leak Proof Easy Snap Lock and BPA-Free Plastic Container Set: Home Improvement, 2021a. URL `https://www.amazon.com/12-Pack-Food-Storage-Containers-Lids/dp/B07C6LRW61/ref=psdc_3744021_t3_B07RVH939S`.

Amazon. Fullstar Food Storage Containers with Lids [10 Pack, 30 Ounce] - Food Containers with Lids Plastic Containers with Lids - Leak Proof Lunch Containers Plastic Storage Containers with Lids: Home Improvement, 2021b. URL `https://www.amazon.com/Food-Storage-Containers-Lids-Ounce/dp/B07RVH939S/ref=psdc_3744021_t3_B07MGFZDRS`.

Amazon. Fullstar (14 Pack) Food Storage Containers with Lids - Plastic Food Containers with Lids - Plastic Containers with Lids BPA-Free - Leftover Food Containers - Airtight Leak Proof Food Container: Kitchen & Dining, 2021c. URL `https://www.amazon.com/Fullstar-Pack-Food-Storage-Containers/dp/B07MGFZDRS/ref=sr_1_3?dchild=1&keywords=reusable+food+containers+670+ml+polypropylene&qid=1619091405&sr=8-3`.

D. Amienyo and A. Azapagic. Life cycle environmental impacts and costs of beer production and consumption in the UK. *International Journal of Life Cycle Assessment*, 21(4):492–509, 2016. ISSN 16147502. doi: 10.1007/s11367-016-1028-6.

I. Arunan and R. H. Crawford. Greenhouse gas emissions associated with food packaging for online food delivery services in Australia. *Resources, Conservation and Recycling*, 168:105299, 5 2021. ISSN 09213449. doi: 10.1016/j.resconrec.2020.105299. URL `https://doi.org/10.1016/j.resconrec.2020.105299https://linkinghub.elsevier.com/retrieve/pii/S0921344920306145`.

M. Barnes, C. Chan-Halbrendt, Q. Zhang, and N. Abejon. Consumer Preference and Willingness to Pay for Non-Plastic Food Containers in Honolulu, USA. *Journal of Environmental Protection*, 02(09): 1264–1273, 2011a. ISSN 2152-2197. doi: 10.4236/jep.2011.29146.

M. Barnes, C. Chan-Halbrendt, Q. Zhang, and N. Abejon. Consumer Preference and Willingness to Pay for Non-Plastic Food Containers in Honolulu, USA. *Journal of Environmental Protection*, 02(09): 1264–1273, 2011b. ISSN 2152-2197. doi: 10.4236/jep.2011.29146.

M. Bortolini, F. G. Galizia, C. Mora, L. Botti, and M. Rosano. Bi-objective design of fresh food supply chain networks with reusable and disposable packaging containers. *Journal of Cleaner Production*, 184:375–388, 5 2018. ISSN 09596526. doi: 10.1016/j.jclepro.2018.02.231. URL https://linkinghub.elsevier.com/retrieve/pii/S0959652618305614.

Z. Boz, V. Korhonen, and C. Koelsch Sand. Consumer Considerations for the Implementation of Sustainable Packaging: A Review. *Sustainability*, 12(6):2192, 3 2020. ISSN 2071-1050. doi: 10.3390/su12062192. URL https://www.mdpi.com/2071-1050/12/6/2192.

C. Bryan. Users Hungry for Food Delivery Amidst the COVID-19, 2021. URL https://vertoanalytics.com/audience-metrics-product-users-hungry-for-food-delivery-amidst-the-covid-19-pandemic/.

K. Buchholz. How has the world's urban population changed? | World Economic Forum, 2020. URL https://www.weforum.org/agenda/2020/11/global-continent-urban-population-urbanisation-percent/.

Bûmerang. Bûmerang. Takeaway food in reusable containers, 2021. URL https://en.youbumerang.com/.

Bûmerang, Ozarka, Tiffin, ReCircle, Loop, SwapBox, EcoBox, Corporate Finance Institute, Deliverzero, Tyme, Shared Packaging, Returnr, GoBox, EcoBox, Sharepack, Tiffin, GoBox, EcoBox, Returnr, P. M. Coelho, B. Corona, R. ten Klooster, E. Worrell, Shared Packaging, Bûmerang, Sharepack, SwapBox, ReCircle, and Deliverzero. Bûmerang. Takeaway food in reusable containers, 5 2021. ISSN 2590289X. URL https://www.deliverzero.com/https://www.recircle.ch/enhttps://www.swap-box.com/http://nlng.nl/sharepack/index.htmlhttps://en.youbumerang.com/https://sharedpackaging.com/https://www.returnr.org/cafe-networkwww.ecobox.luhttps://goboxpdx.com/https:/.

N. Burch. Inverse Transform Sampling. page 2012, 2012. URL https://stephens999.github.io/fiveMinuteStats/inverse_transform_sampling.html.

A. Cascini, C. Mora, A. Pareschi, and E. Ferrari. Multi-objective optimisation modelling for Green Supply Chain Management. In *Proceedings of the Summer School Francesco Turco*, volume 2014-Janua, pages 19–24, 2014.

CBS. Hoogste horecadichtheid in Zeeland in januari 2020, 2020. URL https://www.cbs.nl/nl-nl/nieuws/2020/15/hoogste-horecadichtheid-in-zeeland-in-januari-2020.

Citkar. The Loadster: The e-bike as a commercial vehicle | citkar, 2021. URL https://citkar.com/en/.

ClearanceSolutions. The Difference Between Recycling & Reusing | Clearance Solutions, 2015. URL https://www.clearancesolutionsltd.co.uk/reuse-and-recycling/the-three-rs-the-difference-between-recycling-reusing/https://www.clearancesolutionsltd.co.uk/reuse-and-recycling/the-three-rs-the-difference-between-recycling-reusing/%0Ahttps://www.clearanceso.

P. M. Coelho, B. Corona, R. ten Klooster, and E. Worrell. Sustainability of reusable packaging–Current situation and trends, 5 2020. ISSN 2590289X.

Corporate Finance Institute. Economies of Scale - Definition, Types, Effects of Economies of Scale, 2018. URL https://corporatefinanceinstitute.com/resources/knowledge/economics/economies-of-scale/https://xplaind.com/580682/economies-of-scale%0Ahttps://corporatefinanceinstitute.com/resources/knowledge/economics/economies-of-scale/.

P. Dauvergne. Why is the global governance of plastic failing the oceans? *Global Environmental Change*, 51:22–31, 2018. ISSN 09593780. doi: 10.1016/j.gloenvcha.2018.05.002.

Deliverzero. DeliverZero, 2021. URL https://www.deliverzero.com/.

J. Devenyns. Why reusable food packaging has a promising future | Food Dive, 2019. URL https://www.fooddive.com/news/why-reusable-food-packaging-has-a-promising-future/557119/.

EcoBox. MÉI LAANG GENÉISSEN De lëtzebuerger Pfand-System fir d'Mathuele vun Iessen. Technical report, 2021a. URL www.ecobox.lu.

EcoBox. About us - Ecobox, 2021b. URL https://ecobox.lu/en/about-us/.

EU Commission. Single-use plastics: New EU rules to reduce marine litter. *Ip/18/3927*, (May):1–3, 2018. URL https://ec.europa.eu/commission/presscorner/detail/en/MEMO_18_3909http://europa.eu/rapid/press-release_IP-18-3927_en.htm.

European Commision. Life Cycle Assessment - IPP - Environment - European Commission, 2015. URL https://ec.europa.eu/environment/ipp/lca.htmhttp://ec.europa.eu/environment/ipp/lca.htm.

European Parliament. Parliament seals ban on throwaway plastics by 2021 | News | European Parliament. *European Parliament*, pages 2019–2022, 2019. URL https://www.europarl.europa.eu/news/en/press-room/20190321IPR32111/parliament-seals-ban-on-throwaway-plastics-by-2021.

Eurostat. Glossary:Landfill, 2013. URL https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Landfillhttps://ec.europa.eu/eurostat/statistics-explained/index.php?title=Natural_gas_price_statistics/elhttp://ec.europa.eu/eurostat/statistics-explained/index.php/Causes_of_d.

Eurostat. Glossary:Recycling of waste - Statistics Explained, 2014. URL https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Recyclinghttps://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Recycling_of_waste.

Eurostat. Circular economy flow diagrams, 2018. URL https://ec.europa.eu/eurostat/cache/sankey/circular_economy/sankey.html?geos=EU27&year=2018&unit=G_T&materials=TOTAL&highlight=0&nodeDisagg=0101100100&flowDisagg=false&translateX=246.7708199743842&translateY=76.72525004997655&scale=0.5000000000000002&lang.

Eurostat. Glossary:Backfilling - Statistics Explained, 2019. URL https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Backfilling.

Eurostat. Electricity price statistics - Statistics Explained. *European Commission*, (November):1–12, 2020. URL https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statisticshttps://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics.

M. Fleischmann, P. Beullens, J. M. Bloemhof-Ruwaard, and L. N. Van Wassenhove. The impact of product recovery on logistics network design. *Production and Operations Management*, 10(2):156–173, 2001. ISSN 10591478. doi: 10.1111/j.1937-5956.2001.tb00076.x.

Frauenhofer Institut. Ecological Comparison of One-way and Returnable Packaging Systems. 1993.

FSIN. FSIN-dossier over het effect van corona op onze consumptie, 2020. URL https://fsin.nl/publicaties/778/fsin-dossier-over-het-effect-van-corona-op-onze-consumptie.

L. Gaines. To recycle, or not to recycle, that is the question: Insights from life-cycle analysis. *MRS Bulletin*, 37(4):333–338, 4 2012. ISSN 08837694. doi: 10.1557/mrs.2012.40. URL www.mrs.org/bulletin/mrs.2012.40https://www.cambridge.org/core/terms.https://doi.org/10.1557/mrs.2012.40Downloadedfromhttps://www.cambridge.org/core.

A. Gallego-Schmid, J. M. F. Mendoza, and A. Azapagic. Improving the environmental sustainability of reusable food containers in Europe. *Science of the Total Environment*, 628-629:979–989, 2018. ISSN 18791026. doi: 10.1016/j.scitotenv.2018.02.128.

A. Gallego-Schmid, J. M. F. Mendoza, and A. Azapagic. Environmental impacts of takeaway food containers. *Journal of Cleaner Production*, 211:417–427, 2019. ISSN 09596526. doi: 10.1016/j.jclepro.2018.11.220.

K. Garcia. Five Charts: The State of Food Delivery, 2018. URL https://www.emarketer.com/content/five-charts-the-state-of-food-delivery.

K. Gilsenan. Takeaway Food Delivery Apps and Services: What Brands Should Know, 2018. URL https://blog.globalwebindex.com/trends/takeaway-food-delivery/.

GoBox. GO Box – Zero Waste Takeout with GO Box Reusable Containers & Cups, 2021. URL https://goboxpdx.com/.

P. L. González-Torre, B. Adenso-Díaz, and H. Artiba. Environmental and reverse logistics policies in European bottling and packaging firms. *International Journal of Production Economics*, 88(1):95–104, 3 2004. ISSN 09255273. doi: 10.1016/S0925-5273(03)00181-6.

H. Green. The future of food. *Nutrition Bulletin*, 41(3):192–196, 9 2016. ISSN 1471-9827. doi: 10.1111/nbu.12213. URL https://www.ubs.com/global/en/wealth-management/chief-investment-office/sustainable-investing/2019/food-revolution.htmlhttps://onlinelibrary.wiley.com/doi/10.1111/nbu.12213.

H. G. Grimes-Casey, T. P. Seager, T. L. Theis, and S. E. Powers. A game theory framework for cooperative management of refillable and disposable bottle lifecycles. *Journal of Cleaner Production*, 15 (17):1618–1627, 11 2007. ISSN 09596526. doi: 10.1016/j.jclepro.2006.08.007.

J. N. Hahladakis and E. Iacovidou. Closing the loop on plastic packaging materials: What is quality and how does it affect their circularity? *Science of the Total Environment*, 630:1394–1400, 2018. ISSN 18791026. doi: 10.1016/j.scitotenv.2018.02.330.

D. Hall and N. Lutsey. Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions, 2018. URL https://theicct.org/publications/EV-battery-manufacturing-emissions.

J. Harmsen. Gemeentelijke woonlasten stijgen, vooral de afvalstoffenheffing gaat flink omhoog | Trouw, 2021. URL https://www.trouw.nl/nieuws/gemeentelijke-woonlasten-stijgen-vooral-de-afvalstoffenheffing-gaat-flink-omhoog~bdb9f0c5/.

M. F. Harnoto. A Comparative Life Cycle Assessment of Compostable and Reusable Takeout Clamshells at the University of California, Berkeley. *University of California, Berkeley (USA)*, pages 1–24, 2013. URL https://nature.berkeley.edu/classes/es196/projects/2013final/HarnotoM_2013.pdf.

D. Hellström. The cost and process of implementing RFID technology to manage and control returnable transport items. *International Journal of Logistics Research and Applications*, 12(1):1–21, 2 2009. ISSN 1469848X. doi: 10.1080/13675560802168526. URL https://www.tandfonline.com/doi/full/10.1080/13675560802168526.

Hisham A. Maddah. Polypropylene as a Promising Plastic: A Review. *American Journal of Polymer Science*, 6(1):1–11, 2016. doi: 10.5923/j.ajps.20160601.01. URL http://journal.sapub.org/ajpshttp://article.sapub.org/10.5923.j.ajps.20160601.01.html.

J. Hornik, J. Cherian, M. Madansky, and C. Narayana. Determinants of recycling behavior: A synthesis of research results. *The Journal of Socio-Economics*, 24(1):105–127, 3 1995. ISSN 10535357. doi: 10.1016/1053-5357(95)90032-2. URL https://linkinghub.elsevier.com/retrieve/pii/1053535795900322.

D. Hunkeler, K. Lichtenvort, and G. Rebitzer. Environmental life cycle costing. *Environmental Life Cycle Costing*, (2005):i–iv, 2008. doi: 10.1201/9781420054736.

I. Ivanova. See how much business U.S. restaurants are losing because of the coronavirus - CBS News, 2020. URL https://www.cbsnews.com/news/coronavirus-restaurant-business-decline-cities/.

P. Jacobsen. The profitability drivers in packaging materials reuse for manufacturers in business to business environments. *Technical University of Denmark*, 2015.

R. K. Jain, J. E. Taylor, and P. J. Culligan. Investigating the impact eco-feedback information representation has on building occupant energy consumption behavior and savings. *Energy and Buildings*, 64:408–414, 9 2013. ISSN 03787788. doi: 10.1016/j.enbuild.2013.05.011. URL https://linkinghub.elsevier.com/retrieve/pii/S0378778813002879.

J. Jetten and K. N. De. Quality and safety aspects of reusable plastic food packaging materials: influence of reuse on intrinsic properties. *Food additives and contaminants*, 19(1):76–88, 1 2002. ISSN 0265-203X. doi: 10.1080/02652030110071309. URL http://www.tandfonline.com/doi/abs/10.1080/02652030110071309http://www.ncbi.nlm.nih.gov/pubmed/11811768.

J. Jetten, N. De Kruijf, and L. Castle. Quality and safety aspects of reusable plastic food packaging materials: A European study to underpin future legislation. *Food Additives and Contaminants*, 16(1):25–36, 1999. ISSN 0265203X. doi: 10.1080/026520399284299.

X. Jia, J. J. Klemeš, P. S. Varbanov, and S. R. Wan Alwi. Energy-emission-waste nexus of food deliveries in China. *Chemical Engineering Transactions*, 70:661–666, 2018. ISSN 22839216. doi: 10.3303/CET1870111. URL www.aidic.it/cet.

Just Eat Takeaway. Annual Report 2020. Technical Report 1, 2021.

L. Kroon and G. Vrijens. Returnable containers: an example of reverse logistics. *International Journal of Physical Distribution & Logistics Management*, 25(2):56–68, 1995. ISSN 0960-0035. doi: 10.1108/09600039510083934. URL https://www.emerald.com/insight/content/doi/10.1108/09600039510083934/full/html.

D. W. Krumwiede and C. Sheu. A model for reverse logistics entry by third-party providers. *Omega*, 30(5):325–333, 2002. ISSN 03050483. doi: 10.1016/S0305-0483(02)00049-X.

C. Li, M. Mirosa, and P. Bremer. Review of online food delivery platforms and their impacts on sustainability, 2020. ISSN 20711050.

K. D. Liere and R. E. Dunlap. The social bases of environmental concern: A review of hypotheses, explanations and empirical evidence. *Public Opinion Quarterly*, 44(2):181–197, 6 1980. ISSN 0033362X. doi: 10.1086/268583.

T. N. Ligthart and B. D. Foundation. Single use Cups or Reusable (coffee) Drinking Systems: An Environmental Comparison. *Netherlands Organisation for Applied Scientific Research*, page 121, 2007. URL www.tno.nl.

Loop. Loop US - The Idea, 2020. URL https://loopstore.com/the-idea.

M. Lützbauer. Systems for Returnable Transport Packaging. 1993.

P. D. Luyben and J. S. Bailey. Newspaper Recycling: The Effects of Rewards and Proximity of Containers. *Environment and Behavior*, 11(4):539–557, 12 1979. ISSN 1552390X. doi: 10.1177/001391657911400 6. URL http://journals.sagepub.com/doi/10.1177/0013916579114006.

M. Mahmoudi and I. Parviziomran. Reusable packaging in supply chains: A review of environmental and economic impacts, logistics system designs, and operations management, 2020. ISSN 09255273. URL https://linkinghub.elsevier.com/retrieve/pii/S0925527320301201.

K. Marsh and B. Bugusu. Food Packaging?Roles, Materials, and Environmental Issues. *Journal of Food Science*, 72(3):R39–R55, 4 2007. ISSN 0022-1147. doi: 10.1111/j.1750-3841.2007.00301.x. URL http://doi.wiley.com/10.1111/j.1750-3841.2007.00301.xhttp://www.ncbi.nlm.nih.gov/pubmed/17995809.

T. M. Mata and C. A. V. Costa. LCA: Comparison Between Recycle and Reuse of Glass Beer Bottles. In *Tools and Methods for Pollution Prevention*, pages 85–96. Springer Netherlands, Dordrecht, 1999. doi: 10.1007/978-94-011-4445-2{_}7. URL https://link.springer.com/chapter/10.1007/978-94-011-4445-2_7http://link.springer.com/10.1007/978-94-011-4445-2_7.

D. McKerrow. What makes reusable packaging systems work. *Logistics Information Management*, 9 (4):39–42, 1996. ISSN 0957-6053. doi: 10.1108/09576059610123169.

H. Meyer. Many Happy Returns, 1999. ISSN 02756668.

K. Molina-Besch, F. Wikström, and H. Williams. The environmental impact of packaging in food supply chains—does life cycle assessment of food provide the full picture? *The International Journal of Life Cycle Assessment*, 24(1):37–50, 1 2019. ISSN 0948-3349. doi: 10.1007/s11367-018-1500-6. URL https://doi.org/10.1007/s11367-018-1500-6http://link.springer.com/10.1007/s11367-018-1500-6.

D. Mollenkopf, D. Closs, D. Twede, S. Lee, and G. Burgess. Assessing the viability of reusable packaging: a relative cost approach. *Journal of Business Logistics*, 26(1):169–197, 3 2005. ISSN 07353766. doi: 10.1002/j.2158-1592.2005.tb00198.x. URL http://doi.wiley.com/10.1002/j.2158-1592.2005.tb00198.x.

C. Morales–Caselles, J. Viejo, E. Marti, D. Gonzalez, H. Pragnell– Raasch, J. Gonzalez–Gordillo, E. Montero, G. M. Arroyo, G. Hanke, V. Salvo, B. O.C., N. Mallos, L. Lebreton, F. Echevarria, T. vam Emmerik, C. Duarte, J. Galvey, E. van Sebille, F. Galgani, C. M. Garcia, P. S. Ross, A. Bartual, C. Ioakeimidis, G. Markalain, A. Isobe, and A. Coyar. Global Classification of Ocean Litter Reveals an Inshore–Offshore Sorting System. *(under review)*, 4(6):484–493, 6 2021. doi: 10.1038/s41893-021-00720-8. URL www.nature.com/natsustain484.

U. Nations, D. of Economic, S. Affairs, and P. Division. *World Urbanization Prospects: The 2018 Revision*. 2019. doi: 10.18356/b9e995fe-en.

P. Neo. Safety vs sustainability: Single-use food packaging use rises due to COVID-19 - but is it truly safer?, 2020. URL https://archive.is/416ZLhttps://www.foodnavigator-asia.com/Article/2020/04/07/Safety-vs-sustainability-Single-use-food-packaging-use-rises-due-to-COVID-19-but-is-it-truly-saf

Nespresso. Sustainability and coffee origins | Our choices | Nespresso, 2021. URL https://www.nespresso.com/nl/en/our-choices/sustainable-quality/aluminium.

Ozarka. Milieuvriendelijke maaltijd verpakkingen | Ozarka.nl, 2021. URL https://ozarka.nl/.

P. Passafaro, S. Livi, and A. Kosic. Local norms and the theory of planned behavior: Understanding the effects of spatial proximity on recycling intentions and self-reported behavior. *Frontiers in Psychology*, 10(MAR), 2019. ISSN 16641078. doi: 10.3389/fpsyg.2019.00744.

Picnic. Vacatures: koerier bij Picnic worden? Solliciteer nu en verdien meer!, 2021. URL https://picnic.app/jobs/nl/koerier/.

Plastic Packaging Facts. Resins and Types of Packaging, 2019. URL https://www.plasticpackagingfacts.org/plastic-packaging/resins-types-of-packaging/.

M. E. Porter and C. Van Der Linde. Towards a New Conception of the Environment-Competitiveness Relationship. *The Jounal of Economic Perspectives*, 9(4):97–118, 1995.

M. E. Porter and C. Van Der Linde. Green and competitive: ending the stalemate. *Long Range Planning*, 28(6):128–129, 12 2017. ISSN 00246301. doi: 10.1016/0024-6301(95)99997-E. URL https://linkinghub.elsevier.com/retrieve/pii/002463019599997E.

ReCircle. reCIRCLE - We choose to reuse! | Recircle, 2019. URL https://www.recircle.ch/en.

Returnr. Cafe Network — Returnr, 2021. URL https://www.returnr.org/cafe-network.

M. Roca i Puigvert, S. Ayuso, A. Bala, and P. Fullana-i Palmer. What factors determine attitudes towards the implementation of a packaging deposit and refund system? A qualitative study of the perception of Spanish consumers. *Journal of Environmental Management*, 270:110891, 9 2020. ISSN 10958630. doi: 10.1016/j.jenvman.2020.110891.

D. S. Rogers, B. Melamed, and R. S. Lembke. Modeling and analysis of reverse logistics, 2012. ISSN 07353766. URL http://doi.wiley.com/10.1111/j.0000-0000.2012.01043.x.

J. D. M. Saphores, H. Nixon, O. A. Ogunseitan, and A. A. Shapiro. Household willingness to recycle electronic waste: An application to California. *Environment and Behavior*, 38(2):183–208, 2006. ISSN 00139165. doi: 10.1177/0013916505279045. URL https://escholarship.org/uc/item/0466s7dt.

J. D. M. Saphores, O. A. Ogunseitan, and A. A. Shapiro. Willingness to engage in a pro-environmental behavior: An analysis of e-waste recycling based on a national survey of U.S. households. *Resources, Conservation and Recycling*, 60:49–63, 3 2012. ISSN 09213449. doi: 10.1016/j.resconrec.2011.12.003.

R. C. Savaskan, S. Bhattacharya, and L. N. Van Wassenhove. Closed-Loop Supply Chain Models with Product Remanufacturing. *Management Science*, 50(2):239–252, 2004. ISSN 00251909. doi: 10.1287/mnsc.1030.0186.

E. Schumaker. This is why vaccine lottery prizes may work for some, according to psychology experts - ABC News, 2021. URL https://abcnews.go.com/Health/vaccine-lottery-prizes-work-psychology-experts/story?id=77891540.

Senna Plastic. China Disposable Lunch Box Take Away Plastic Container Fruit Vegetable Salad Deli Sushi Plastic PP Food Container - China Food Container and Plastic Container price, 2021a. URL https://sennaplastic.en.made-in-china.com/product/WwafqmgjsnUL/China-Disposable-Lunch-Box-Take-Away-Plastic-Container-Fruit-Vegetable-Salad-Deli-Sushi-Plastic-
html.

Senna Plastic. China BPA Free Disposable Plastic Biodegradable Clear Black Round Rectangle Meal Prep Airtight Takeaway Lunch Box Soup Bowl Compartments Freezer PP Food Container - China Eco-Friendly and Food Container price, 2021b. URL https://sennaplastic.en.made-in-china.com/product/fFuatosKXAkV/China-BPA-Free-Disposable-Plastic-Biodegradable-Clear-Black-Round-Rectangle-Meal-Prep-Airtight-Ta
html.

Shared Packaging. Home - Shared Packaging, 2020. URL https://sharedpackaging.com/.

J. Shen and T. Saijo. Reexamining the relations between socio-demographic characteristics and individual environmental concern: Evidence from Shanghai data. *Journal of Environmental Psychology*, 28(1):42–50, 3 2008. ISSN 02724944. doi: 10.1016/j.jenvp.2007.10.003. URL https://link.springer.com/chapter/10.1007/978-3-642-11762-6_5http://link.springer.com/10.1007/978-3-642-11762-6_5https://linkinghub.elsevier.com/retrieve/pii/S0272494407000783.

F. Silvenius, K. Grönman, J.-M. Katajajuuri, R. Soukka, H.-K. Koivupuro, and Y. Virtanen. The Role of Household Food Waste in Comparing Environmental Impacts of Packaging Alternatives. *Packaging Technology and Science*, 27(4):277–292, 4 2014. ISSN 08943214. doi: 10.1002/pts.2032. URL http://doi.wiley.com/10.1002/pts.2032.

S. P. Singh, V. Chonhenchob, and J. Singh. Life cycle inventory and analysis of re-usable plastic containers and display-ready corrugated containers used for packaging fresh fruits and vegetables. *Packaging Technology and Science*, 19(5):279–293, 9 2006. ISSN 08943214. doi: 10.1002/pts.731.

G. Song, H. Zhang, H. Duan, and M. Xu. Packaging waste from food delivery in China's mega cities, 3 2018. ISSN 18790658.

M. F. Sorkun. How do social norms influence recycling behavior in a collectivistic society? A case study from Turkey. *Waste Management*, 80:359–370, 10 2018. ISSN 18792456. doi: 10.1016/j.wasman.2018.09.026.

SPC. The SPC's Goals Database, 2020. URL https://sustainablepackaging.org/goals/?memberhttps://sustainablepackaging.org/goals.

S. K. Srivastava. Green supply-chain management: A state-of-the-art literature review, 2007. ISSN 14608545.

Statista. Online Food Delivery - The Netherlands | Statista Market Forecast, 2020a. URL https://www.statista.com/outlook/374/144/online-food-delivery/netherlands?currency=eur.

Statista. Online Food Delivery - Worldwide | Statista Market Forecast, 2020b. URL https://www.statista.com/outlook/374/100/online-food-delivery/worldwide?currency=eur.

N. D. Steenis, E. van Herpen, I. A. van der Lans, T. N. Ligthart, and H. C. van Trijp. Consumer response to packaging design: The role of packaging materials and graphics in sustainability perceptions and product evaluations. *Journal of Cleaner Production*, 162:286–298, 9 2017. ISSN 09596526. doi: 10.1016/j.jclepro.2017.06.036. URL https://linkinghub.elsevier.com/retrieve/pii/S0959652617312052.

P. C. Stern, T. Dietz, and J. S. Black. Support for environmental protection: The role of moral norms. *Population and Environment*, 8(3-4):204–222, 9 1985. ISSN 15737810. doi: 10.1007/BF01263074.

M. Struk. Distance and incentives matter: The separation of recyclable municipal waste. *Resources, Conservation and Recycling*, 122:155–162, 2017. ISSN 18790658. doi: 10.1016/j.resconrec.2017.01.023. URL http://dx.doi.org/10.1016/j.resconrec.2017.01.023.

U. Suwanmanee, V. Varabuntoonvit, P. Chaiwutthinan, M. Tajan, T. Mungcharoen, and T. Leejarkpai. Life cycle assessment of single use thermoform boxes made from polystyrene (PS), polylactic acid, (PLA), and PLA/starch: Cradle to consumer gate. *International Journal of Life Cycle Assessment*, 18(2):401–417, 2013. ISSN 16147502. doi: 10.1007/s11367-012-0479-7.

SwapBox. Sustainable and Reusable Food Packaging | SwapBox | Netherlands, 2021. URL https://www.swap-box.com/.

F. Thevenon, C. Carroll, and J. Sousa. *Plastic debris in the ocean: the characterization of marine plastics and their environmental impacts, situation analysis report*. International Union for Conservation of Nature, 1 2015. ISBN 9782831716961. doi: 10.2305/IUCN.CH.2014.03.en. URL www.iucn.orghttps://portals.iucn.org/library/node/44966.

Tiffin. Tiffin, 2021. URL https://tiffin.be/tiffin/.

M. L. Tseng, M. S. Islam, N. Karia, F. A. Fauzi, and S. Afrin. A literature review on green supply chain management: Trends and future challenges, 2019. ISSN 18790658.

C. A. Tsiliyannis. Parametric analysis of environmental performance of reused/recycled packaging. *Environmental Science and Technology*, 39(24):9770–9777, 12 2005. ISSN 0013936X. doi: 10.1021/es050970s. URL https://pubs.acs.org/doi/abs/10.1021/es050970s.

D. Twede. Can you justify returnables? *Transportation & Distribution*, 40(4):85–88, 4 1999. URL https://search.proquest.com/docview/233560816?accountid=26642%0Ahttp://link.periodicos.capes.gov.br/sfxlcl41?url_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&genre=article&sid=ProQ:ProQ%3Amaterialscienceengineering&atitle=Can+you+justify+retur.

D. Twede and R. Clarke. Supply chain issues in reusable packaging. *Journal of Marketing Channels*, 12(1):7–26, 10 2005. ISSN 1046669X. doi: 10.1300/J049v12n01{_}02. URL https://www.tandfonline.com/action/journalInformation?journalCode=wjmc20.

Tyme. The Easiest Way to Eat Well, 2020. URL https://tymefood.com/.

C. Valor. Can Consumers Buy Responsibly? Analysis and Solutions for Market Failures. *Journal of Consumer Policy*, 31(3):315–326, 9 2008. ISSN 0168-7034. doi: 10.1007/s10603-008-9070-9. URL https://link.springer.com/article/10.1007/s10603-008-9070-9http://link.springer.com/10.1007/s10603-008-9070-9.

M. van Birgelen, J. Semeijn, and M. Keicher. Packaging and Proenvironmental Consumption Behavior. *Environment and Behavior*, 41(1):125–146, 1 2009. ISSN 0013-9165. doi: 10.1177/0013916507311140. URL http://journals.sagepub.com/doi/10.1177/0013916507311140.

K. Van Doorsselaer and F. Lox. Estimation of the energy needs in life cycle analysis of one-way and returnable glass packaging. *Packaging Technology and Science*, 12(5):235–239, 1999. ISSN 08943214. doi: 10.1002/(SICI)1099-1522(199909/10)12:5<235::AID-PTS474>3.0.CO;2-W.

F. Wang, X. Lai, and N. Shi. A multi-objective optimization for green supply chain network design. *Decision Support Systems*, 51(2):262–269, 2011. ISSN 01679236. doi: 10.1016/j.dss.2010.11.020.

D. C. Wilson, P. Modak, R. Soos, and A. C. Rogero. Background, definitions, concepts and indicators. In *Global Waste Management Outlook*, pages 19–50. 2016. doi: 10.18356/dd48a958-en. URL https://www.unep.org/resources/report/global-waste-management-outlookhttps://www.unenvironment.org/resources/report/global-waste-management-outlook.

R. Yazdanifard and I. E. Mercy. The impact of Green Marketing on Customer satisfaction and Envi- ronmental safety. *International Conference on Computer Communication and Management*, 5(January 2011):637–641, 2011.

Y. Yi, Z. Wang, R. Wennersten, and Q. Sun. Life Cycle Assessment of Delivery Packages in China. *Energy Procedia*, 105:3711–3719, 2017. ISSN 18766102. doi: 10.1016/j.egypro.2017.03.860. URL https://linkinghub.elsevier.com/retrieve/pii/S1876610217309451.

S. Zhang, M. Zhang, X. Yu, and H. Ren. What keeps Chinese from recycling: Accessibility of recycling facilities and the behavior. *Resources, Conservation and Recycling*, 109:176–186, 2016. ISSN 18790658. doi: 10.1016/j.resconrec.2016.02.008. URL http://dx.doi.org/10.1016/j.resconrec.2016.02.008.

Y. Zhou, Y. Shan, D. Guan, X. Liang, Y. Cai, J. Liu, W. Xie, J. Xue, Z. Ma, and Z. Yang. Sharing tableware reduces waste generation, emissions and water consumption in China's takeaway packaging waste dilemma. *Nature Food*, 1(9):552–561, 2020. ISSN 2662-1355. doi: 10.1038/s43016-020-00145-0. URL http://dx.doi.org/10.1038/s43016-020-00145-0.

A. Zion, J. Spangler, and H. Thomas. Food Delivery Apps: Usage and Demographics — Winners, Losers and Laggards, 2020. URL https://www.zionandzion.com/research/food-delivery-apps-usage-and-demographics-winners-losers-and-laggards/.

Zjpypaper. China 500ml 650ml 750ml 1000ml Black Microwaven Round Disposable Bento Takeaway PP Plastic Food Container with Lid - China Plastic Food Container and Disposable Food Container price, 2021. URL https://zjpypaper.en.made-in-china.com/product/YvRnWDPxaZVH/China-500ml-650ml-750ml-1000ml-Black-Microwaven-Round-Disposable-Bento-Takeaway-PP-Plastic-Food-
html.

A

Scientific Paper

https://repository.tudelft.nl/ 00 (2021) 1–10
www.elsevier.es/RIAI

Reducing packaging waste in the meal delivery industry: A quantitative evaluation study on handling methods for the reuse of food containers

Céline van Hooff[a,*]

[a] *Technical University of Delft, The Netherlands*

Abstract

Online meal delivery platforms are growing worldwide. Nevertheless, the takeaway business model is currently the major source of plastic packaging waste generation. The alarming growth of plastic pollution leads to action among governments worldwide resulting in single-use plastic bans. A handful of start-ups offer reusable food container services. However, no online meal delivery platform has adopted such as service. The market size of these initiatives is therefore still small. There is no proof of concept on a larger scale. For this purpose, this study identifies, defines, and evaluates reusable food container handling methods in the meal delivery industry. We conduct a simulation study to measure the environmental- and economical performance of different container handling methods. Our experimental findings suggest that: (i) food container returnment by drivers results in the largest amount of cost- and emission savings, (ii) customer returnment to any random reusable restaurant results in a less controllable system, resulting in more redistribution events, higher costs, and more emissions, (iii) the hybrid container handling method gives two options for return which enlarges the convenience for return by a wide variety of customers. We thus conclude that the passive handling method results in the largest cost- and emission savings, however, the practical implications i.a. concept convenience remains an important topic for further research.

Keywords: Evaluation study, meal delivery industry, reusable food containers, economical performance, and environmental impact

---

1. Introduction

COVID-19 accelerated the shift from restaurant dinners to ordering food online (Li et al., 2020). Data from the reservation system 'OpenTable' shows that due to lockdowns, sit-down traffic at restaurants decreased by 83% globally (Ivanova, 2020). Consequently, the number of users and revenue of online meal delivery services grew with 10% worldwide over the last year (Statista, 2020). According to Statista (2020), this growth is continuing worldwide with an annual factor of 6.4%. Nevertheless, the meal delivery industry significantly contributes to environmental pollution that occurs from food packaging, production, and waste generation (Song et al., 2018; Yi et al., 2017; Li et al., 2020; Jia et al., 2018). Yearly 8 million tons of plastic end up in the oceans (Thevenon et al., 2015; EU Commission, 2018). The takeaway industry is the largest contributor to this waste generation (MoralesâCaselles et al., 2021). Unfortunately, only 14% of the plastic packaging is collected for recycling and just 5% of it is successfully recycled into new plastic (Dauvergne, 2018; Hahladakis and Iacovidou, 2018).

The alarming growth of plastic pollution leads to actions among organizations worldwide. Packaging management is necessary within almost all industrial sectors (Bortolini et al., 2018). In 2019, the European Parliament approved a new law banning the top ten single use plastic items found on EU beaches (European Parliament, 2019). The ban will apply to plastic cotton buds, cutlery, plates, straws, drink stirrers, and balloon sticks (EU Commission, 2018). For food containers and drink cups, reduction measures should be introduced by member states. They can do so by ensuring that plastic products cannot be provided free of charge, setting national reduction targets, or making alternative products available at the point of sale. One of the reduction measures already introduced is the increase of taxes on the incineration of waste (Harmsen, 2021). Hereby, governments discourage single-use products and thereby stimulate the recycling or reuse of products.

Consequently, the need occurs for online meal delivery platforms to consider alternatives for meal packaging. These alternatives should be beneficial, both economically as environmentally.

---

[*] Author and correspondence.

According to this background, the reminder of this paper is organized as follows. Section 2 revises literature on reusable systems, key success factors for reuse, and methodologies that are able to measure the environmental- and economical performance of packaging systems. In addition, system boundaries and the functional unit for environmental- and economical evaluation are identified. Section 3 considers the definition of reusable container handling methods. Based on this information, a simulation model is defined in Section 4. Section 5 covers the evaluation and discussion of the simulation results. Given these outcomes, conclusions, recommendations, and future research suggestions are formulated in Section 6.

2. Literature

2.1. Success Factors of Reuse

Jacobsen (2015) proposes in his study four main drivers of profitability in packaging material reuse for companies. First of all, the number of avoided costs of purchasing new packaging materials for single-use packaging. Secondly, the firm's ability to reduce the cost of reverse transportation which is required for reuse. Additionally, the internal cost of handling, sorting, and cleaning packaging materials is relevant. Lastly, the firm's cost of disposing non-reusable materials. However, to be successful in all these aspects, a sufficient logistics system design and management is important. Meyer (1999); Rogers et al. (2012) underline the complexity of reverse logistic processes. Many companies are unable to handle the complex networking necessary to have an efficient reverse logistics process (Krumwiede and Sheu, 2002). It is therefore important to gather knowledge on the performance of different logistics systems for reuse.

Additional to the cost-related aspects, the "green" image has become an important marketing element since customers increasingly expect companies to reduce their environmental footprint (Fleischmann et al., 2001). Besides that, research by Barnes et al. (2011a) shows additional willingness to pay for more sustainable packaging among consumers. However, Mahmoudi and Parviziomran (2020) highlight that reuse strategies also have been criticized by decision makers if there are not designed well since this could result in more required vehicles, added packaging weight, reverse logistics cost, and extra energy to clean the packaging.

Beer bottles have been successfully reused for several decades, due to high turnover rates, relative short transporting distances, and well-designed packaging systems (Mata and Costa, 1999). The key of this reuse success lays in the standardization of the beer bottle design which fosters the handling of the products (Gaines, 2012). Furthermore, due to standardization more actors within the network will use the same product resulting in higher product quantities, which is beneficial due to the economy of scale. This effect is enhanced by a growing sales market of the product. Resulting in advantages that arise due to the inverse relationship between per unit fixed costs and the processed quantity (Corporate Finance Institute, 2018). However, in the past decades, we have observed a trend away from standardized beer bottles since the design became part of the marketing strategy of beer companies. For the same reason, soft drinks and (spring) water distribution has shifted massively to disposable packaging products.

2.2. Reusable Packaging Systems

A variety of possible design concepts for reusable container systems are proposed in literature (Kroon and Vrijens, 1995; Lützbauer, 1993; Savaskan et al., 2004). The basis of the concepts come from a study by Lützbauer (1993) in which three types of reusable packaging systems are proposed: switch pool systems (each participant (restaurant, driver, customer) has its own share of food containers, for which the participant is responsible), systems with return logistics (facilitating company is owns food containers and is responsible for the return logistics), and systems without return logistics (restaurants rent food container from a facilitating company, restaurants are responsible for the return logistics).

Especially, the differences in the transfer or depot principle suggested by Hellström (2009) can have a large impact on the practical implication of the reusable system. In a transfer system, restaurants are responsible for cleaning and storing food containers. This results in less transport distance in comparison with the depot principle, in which food containers are stored and cleaned in a central depot by the facilitating company. Nevertheless, the cleaning quality can more easily be guaranteed in a central depot than in a variety of restaurants. Furthermore, Mahmoudi and Parviziomran (2020) suggest to include a quality check in these systems. It is more reliable to check the container quality in a central location. The scope of the system, the willingness to invest (both from the restaurant side as the customer side), the storage space available, the size of the restaurant's organization, and the acceptance in the market, influence the decision on the type of system (Kroon and Vrijens, 1995; Hellström, 2009).

Currently, restaurants depend heavily on online food ordering platforms, such as Thuisbezorgd.nl, UberEats, and Deliveroo. The power of these networks has a major impact on the meal delivery industry. Most restaurants are small companies for which an investment in reusable packaging has an impact on their financial situation. Normally, individual restaurants do not take advantage of the scale since their quantities are relatively low compared to the whole market. Collaborating with a facilitating company that rents out reusable food containers is favorable. A driver network of online food platforms in combination with reusable packaging systems could have an impactful and profitable potential. However, evaluation studies on these logistic systems are lacking in literature so far.

2.3. Key Factors for the Adoption of Reusable Food Containers

The online meal delivery platform, restaurants, and customers are the most impactful stakeholders in the system. They have a high level of power and interest in the development of reusable food containers. We therefore investigate relevant factors for the adoption of a reusable container from the perspective of each of these stakeholders.

For meal platforms, the key main barrier identified in the literature is the increased logistic complexity, requiring the reorganization of supply chains to ensure that food containers are available. Besides that, the return rates and turn-around time to prepare the food container for a new cycle affect the system (Coelho et al., 2020). Furthermore, the upfront investments in reusable food containers are noted as a barrier (Coelho et al., 2020).

From a restaurant perspective, the operations management of reusable containers is one of the main concerns of companies who are willing to adopt reusable containers for their own business (Mahmoudi and Parviziomran, 2020). Next to cost and logistics complexity, product safety is an important concern for both meal delivery services as restaurants (Coelho et al., 2020). Jetten et al. (1999) conclude that reuse of plastic food packaging does not significantly influence the food quality and safety. In further research, Jetten and De (2002) found that the characteristics of the plastic did not change significantly after repeated washing. However, for strongly flavored meals, the flavor may likely be carried over to the food packaging. Using professional dishwasher machines helps to solve this problem. Furthermore, the more intensive usage of dishwashers at restaurants for food container cleaning may result in higher risks for maintenance and increased cleaning costs. Meal delivery platforms could take that risk from the restaurants' hands by facilitating the storage, cleaning, and transport of reusable food containers.

Research by Grimes-Casey et al. (2007) showed that a reusable packaging system will depend on the willingness to return by customers. It is therefore important to investigate how the customer market of the meal delivery industry looks like, which factors play an important role in customer decisions for the usage of reusable packaging, and what motivates them to reuse (Grimes-Casey et al., 2007).

According to Garcia (2018); Zion et al. (2020); Bryan (2021); Green (2016), meal delivery adoption is very much related to age. However, looking at the general findings on sociodemographic, the results appear to be inconsistent (Saphores et al., 2012). Variables such as, gender, age, income and education, are statistically significant however their explanatory power tends to be small (Hornik et al., 1995). Therefore, we cannot assign any characteristics about the willingness of reuse to specific customer groups. Roca i Puigvert et al. (2020) concludes that the behavior, attitudes, and intentions towards reuse and recycling depend highly on the perceived convenience and efficacy of the new system as well as the values and subjective norms with which they are associated.

Furthermore, convenience affects the acceptance of reusable packaging systems by consumers (Coelho et al., 2020). When you give a customer the choice between the most convenient option and the most sustainable options, the convenient option wins (Devenyns, 2019). Return opportunities (e.g., in-store, pick-up) play an important role in customer convenience (Saphores et al., 2006). Furthermore, consumers are more likely to choose for a more environmentally friendly purchase if consumers believe that their environmental purchase would make a positive impact on the environment (Valor, 2008). Jain et al. (2013) concludes in their study that tallying environmental units (e.g., the number of "trees needed to offset emissions" of customer consumed energy) to be more effective in cutting energy use than other information strategies, both short- and long-term. As such, green marketing is not just an environmental protection tool but also a successful marketing strategy (Yazdanifard and Mercy, 2011). Research by Agatz et al. (2021) on time slot choice for food delivery shows that green labels outperform price incentives leading to greater cost savings. Furthermore, providing correct information about the footprint of the packaging to the consumer is essential since research shows that most consumers have misconceptions on sustainability in general. This aligns with the results in Steenis et al. (2017) that show consumer opinions on sustainable packaging do not always align with the actual sustainability of a package determined in the Life Cycle Assessment (LCA).

According to Agatz et al. (2021), three-quarters of the participants claimed willingness to pay up for environmental friendly products. This aligns with the results in Barnes et al. (2011b); van Birgelen et al. (2009), which demonstrates an increase in the consumer's willingness to pay for more environmentally friendly food containers. However, Coelho et al. (2020) suggests that for the general public, the 'feel-good factor' of sustainable packaging is not enough. Hence, a financial incentive may be important to change consumers to switch to reusable packaging systems. Financial incentive programs such as cash for recyclables, lotteries, and prizes on recycling behavior could have a positive impact on the amount of recycled waste (Struk, 2017). However, the encountered effect of economic incentives does not persist for a long period. The effect disappears when the financial incentives are removed (Luyben and Bailey, 1979). Furthermore, according to Roca i Puigvert et al. (2020) the economic deposit system generally induces a negative reaction. Consumers perceive it as a coercive rather than motivating system.

2.4. *Research Gap*

A driver network of online food platforms in combination with reusable packaging systems could have an impactful and profitable potential. However, evaluation studies on these logistic systems are lacking in the literature so far. If reusable systems are not designed well, it could require more vehicles, added packaging weight, reverse logistics cost, and extra energy to clean the packaging. Therefore, it is important to gain knowledge on the design and performance of multiple container handling methods. However, the economical and environmental trade-off between disposable- and reusable food containers in the meal delivery industry has not been studied before in literature.

Therefore, the following research question for our evaluation study is defined: What is the economical- and environmental impact of integrating reusable food containers in the meal delivery industry?

2.4.1. *Scope*

In this paper, we focus on the Life Cycle Analysis (LCA) of reusable- and disposable food containers. Therefore, we distinguish two different life cycles (see Figure 1). The following system barriers are taken into account for the LCA and Life Cycle Costing (LCC): (i) we include activities associated with

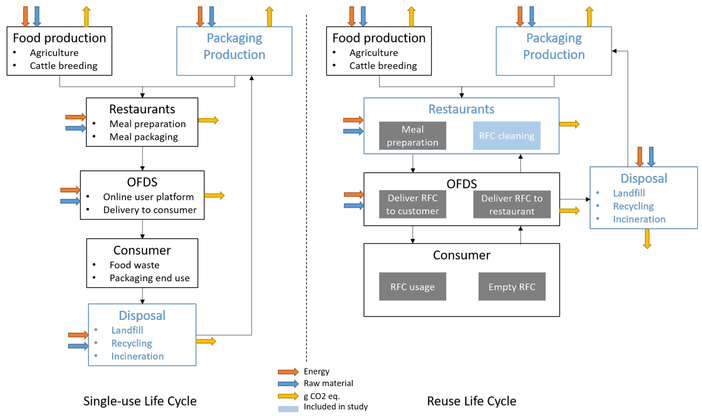


Figure 1: Scope of the LCA. On the left side: single-use packaging life cycle. On the right side: reusable packaging life cycle. The text boxes marked in blue are included in the LCC and LCA.

the production, usage, and disposal of food containers, (ii) the usage of single-use containers is considered to not have any impact since the packaging is disposed after usage. For reusable food containers, cleaning is considered, (iii) we exclude delivery cost- and emissions since this is similar for both food container types. The functional unit considered is defined as the production and disposal of a reusable- and disposable- food container (670 ml) storing a meal for one person.

3. Research Approach

3.1. Reusable Container Handling Innovations

With the increase of takeaway food orders, the number of companies providing reusable transit packaging has been growing (Coelho et al., 2020). All these initiatives have a common goal: creating a network for reusable food packaging. However, they differ in their size, market approach, and container handling methods. The design of these networks can be divided into three categories: forward logistics, reverse logistics, and recycling logistics.

From our case-study, we can see some first concepts that are trying to collaborate with large online platforms. For example, customers at Takeaway, UberEats or Deliveroo are able to order their food in a SwapBox if the restaurant is connected to the network of SwapBox (2021). However, this currently depends heavily on the customer knowledge of the concept since the customer should include their special wish for meal delivery in a reusable food container in the 'notes to the restaurant'. This is not user-friendly. Furthermore, besides Deliverzero (2021), all initiatives depend on the customers' willingness to return since the customer has to return their containers to a drop-off point or any restaurant in the system.

3.2. Container Handling Method Definition

Based on the literature review and the multi-case study, we define the container handling methods for our evaluation study: (i) **Active**: Customers actively return the reusable food container(s) to any restaurant connected to the reusable food container network. (ii) **Passive**: The driver has a storage capacity in which containers from the customer can be stored. The customer returns the container to the driver when the driver comes by to deliver the next order to that customer. The driver checks at each delivery if the customer has any containers in stock. If the driver has enough free space in his own storage, he takes the container with him. The driver only drops the container at a reusable restaurant if the order that he picks up at that restaurant is an order in a reusable food container. (iii) the **hybrid** handling method combines the active- and passive handling methods. A customer could return the container to any reusable restaurant in the system or the driver could pick up a used container from the customer.

3.3. Container Redistribution Events

In general, a redistribution action is triggered when the number of reusable food containers in stock at any reusable restaurant node gets below the required stock level. We reconfigure the reusable food containers either by redistributing them over all reusable restaurant nodes (restock event) or by adding new packages to all reusable restaurant nodes (refill event).

3.4. Life Cycle Assessment

Since this research mainly focuses on the global warming potential (GWP) of the products, we express the environmental footprint in g CO_2 equivalent. The GWP for single use equals 151 g CO_2 equivalent and 673 g CO_2 equivalent for reusable food containers. We apply the concept of 'transition point' to define where the system of reusable containers starts to perform better than the single-use containers (Ligthart and Foundation, 2007). It can be seen that the reusable PP containers should be used at least 5 times to balance out the GWP of single-use PP containers. Another factor that should be included in the environmental assessment are the emissions caused by reusable food container cleaning. Based on the study by Gallego-Schmid et al. (2019), we assume that 12 g CO_2 equivalent is emitted due to cleaning.

Container redistribution is performed by a Light Electrical Vehicle (LEV). According to Hall and Lutsey (2018), the life cycle emission of an electric vehicle in the European Union equals 125 g CO_2 equivalent per kilometer. According to Zhou et al. (2020), the average travel distance to a restaurant in an urban area equals 2.5 kilometers. According to Eurostat (2020), the emissions per kWh in the European Union are equal to 275 g CO_2 equivalent.

3.5. Life Cycle Costing

Based on comparative commodity research, we define the cost for a reusable food container as €1.92, and cost for a disposable food container as €0.05. The cost for redistribution consists of labor costs and transport costs. According to Picnic (2021), the salary of a driver is equal to €10.69 per hour. We assume that the handling time per restaurant equals 10 minutes. According to Citkar (2021), the cost for fuel and vehicle investment per kilometer equals €0.36 per kilometer.

4. Model

The meal delivery network for a single service region is represented by a complete graph $G = (N, E)$, where N is a set of nodes and E is the set of edges connecting nodes in N. Each node is connected to every other node by undirected edges. **Nodes:** the set of nodes consists of two subsets: the subset of restaurants (N^R), and the subsets of customers (N^C) for which holds: $N = N^R \cup N^C$.

- **Restaurant Nodes:** Take n_R as the number of restaurants ($|N^R|$) in the meal delivery system. Two types of restaurants are distinguished, (i) restaurants offering reusable containers, denoted by set N^R_r, and (ii) restaurants without reusable containers, denoted by set N^R_{nr}.

  Reusing restaurant nodes have the possibility to deliver meal orders in reusable food containers and disposable food containers, whereas non-reusing restaurant nodes will only use disposable food containers to deliver their meals. Note that a reusing restaurant will only use reusable food containers if the ordering customer demands its meal in a reusable food container. Otherwise, the reusing restaurant will use a disposable to deliver the ordered food.

  Let α be the ratio of the restaurants offering reusable containers among all restaurants in the system; i.e., $\alpha = \frac{|N^R_r|}{n_R}$.

  Let us define the average number of orders ordered at a restaurant per day as ORDER_FREQ _REST. We assume no difference in restaurant popularity, the ORDER_FREQ_REST is equal and constant for all restaurants.

  For each order, a restaurant is randomly sampled from the set of all restaurants with equal probability per restaurant, i.e., we assume a uniform sampling distribution. Note that this implies that the choice of a restaurant does not depend on whether or not a customer wants its food delivered in a reusable package. The customer preference for food container type is only taken into account after restaurant sampling. We define a minimum required stock of reusable food containers per reusing restaurant. If the stock is below this level, it will trigger an action to fill its stock.

  The minimum required stock level of each restaurant is defined as MIN_PACK_LEVEL. Take p_{init} as the initial number of reusable containers each reusable restaurant has in stock at time zero.

- **Customer Nodes:** Take n_c as the number of customers ($|N^C|$) in the meal delivery system. Two types of restaurants are distinguished (i) customers that demand for reusable containers, denoted by set N^C_r, and (ii) customers that demand for non-reusable food containers, denoted by set N^C_{nr}.

  Per time step, the customer that places an order is randomly sampled from a distribution based on order-frequency data obtained from 'Takeaway.com'. The restaurant at which this order is placed is uniformly sampled from the set of restaurants (N^R).

  Each customer node starts the simulation with zero containers in stock. Over time, the customer can develop a stock of multiple containers. Reusing customer nodes always choose for reusable food containers if the restaurant offers these. Whereas the non-reusable customers always demand their orders in disposable food containers.

  Let β be the ratio of the customers that demand for reusable food containers among all customers in the system; i.e., $\beta = \frac{|N^C_r|}{n_C}$.

  A customer can be allowed to return a reusable food container to a reusable restaurant by itself. The return behavior of a customer is defined by: (i) the number of days after which the customer will start to return a food container is defined as CUST_RETURN_PACK_THRES; after this number of days, (ii) the chance of return is given by CUST_RETURN_PACK_CHANCE. The restaurant to which the customer returns its reusable food container is sampled uniformly from N^R_r.

  The total number of nodes of the graph is given by $n = n_R + n_C$. There is no geographical distance included in the system, i.e., we do not consider the nodes to have a specific location.

Edges: The set of edges is denoted by E. We assume all nodes to be connected to each other, i.e., our graph is fully connected. As we do not consider any location information for the nodes, the edges do not have travel time characteristics. In our discrete simulations, we will assume that every edge can be traveled to in one time step.

Food containers function as packaging for meals that are ordered by customers and produced by restaurants. A reusable food container can only be used a fixed number of times before it is discarded. The maximum number of uses is defined as the parameter: LIFESPAN. The container size is standardized. There is one type of disposable food container and one type of reusable food container.

Drivers move on the graph to fulfill the transport of orders from restaurant nodes to customer nodes.The number of drivers is defined as d. The routes are assumed to be given. Besides that, drivers can play a role in the return logistics of reusable food containers to the reusable restaurant nodes. All drivers move in sync. A time step is defined as one delivery trip of a driver. Each time step every driver moves from a restaurant node to a customer and back to a restaurant. The average number of trips a driver can execute in one day is defined as the TRIP_FREQ_DRIVER. The driver has the possibility to store reusable food containers. The maximum number of containers a driver can take in storage is defined as the MAX_PACK_CAP.

4.1. Algorithms

The simulation model is written in Python, the code can be seen in *GITHUB - reusable_food_container_network*. For more details see the README file. The algorithms explained in this section are a simplification of the simulation model. We present the algorithms per handling method. The functions used in the algorithms are explained after the description of the algorithms.

Algorithm 1: RUN Active Approach

```
while $t \leq T$ do
    for each Driver in Drivers do
        SAMPLE_RESTAURANT();
        SAMPLE_CUSTOMER($t$);
        if Sampled_Restaurant uses reusable packages and Sampled_Customer uses reusable packages then
            TAKE_PACKAGES_FROM(Driver, Sampled_Restaurant, 1);
            DROP_PACKAGES_AT(Driver, Sampled_Customer, 1);
    for each Reusing_Cust_Node in Reusing_Cust_Nodes do
        if Stored_Packages_Customer > 0 at $t - 1$ and RAND_UNI() > CUST_RETURN_CHANCE then
            SAMPLE_RESTAURANT();
            MOVE_PACKAGES_FROM(Reusing_Cust_Nodes, Sampled_Restaurant, Stored_Packages_Customer);
    if CHECK_NEED_FOR_REFILL() then
        REFILL()
```

Algorithm 2: RUN Active Approach

```
while $t \leq T$ do
    for each Driver in Drivers do
        SAMPLE_RESTAURANT();
        SAMPLE_CUSTOMER($t$);
        if Sampled_Restaurant uses reusable packages and Sampled_Customer uses reusable packages then
            TAKE_PACKAGES_FROM(Driver, Sampled_Restaurant, 1);
            DROP_PACKAGES_AT(Driver, Sampled_Customer, 1);
    for each Reusing_Cust_Node in Reusing_Cust_Nodes do
        if Stored_Packages_Customer > 0 at $t - 1$ and RAND_UNI() > CUST_RETURN_CHANCE then
            SAMPLE_RESTAURANT();
            MOVE_PACKAGES_FROM(Reusing_Cust_Nodes, Sampled_Restaurant, Stored_Packages_Customer);
    if CHECK_NEED_FOR_REFILL() then
        REFILL()
```

Algorithm 3: RUN Hybrid Approach

```
while $t \leq T$ do
    for each Driver in Drivers do
        SAMPLE_RESTAURANT();
        SAMPLE_CUSTOMER($t$);
        if Sampled_Restaurant uses reusable packages and Sampled_Customer uses reusable packages then
            DROP_PACKAGES_AT(Driver, Sampled_Restaurant, Stored_Packages_Driver);
            TAKE_PACKAGES_FROM(Driver, Sampled_Restaurant, 1);
            DROP_PACKAGES_AT(Driver, Sampled_Customer, 1);
        if Stored_Packages_Customer > 0 at $t - 1$ then
            TAKE_PACKAGES_FROM(Driver, Sampled_Customer, Stored_Packages_Customer);
        if $t = T$ then
            SAMPLE_RESTAURANT();
            DROP_PACKAGES_AT(Driver, Sampled_Restaurant, Stored_Packages_Driver);
    for each Reusing_Cust_Node in Reusing_Cust_Nodes do
        if Stored_Packages_Customer > 0 at $t - 1$ and RAND_UNI() > CUST_RETURN_CHANCE then
            SAMPLE_RESTAURANT();
            MOVE_PACKAGES_FROM(Reusing_Cust_Nodes, Sampled_Restaurant, Stored_Packages_Customer);
    if CHECK_NEED_FOR_REFILL() then
        REFILL()
```

Explanation of the functions:

- SAMPLE_RESTAURANT(): sample one restaurant node from the set of restaurant nodes with equal probability per element, i.e., using a uniform distribution. The sampled restaurant is assigned to the *Sampled_Restaurant* variable. A specific restaurant node can be sampled multiple times per time step, i.e., we sample with replacement.
- SAMPLE_CUSTOMER(t): sample one customer from the set of customer nodes using the order frequency distribution based on "Takeaway.com" data. The sampled customer is assigned to the *Sampled_Customer* variable. A customer node can only be sampled once per time step, i.e., we sample without replacement. This implies that a customer can only order once per time step.
- DROP_PACKAGES_AT(*Driver, Node, Number of Packages*): The 'Driver' object drops 'Number of Packages' amount of reusable food containers from its storage at 'node'.
- TAKE_PACKAGES_FROM(*Driver, Node, 1*): The 'Driver' object takes one reusable food container (meal order) from 'Node'.
- CHECK_NEED_FOR_REFILL(): check for each reusable restaurant if its stock level of reusable food containers is below MIN_PACK_LEVEL.

- REFILL(): A refill action is performed. All reusable food containers at the restaurant nodes are equally distributed over the reusable restaurant nodes. If the number of reusable food containers at any of the reusable restaurant nodes is still below the MIN_PACK_LEVEL we refill the number of containers at all reusable restaurant nodes to the initial number of reusable food containers in the system p_{init}.

- MOVE_PACK_FROM(*From Node, To Node, Number of Packages*): 'Number of Packages' amount of reusable food container in storage at 'From Node' is moved to 'To Node'.

5. Results

We evaluate the simulation with an equal number of reusable container usages in the steady state of the system. Based on the outcomes of our simulation study (Table 5), we can draw the following conclusions:

- We see that the active container handling approach results in the highest number of redistribution events, while the passive and hybrid container handling methods require almost no redistribution actions. This is a result of the uncontrollability of the random return action by customers in the active handling method, resulting in a high number of redistribution events (see Figure 2). The difference in cost between these methods becomes smaller when the number of reusable restaurants in the system is smaller. In such a scenario, the chance that a container is returned to a restaurant that is in need of a reusable container is larger than for more reusable restaurants. The number of redistribution events decreases resulting in lower cost.

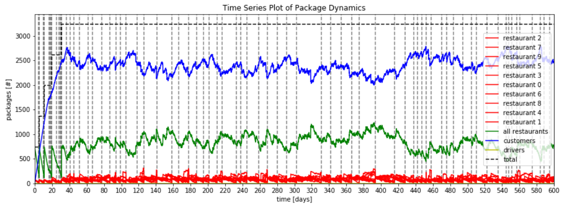


Figure 2: Time Series Graph Scenario 1 Active container handling method

- Since the redistribution is executed by a Light Electrical Vehicles, a relative small amount of emissions is emitted. The redistribution events have a smaller impact on the total emissions than on the total cost. The number of reusable orders dominates the total emissions. Since these are equal for each of the container handling methods, we see that the shape of the graph depends on the number of redistribution events. Therefore, the environmental impact of the active container handling method is larger than the hybrid method which is larger than the passive method.

- We can conclude that the passive container handling method performs best economically and environmentally. In scenario 1, we see that the passive handling method saves 0.04 euro cent per order compared to no savings for the active handling method.

- Higher customer stocks result in more reusable food containers in the system, which increases the investment cost. From Figure 3, we see that the active container handling method requires overall the the highest investment cost. In Figure 3, we see that scenario 1 requires the most food containers and scenario 4 the least. From this we conclude that the number of reusable restaurants and customers effects the number of reusable orders in the system and therefore the total number of required food containers.

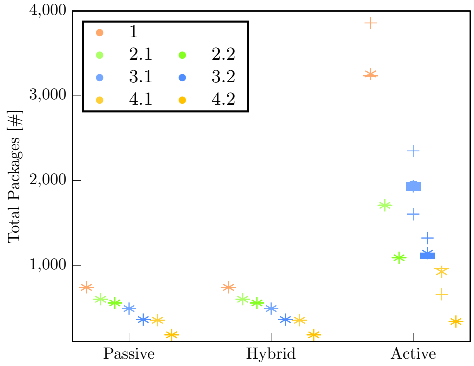


Figure 3: Total number of packages per scenario per container handling method

- According to our sensitivity analysis, increasing the lifespan results in lower cost and emissions. Furthermore, the CUSTOMER_RETURN_CHANCE has the largest impact on the customer return action compared to CUSTOMER_RETURN_THRES. An increase of CUSTOMER_RETURN_CHANCE results in less redistribution events (see Figure 4).

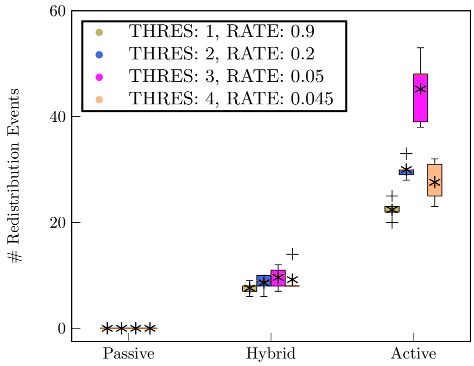


Figure 4: Variation in CUSTOMER_RETURN_THRES and CUSTOMER_RETURN_CHANCE

		Passive	Hybrid	Active
Scenario 1	Redistribution events [#]	0	9	53
	Usage costs [€/order]	-0.04	-0.03	0.00
	Emissions [kg CO2 equivalent/order]	-0.1356	-0.1351	-0.1326
	Investment cost [€/order]	0.02	0.02	0.10
Scenario 2.1	Redistribution events [#]	0	1	3
	Usage costs [€/order]	-0.04	-0.04	-0.04
	Emissions [kg CO2 equivalent/order]	-0.1335	-0.1334	-0.1333
	Investment cost [€/order]	0.05	0.05	0.14
Scenario 2.2	Redistribution events [#]	0	0	0
	Usage costs [€/order]	-0.04	-0.04	-0.04
	Emissions [kg CO2 equivalent/order]	-0.1336	-0.1336	-0.1336
	Investment cost [€/order]	0.09	0.09	0.17
Scenario 3.1	Redistribution events [#]	0	8	42
	Usage costs [€/order]	-0.02	-0.01	-0.01
	Emissions [kg CO2 equivalent/order]	-0.0552	-0.0548	-0.0531
	Investment cost [€/order]	0.02	0.02	0.06
Scenario 3.2	Redistribution events [#]	0	6	42
	Usage costs [€/order]	-0.01	0.00	0.02
	Emissions [kg CO2 equivalent/order]	-0.0257	-0.0254	-0.0237
	Investment cost [€/order]	0.01	0.01	0.03
Scenario 4.1	Redistribution events [#]	0	1	13
	Usage costs [€/order]	-0.02	-0.02	-0.01
	Emissions [kg CO2 equivalent/order]	-0.0582	-0.0581	-0.0574
	Investment cost [€/order]	0.03	0.03	0.08
Scenario 4.2	Redistribution events [#]	0	1	13
	Usage costs [€/order]	-0.01	-0.01	-0.01
	Emissions [kg CO2 equivalent/order]	-0.0350	-0.0317	-0.0313
	Investment cost [€/order]	0.03	0.03	0.05

Figure 5: Overview experimental results

5.1. *Limitations*

Some limitations of the study should be considered.

- We expect the reusable container return option to the driver to be the most convenient return action for the customer, since the customer does not have to travel to any drop-off location. However, this is just a hypothesis which is not customer preference data.
- Currently, the driver only drops a reusable food container at a reusable restaurant if the next order is also in a reusable food container. Future research could include different control actions. For example, the driver drops its food containers at reusable restaurants with low stock levels.
- The restaurant popularity is equal for all restaurants in the current simulation model. However, one could assume that some restaurants receive more orders than others. The chance for sampling these restaurants should increase.
- In our current simulation model, we sample, independently from the customers' food container preferences, a restaurant from the set of both reusable- as non-reusable restaurants. This is based on the idea that a customer first selects a restaurant based on its meal preferences. Whether the meal is served in a reusable food container or not is a consequence of the type of restaurant that is sampled. In future research, the customers' food container preferences could play a distinctive role in the selection of restaurants from which a meal order is sampled.

6. Discussion and conclusion

6.1. *Scientific Contributions*

This study has contributed to our understanding of the environmental and economical effects of three different reusable container handling methods, particularly in the meal delivery industry. Almost all existing food container studies mainly focus on the environmental quantification of different food container types, such as those by Arunan and Crawford (2021); Gallego-Schmid et al. (2018, 2019). However, these studies only focus on the performance of the packaging product itself. This study provides the first insight into different container handling methods for both disposable as reusable food containers.

We used a life cycle assessment and life cycle costing approach in combination with a simulation study to evaluate the environmental- and economical effects of packaging materials for different container handling methods. The methods used can be replicated for any meal delivery network. To obtain comparable and universal results on the environmental- and economical performance of different container handling methods in the meal delivery industry, it is suggested that, where feasible, studies across the world follow one approach across different spatial scales. The results obtained in this study provide further knowledge on the potential emissions and cost of disposable- and reusable food containers within the meal delivery industry. Which can be used to inform online meal delivery platforms about the implementation consequences of reusable food containers. Furthermore, insights into the potential of reusable food containers can be useful for decision makers relating to their policy on banning single-use food containers.

6.2. *Recommendations from the Study*

Since our study is based on a simulation study, we recommend to start a pilot project to evaluate the expected environmental- and economical performance which follow from our study. The following practical recommendations for the pilot study are defined.

- In our evaluation study, we assume a lifespan of 200 uses for reusable food containers. We recommend to track the number of uses for each reusable food container in a pilot project. Hereby, a more reliable estimation can be made for the lifespan of a reusable food container implying the investment cost.
- In our evaluation study, we see that the active handling method requires much more reusable food containers in the system, since customers randomly return their food container after some time, to a random restaurant in the system. We expect the total customer container stock to increase. However, it is relevant to research the return behavior of customers in a pilot since it has a large impact on the number of reusable containers in the system.

- There exist different system behavior in the warm-up period and the steady state of the system for each type of handling method. Therefore, we recommend to plan a pilot project longer than the warm-up phase. The system then performs in a steady state which is more controllable than the warm-up period. We observe that fewer redistribution methods are needed in the steady state of the system for each of the handling methods. Therefore, the expected cost and emissions for transportation will be lower than in the warm-up phase.

- Another recommendation for the design of a pilot project is to start with a small group of reusable customers and a restaurant in which each customer starts with a reusable food container at home. In the case of passive- and hybrid container handling methods, this directly results in a steady state of the system. Resulting in time savings for insights into the expected performance of the system on the long term.

6.3. Further Research

Being the first evaluation study on the economical- and environmental performance of reusable food container integration in the meal delivery industry, there are many areas in which this research can be expanded.

- The current model assumes reusable container cleaning and storage at restaurants connected to the reusable container network. This is defined by Hellström (2009) as the transfer approach. We choose this approach since it results in the most efficient transport of reusable food containers compared to a system where drop-off locations or a central hub for cleaning and storage is chosen (depot approach (Hellström, 2009)). Besides that, we expect the depot approach to result in higher storage costs since one should invest in a central depot cleaning facility. Further research can investigate the differences in the economical- and environmental performance between the transfer approach and the depot approach.

- Furthermore, we expect that putting the cleaning responsibility on the restaurants could result in a lower or less reliable cleaning quality of the reusable food containers. At least, the online meal delivery platform has less control over the cleaning process than when the platform has its own cleaning facility in a central depot. This could increase the quality of the reusable food container service. This important adoption aspect could be a relevant subject to a survey among restaurants in the meal delivery industry.

- Because in our current system the reusable food containers are owned by the online meal delivery platform but used by restaurants and customers, it is relevant to research different tracking technologies for managing food container inventory at different locations. Mahmoudi and Parviziomran (2020) identifies five types of tracking technologies: barcode, passive radio-frequency identification (RFID), active RFID, Wi-Fi, and global positioning system (GPS). Which one is most applicable for reusable food container usage in the meal delivery industry provides insight into relevant practicalities for implementation.

References

Agatz, N., Fan, Y., and Stam, D. (2021). The Impact of Green Labels on Time Slot Choice and Operational Sustainability. *Production and Operations Management*, page poms.13368.

Arunan, I. and Crawford, R. H. (2021). Greenhouse gas emissions associated with food packaging for online food delivery services in Australia. *Resources, Conservation and Recycling*, 168:105299.

Barnes, M., Chan-Halbrendt, C., Zhang, Q., and Abejon, N. (2011a). Consumer Preference and Willingness to Pay for Non-Plastic Food Containers in Honolulu, USA. *Journal of Environmental Protection*, 02(09):1264–1273.

Barnes, M., Chan-Halbrendt, C., Zhang, Q., and Abejon, N. (2011b). Consumer Preference and Willingness to Pay for Non-Plastic Food Containers in Honolulu, USA. *Journal of Environmental Protection*, 02(09):1264–1273.

Bortolini, M., Galizia, F. G., Mora, C., Botti, L., and Rosano, M. (2018). Bi-objective design of fresh food supply chain networks with reusable and disposable packaging containers. *Journal of Cleaner Production*, 184:375–388.

Bryan, C. (2021). Users Hungry for Food Delivery Amidst the COVID-19.

Citkar (2021). The Loadster: The e-bike as a commercial vehicle — citkar.

Coelho, P. M., Corona, B., ten Klooster, R., and Worrell, E. (2020). Sustainability of reusable packagingâCurrent situation and trends.

Corporate Finance Institute (2018). Economies of Scale - Definition, Types, Effects of Economies of Scale.

Dauvergne, P. (2018). Why is the global governance of plastic failing the oceans? *Global Environmental Change*, 51:22–31.

Deliverzero (2021). DeliverZero.

Devenyns, J. (2019). Why reusable food packaging has a promising future — Food Dive.

EU Commission (2018). Single-use plastics: New EU rules to reduce marine litter. *Ip/18/3927*, (May):1–3.

European Parliament (2019). Parliament seals ban on throwaway plastics by 2021 — News — European Parliament. *European Parliament*, pages 2019–2022.

Eurostat (2020). Electricity price statistics - Statistics Explained. *European Commission*, (November):1–12.

Fleischmann, M., Beullens, P., Bloemhof-Ruwaard, J. M., and Van Wassenhove, L. N. (2001). The impact of product recovery on logistics network design. *Production and Operations Management*, 10(2):156–173.

Gaines, L. (2012). To recycle, or not to recycle, that is the question: Insights from life-cycle analysis. *MRS Bulletin*, 37(4):333–338.

Gallego-Schmid, A., Mendoza, J. M. F., and Azapagic, A. (2018). Improving the environmental sustainability of reusable food containers in Europe. *Science of the Total Environment*, 628-629:979–989.

Gallego-Schmid, A., Mendoza, J. M. F., and Azapagic, A. (2019). Environmental impacts of takeaway food containers. *Journal of Cleaner Production*, 211:417–427.

Garcia, K. (2018). Five Charts: The State of Food Delivery.

Green, H. (2016). The future of food. *Nutrition Bulletin*, 41(3):192–196.

Grimes-Casey, H. G., Seager, T. P., Theis, T. L., and Powers, S. E. (2007). A game theory framework for cooperative management of refillable and disposable bottle lifecycles. *Journal of Cleaner Production*, 15(17):1618–1627.

Hahladakis, J. N. and Iacovidou, E. (2018). Closing the loop on plastic packaging materials: What is quality and how does it affect their circularity? *Science of the Total Environment*, 630:1394–1400.

Hall, D. and Lutsey, N. (2018). Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions.

Harmsen, J. (2021). Gemeentelijke woonlasten stijgen, vooral de afvalstoffenheffing gaat flink omhoog — Trouw.

Hellström, D. (2009). The cost and process of implementing RFID technology to manage and control returnable transport items. *International Journal of Logistics Research and Applications*, 12(1):1–21.

Hornik, J., Cherian, J., Madansky, M., and Narayana, C. (1995). Determinants of recycling behavior: A synthesis of research results. *The Journal of Socio-Economics*, 24(1):105–127.

Ivanova, I. (2020). See how much business U.S. restaurants are losing because of the coronavirus - CBS News.

Jacobsen, P. (2015). The profitability drivers in packaging materials reuse for manufacturers in business to business environments. *Technical University of Denmark*.

Jain, R. K., Taylor, J. E., and Culligan, P. J. (2013). Investigating the impact eco-feedback information representation has on building occupant energy consumption behavior and savings. *Energy and Buildings*, 64:408–414.

Jetten, J. and De, K. N. (2002). Quality and safety aspects of reusable plastic food packaging materials: influence of reuse on intrinsic properties. *Food additives and contaminants*, 19(1):76–88.

Jetten, J., De Kruijf, N., and Castle, L. (1999). Quality and safety aspects of reusable plastic food packaging materials: A European study to underpin future legislation. *Food Additives and Contaminants*, 16(1):25–36.

Jia, X., Klemeš, J. J., Varbanov, P. S., and Wan Alwi, S. R. (2018). Energy-emission-waste nexus of food deliveries in China. *Chemical Engineering Transactions*, 70:661–666.

Kroon, L. and Vrijens, G. (1995). Returnable containers: an example of reverse logistics. *International Journal of Physical Distribution & Logistics Management*, 25(2):56–68.

Krumwiede, D. W. and Sheu, C. (2002). A model for reverse logistics entry by third-party providers. *Omega*, 30(5):325–333.

Li, C., Mirosa, M., and Bremer, P. (2020). Review of online food delivery platforms and their impacts on sustainability.

Ligthart, T. N. and Foundation, B. D. (2007). Single use Cups or Reusable (coffee) Drinking Systems: An Environmental Comparison. *Netherlands Organisation for Applied Scientific Research*, page 121.

Lützbauer, M. (1993). Systems for Returnable Transport Packaging.

Luyben, P. D. and Bailey, J. S. (1979). Newspaper Recycling: The Effects of Rewards and Proximity of Containers. *Environment and Behavior*, 11(4):539–557.

Mahmoudi, M. and Parviziomran, I. (2020). Reusable packaging in supply chains: A review of environmental and economic impacts, logistics system designs, and operations management.

Mata, T. M. and Costa, C. A. V. (1999). LCA: Comparison Between Recycle and Reuse of Glass Beer Bottles. In *Tools and Methods for Pollution Prevention*, pages 85–96. Springer Netherlands, Dordrecht.

Meyer, H. (1999). Many Happy Returns.

MoralesâCaselles, C., Viejo, J., Marti, E., Gonzalez, D., Pragnellâ Raasch, H., GonzalezâGordillo, J., Montero, E., Arroyo, G. M., Hanke, G., Salvo, V., O.C., B., Mallos, N., Lebreton, L., Echevarria, F., vam Emmerik, T., Duarte, C., Galvey, J., van Sebille, E., Galgani, F., Garcia, C. M., Ross, P. S., Bartual, A., Ioakeimidis, C., Markalain, G., Isobe, A., and Coyar, A. (2021). Global Classification of Ocean Litter Reveals an InshoreâOffshore Sorting System. *(under review)*, 4(6):484–493.

Picnic (2021). Vacatures: koerier bij Picnic worden? Solliciteer nu en verdien meer!

Roca i Puigvert, M., Ayuso, S., Bala, A., and Fullana-i Palmer, P. (2020). What factors determine attitudes towards the implementation of a packaging deposit and refund system? A qualitative study of the perception of Spanish consumers. *Journal of Environmental Management*, 270:110891.

Rogers, D. S., Melamed, B., and Lembke, R. S. (2012). Modeling and analysis of reverse logistics.

Saphores, J. D. M., Nixon, H., Ogunseitan, O. A., and Shapiro, A. A. (2006). Household willingness to recycle electronic waste: An application to California. *Environment and Behavior*, 38(2):183–208.

Saphores, J. D. M., Ogunseitan, O. A., and Shapiro, A. A. (2012). Willingness to engage in a pro-environmental behavior: An analysis of e-waste recycling based on a national survey of U.S. households. *Resources, Conservation and Recycling*, 60:49–63.

Savaskan, R. C., Bhattacharya, S., and Van Wassenhove, L. N. (2004). Closed-Loop Supply Chain Models with Product Remanufacturing. *Management Science*, 50(2):239–252.

Song, G., Zhang, H., Duan, H., and Xu, M. (2018). Packaging waste from food delivery in China's mega cities.

Statista (2020). Online Food Delivery - Worldwide — Statista Market Forecast.

Steenis, N. D., van Herpen, E., van der Lans, I. A., Ligthart, T. N., and van Trijp, H. C. (2017). Consumer response to packaging design: The role of packaging materials and graphics in sustainability perceptions and product evaluations. *Journal of Cleaner Production*, 162:286–298.

Struk, M. (2017). Distance and incentives matter: The separation of recyclable municipal waste. *Resources, Conservation and Recycling*, 122:155–162.

SwapBox (2021). Sustainable and Reusable Food Packaging — SwapBox — Netherlands.

Thevenon, F., Carroll, C., and Sousa, J. (2015). *Plastic debris in the ocean: the characterization of marine plastics and their environmental impacts, situation analysis report*. International Union for Conservation of Nature.

Valor, C. (2008). Can Consumers Buy Responsibly? Analysis and Solutions for Market Failures. *Journal of Consumer Policy*, 31(3):315–326.

van Birgelen, M., Semeijn, J., and Keicher, M. (2009). Packaging and Proenvironmental Consumption Behavior. *Environment and Behavior*, 41(1):125–146.

Yazdanifard, R. and Mercy, I. E. (2011). The impact of Green Marketing on Customer satisfaction and Envi- ronmental safety. *International Conference on Computer Communication and Management*, 5(January 2011):637–641.

Yi, Y., Wang, Z., Wennersten, R., and Sun, Q. (2017). Life Cycle Assessment of Delivery Packages in China. *Energy Procedia*, 105:3711–3719.

Zhou, Y., Shan, Y., Guan, D., Liang, X., Cai, Y., Liu, J., Xie, W., Xue, J., Ma, Z., and Yang, Z. (2020). Sharing tableware reduces waste generation, emissions and water consumption in Chinaâs takeaway packaging waste dilemma. *Nature Food*, 1(9):552–561.

Zion, A., Spangler, J., and Thomas, H. (2020). Food Delivery Apps: Usage and Demographics â Winners, Losers and Laggards.

B

Material Details

Table B.1: Overview of materials used in reusable food containers per multi-case study

Material	Reference
Polypropylene	SwapBox, GoBox, Deliverzero, Bûmerang, EcoBox, Sharepack
Sylicone	Ozarka
Polybutylene terepthalate	ReCircle
Tifin	Returnr, Tiffin

Table B.2: Costs for reusable- and disposable container types

Container type	Cost (€)	References
Reusable	1.92	Amazon (2021a), Amazon (2021b), Amazon (2021c)
Disposable	0.05	Senna Plastic (2021a) Senna Plastic (2021b), Zjpypaper (2021)

C

Detailed Results

In this chapter, we discuss the result of each of the scenarios as defined in Section 4.3.3. The results are shown in box-plot graphs, one for the number of redistribution events, and one showing the cost on one y-axis and emissions on the other y-axis. Since the number of reusable container usages is equal for each of the container handling methods, the blue dotted line shows the cost/emission for these food container usages. The additional cost and emissions shown above the blue line are the result of redistribution events.

Scenario 1

The box plots in Figure 5.1a, and Figure 5.1b in Section 5.1, show us the simulation results for scenario 1. In this scenario, all customers and all restaurants reuse. Figure 5.1a shows that the passive- and hybrid container handling methods require almost no redistribution actions. On the contrary, the active container handling method requires on average 60 redistribution actions. Additionally, we see that the environmental performance of the three container handling methods differs due to the high number of redistribution events for the active handling method. All in all, the passive container handling system performs best for this scenario in which all customers and restaurants reuse.

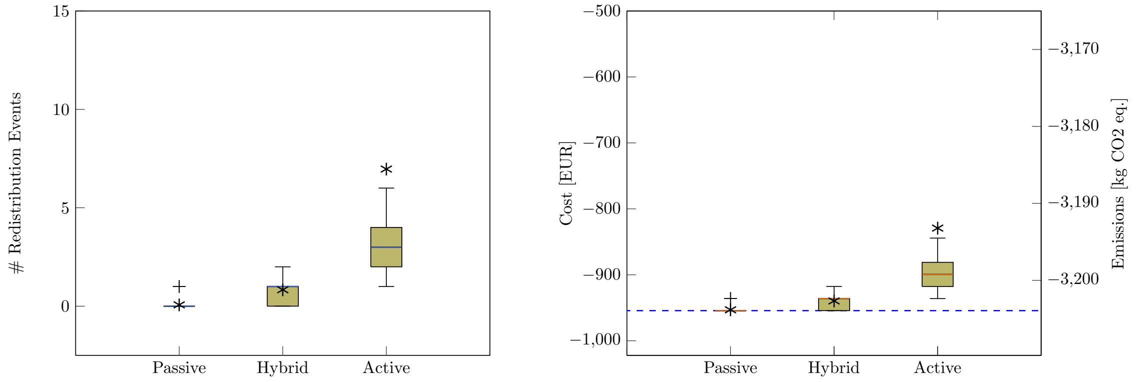
Scenario 2

In scenario 2, all customers reuse and some restaurants reuse. We differ the percentage of reusable restaurants in scenario 2.1 (40% of the restaurants reuses) and scenario 2.2 (20% of the restaurants reuses).

Scenario 2.1

The box plots in Figure C.1a, and Figure C.1b, show us the simulation results for scenario 2.1. In this scenario, all customers reuse, and 40% of restaurants reuse. Figure C.1a shows that the passive- and hybrid container handling methods require almost no redistribution actions. Since there are fewer reusable restaurants in the system than in scenario 1, there is a greater chance of container returnment to a reusable restaurant that needs a reusable food container. Therefore, the number of redistribution actions is lower than in scenario 1. Besides that, the total number of orders than can be handled in the system is lower due to less reusable restaurants.

The high number of redistribution events for the active container handling method results in less cost- and emission savings than for the passive container handling method in which no redistribution events are required. Figure C.1b shows the difference in cost- and emission savings. All in all, based on this outcome, we conclude that the passive container handling method results in the highest cost savings.

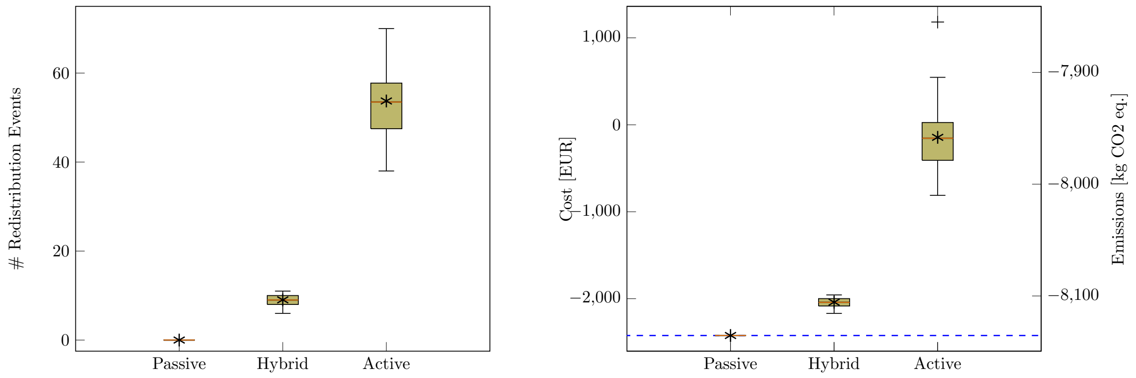


(a) Redistribution events per container handling method **(b)** Emission and cost per container handling method

Figure C.1: Results scenario 2.1

Scenario 2.2

The box plots in Figure C.2a and C.2b, show us the simulation results for scenario 2.2. In this scenario, all customers reuse, and 20% of restaurants reuse. This results in two reusable restaurant nodes. The chance that a customer or driver returns a reusable food container to a restaurant that needs a reusable food container is large. Therefore, in all container handling methods, no redistribution events occur. The economical- and environmental performance of each of the methods is therefore almost equal. The variance in the results is caused by the random sampling of customers and restaurants. A reusable food container is only used if both the sampled customer as the restaurant reuse. This leads in some cases to more reusable food container use than in the other simulation runs.



(a) Redistribution events per container handling method **(b)** Emission and cost per container handling method

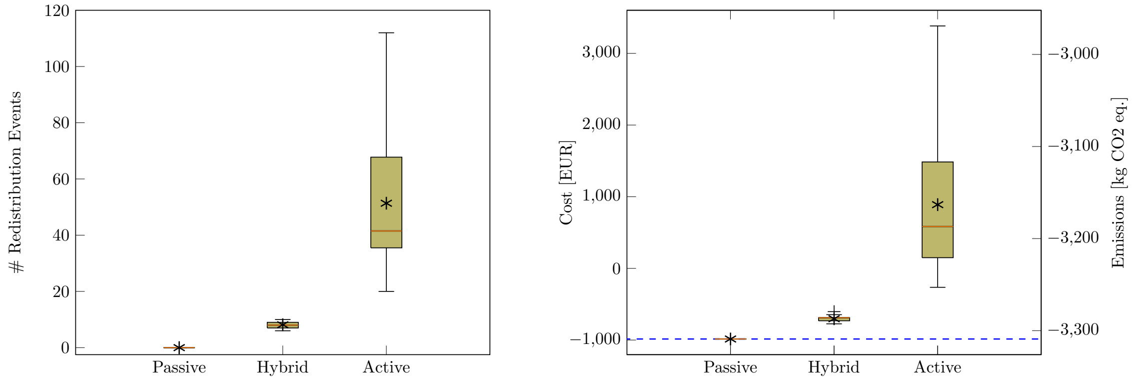
Figure C.2: Results scenario 2.2

Scenario 3

In scenario 3, some customers reuse and all restaurants reuse. We differ the percentage of reusable customers in scenario 3.1 (50% of the customers reuses) and scenario 3.2 (25% of the customers reuses).

Scenario 3.1

The box plots in Figure C.3a and C.3b, show the simulation results for scenario 3.1. In this scenario 50% of the customers reuse and all restaurants reuse. From Figure C.3a, we see that the active handling method requires 25 redistribution events. The hybrid handling method requires approximately four redistribution events and the passive handling method requires none.



(a) Redistribution events per container handling method

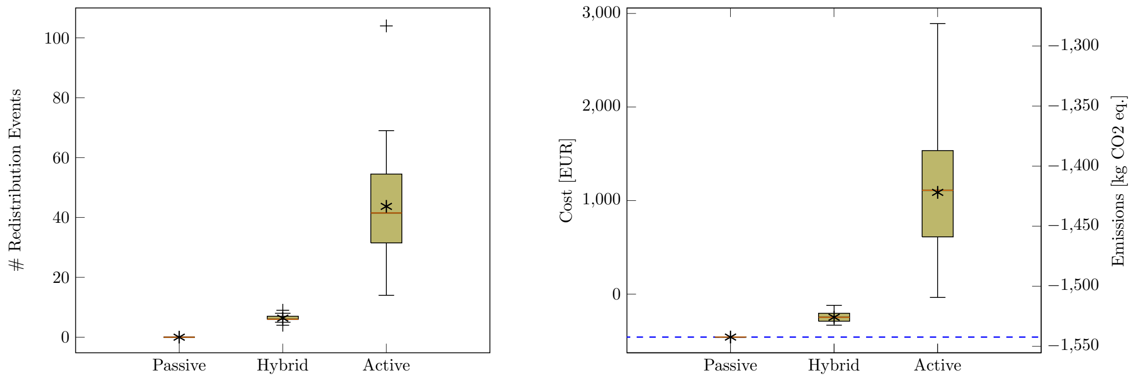
(b) Emission and cost per container handling method

Figure C.3: Results scenario 3.1

Looking at the box plot in Figure C.3b, the high number of redistribution events result in high costs for the active handling method. However, there are still cost savings compared to a situation in which all customers and restaurants use disposable food containers. The largest cost saving can be seen when the passive handling method is used. The cost savings for the hybrid handling method are a little less than in the passive method since more redistribution events are required due to the random returnment of food containers to restaurants by customers.

Scenario 3.2

The box plots in Figure C.4a, C.4b, show the experimental results for scenario 3.2. In this scenario 25% of the customers reuse and all restaurants reuse. From Figure C.4a, we see that the active handling method requires 26 redistribution events. The hybrid handling method requires approximately three redistribution events and the passive handling method requires none.



(a) Redistribution events per container handling method

(b) Emission and cost per container handling method

Figure C.4: Results scenario 3.2

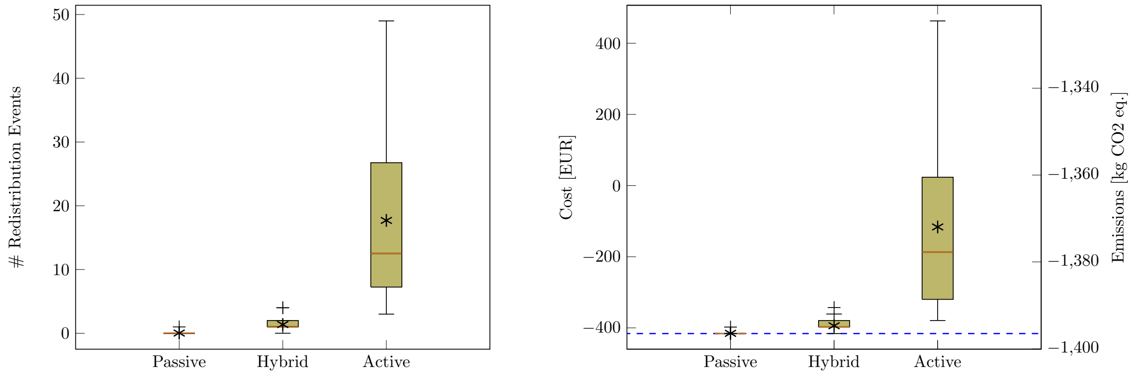
The high number of redistribution events results in high redistribution costs, which causes a reduce in cost and emission savings for the active container handling method. This can be seen in Figure C.4b.

Scenario 4

In scenario 4, some customers reuse and some restaurants reuse. We differ the percentage of reusable customers and restaurants in scenario 4.1 (50% of the customers reuses, 40% of the restaurants reuses) and scenario 4.2 (25% of the customers reuses, 20% of the restaurants reuses).

Scenario 4.1

The box plots in Figure C.5a and C.5b, show the simulation results for scenario 4.1. In this scenario 50% of the customers reuse and 40% of the restaurants reuses. From Figure C.5a, we see that the active handling method requires four redistribution events. The hybrid handling method requires approximately one redistribution event and the passive handling method requires none.



(a) Redistribution events per container handling method

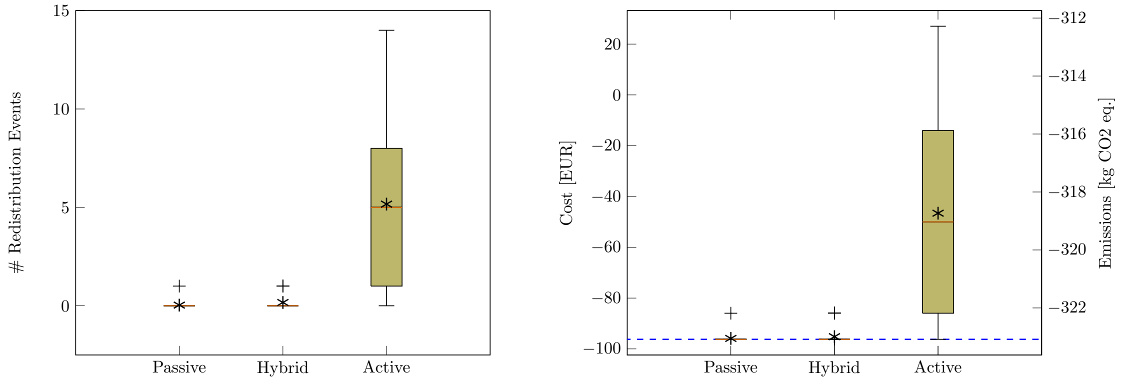
(b) Emission and cost per container handling method

Figure C.5: Results scenario 4.1

As Figure C.6b shows, the high number of redistribution events results in high redistribution costs and emissions, which causes a reduce in cost and emission savings for the active container handling method.

Scenario 4.2

The box plots in Figure C.6a and C.6b, show us the simulation results for scenario 4.2. In this scenario, 25% of the customers reuse, and 20% of restaurants reuse. This results in two reusable restaurant nodes. The chance that a customer or driver returns a reusable food container to a restaurant that needs a reusable food container is large. Therefore, in all container handling methods, no redistribution events occur. This is shown in Figure C.6a. The economical- and environmental performance of each of the methods is therefore almost equal.



(a) Redistribution events per container handling method

(b) Emission and cost per container handling method

Figure C.6: Results scenario 4,2