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"Single-use" versus "reusable" food packaging in the supply chain of catering services : a case study comparison between the financial and environmental impacts of the plastic trays and stainless steel containers

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'SINGLE-USE' VERSUS 'REUSABLE' FOOD PACKAGING IN THE SUPPLY CHAIN OF CATERING SERVICES: A CASE STUDY COMPARISON BETWEEN THE FINANCIAL AND ENVIRONMENTAL IMPACTS OF THE PLASTIC TRAYS AND STAINLESS STEEL CONTAINERS

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AWAC: Agence Wallonne de l'Air et du Climat

B2B : Business-to-Business

B2C : Business-to-Consumer

CHUV: Centre Hospitalier Universitaire Vaudois

CPU: Central Production Unit

CSR: Corporate Social Responsibility

EOL : End Of Life

EU GPP: European Union Green Public Procurement

FMCG: Fast-Moving Consumer Goods

FTEs: Full-Time Equivalents

GHG: Greenhouse gas

GN: Gastro-Norm

LCA: Life Cycle Analysis

LCI: Life Cycle Inventory

NHS: National Health Service

PP: Polypropylene

RTIs: Returnable Transport Items

U.S. EPA: United States Environmental Protection Agency

VAT: Value-Added Tax

WHO: World Health Organization

WRAP: Waste and Resources Action Programme

WWF: World Wide Fund for nature

1. Introduction

1.1. Context description

Since the beginning of the century, greater attention has been paid to pollution and environmental matters. The economic models are shifting more and more towards a 'decreased waste' strategy in the lifecycle of products, which leads some industries and companies to adopt new systems that are taking new needs and standards into account. Among those new systems, different concepts have emerged. Nunez (2020) cites circular economy as a new concept that rethinks the way products are conceived, while minimizing the unnecessary use of resources, extending the use life of items and planning the reuse of material back to the economy afterwards. Rogers & Tibben-Lembke (as cited in Limbourg, 2019, p. 3) have defined another concept, reverse logistics, as a "process of planning, implementing and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal". Those new concepts are thus more and more central within current companies' cultures, especially for those known to cause important external costs to their environment.

Among those industries which have broad supply chains and non-neglectable environmental impacts, one can find the packaging industry, big consumer of plastic components, tailored to any end application it may have – food safety, damage protection, humidity resilience, and so on. Indeed, a study realized by Vault Consulting LLC for the American Chemistry Council Plastics Industry Producers' Statistics Group (2019) has shown that the biggest share of sales for thermoplastic resins was attributed to packaging applications, representing 31% of the total sales.

However, it is common knowledge that plastic waste is a growing concern in today's society. Indeed, the annual global plastics production has exploded in the last few decades, shifting from 70 million tons in 1980 to 381 million tons in 2015 (Geyer et al, as cited in Ritchie & Roser, 2018). In 2015, Europe was the second biggest global plastic producer – 20% –, right behind China – 24.8% (Plastics Europe, 2015).

One of the main issues with plastics is the disposal method used at the end of their life, with the general alternatives being recycling, incineration and discarding. Ritchie & Roser (2018) have highlighted that the share of plastic waste being recycled and incinerated has increased since 1980, to reach respectively 20% and 25% in 2015.

Nevertheless, the issue still comes from the discarded part of waste which is not managed in an efficient way and often ends up in uncontrolled landfills or in the oceans, which is affecting mostly marine life, and thus indirectly human life. A 2016 study released by the World Economic Forum (as cited in Jacobo, 2019) has shown that 8 million tons of plastics enters the oceans every year; most of the time due to heavy rains which are moving landfilled plastics to rivers, and then to the oceans. Plastic is therefore more and more seen as an adverse product that needs to be put away from the supply chains as often as possible.

Following those observations, series of measures have been taken by governments and legal entities to slow down the negative effects associated to the use of plastics. Among those, one can cite the 'Circular Economy Action Plan' – as part of the new 'European Green Deal' – , which states legal proposals on waste and long-term sustainable achievements to stimulate the transition towards a more circular economy in Europe (European Commission, 2019). Some of the key elements committed for this new action plan are the following:

- Targeting 75% of packaging waste to be recycled by 2030
- Reducing landfill to maximum 10% of municipal waste by 2030
- Promoting re-use of materials
- Incentivizing greener and easier-to-recycle products
- …

However, all of these measures, facts and figures have raised awareness amongst consumers and supply chain actors, which are phasing-out single-use plastics and are turning to more reusable and sustainable solutions (J.P. Morgan, 2019). This new consideration has largely changed the behavior of supermarkets, retailers or even Fast-Moving Consumer Goods (FMCG) companies, which are looking at alternative materials for their packaging, such as compostable or bioplastics packaging.

That being said, the actors of the food industry sector, huge consumers of packaging, have thus been impacted by these new trends in the past few years and are trying to find alternatives to single-use plastics respecting the best tradeoff possible between environmental-friendly and financially-viable criteria. Some cities and states have also set up their own restrictions for packaging. Indeed, when it comes to packaging, one can see the progressive adoption of reusable recipients, containers, etc., for example inside companies as a new Corporate Social Responsibiliy (CSR) tool or even in the cities which want to commit to a 'greener' public area.

Some restaurants, for example, started prohibiting different kinds of plastic food containers, providing certified-compostable packaging or charging customers for the use of any single-use food container (National Restaurant Association, 2019).

Other catering services such as schools or hospitals canteens are also following the 'plastic cut' move, like for example the National Health Service (NHS) – publicly funded healthcare system in the United Kingdom – which has published in October 2019 a statement according to which around one hundred million plastic straws, cups and cutlery will be cut from hospital canteens, as part of a measure that the NHS group wants to follow in order to reduce environmental impacts on the health service (George, 2019). The goal is to start with the ban of straws and stirrers and extend that measure to plastic plates in the following year.

Nevertheless, despite the trends pushing towards the removal of any type of single-use plastics, the other packaging alternatives are not automatically considered as a better solution, given the supply chain constraints that they imply – for example additional transportation, cleaning, … – in terms of financial and environmental costs. This is what will be discussed within the scope of this thesis.

More specifically, the thesis will look into the kind of food container – single-use or reusable – which is used in a specific public catering context. The question as to whether or not it is preferable to favor reusable or single-use container can depend on some factors/stages of the lifecycle and emission indicators, and that is what will be investigated further in this specific research. Shifting from literature to reality, a deeper study will be performed in the framework of a hospital. Indeed, even though the food department in hospitals may not be the main focus area, it still has to provide important day-to-day supply chain activities, which made it relevant to choose this particular context for the case study.

1.2. Research question

The research question forming the basis of this thesis can be defined as:

'Single-use' versus 'reusable' food packaging in the supply chain of catering services: A case study comparison between the financial and environmental impacts of the plastic trays and stainless steel containers.

This will be done mainly by presenting the situation of the food supply chain in a Belgian hospital group – Vivalia Group – which is currently using disposable plastic trays in polypropylene (PP) for the preservation and transport of 'bulk food' from a Central Production Unit (CPU) until the hospital site(s). This situation will be then compared to a potential 'to be' situation, using reusable stainless steel containers.

1.3. Goal of the research

The main goal of this thesis is the evaluation of the financial and environmental impacts of the different life-cycle stages for single-use versus reusable food trays in the catering industry, in the particular framework of an hospital. It will also highlight the field of application, advantages and drawbacks of both types of trays, and involve a discussion on the possible deeper research to be realized.

1.4. Definition of the scope

The research is a first approach to a comparative Life Cycle Analysis (LCA) study realized on single-use plastic trays versus the reusable stainless steel containers. A 'cradle-to-grave' approach has been considered, taking into account the manufacturing, transportation/distribution, use and end-of-life stages. Some hypotheses were studied to estimate the data which was more difficult to collect.

1.5. Thesis structure

The first part of this paper consists in a review of the literature – both scientific articles and information obtained from the 'grey literature' –, which will be separated into three main points:

- An overview of packaging applications and trends, and an introduction to Life Cycle Analysis concept and environmental impact indicators.
- The main findings of research already done on the environmental or financial impacts of any kind of single-use versus reusable food containers, all along their life-cycle. An identification of the dimensions the most impacted in the life-cycle of those food containers will be realized as well.
- The main findings of research regarding the implementation of stainless steel containers versus plastic trays already realized within public catering services, as an introduction to the case study.

The second part will consist in an overview of the different supply chain network configurations for the two situations studied, for which information was collected in a hospital intermunicipal association – namely the Vivalia Group. The life cycle inventory will be presented for both situations, summarizing the data that will be used. After this, the evaluation of environmental impacts will be realized for each step of the life-cycle, followed by the evaluation of costs.

Finally, the last part of the thesis will concern the potential advantages/issues and challenges regarding both types of packaging, as well as discussions and recommendations on the alternative that might be preferable to use, and the dimensions to focus on for any potential further investigation.

Regarding the methodology and tools used, the data collected is based on research and interviews with Mr Philip Gaspar and Mr Hugues Renard, respectively Head of Catering and Coordinator at the Food CPU for the Vivalia Group. The analysis on the different dimensions of the supply chain has been done thanks to a first approach to life-cycle analysis methodology, and the evaluation of environmental impacts has been realized with the use of a tool called 'Bilan Produit®', developed by the 'Agence de la transition écologique'(ADEME). A second tool called 'EcoTransIt' was used to challenge the results obtained for the transportation flows with the first tool.

2. Literature review

In this first part, the global trends of food packaging will be mentioned, as well as the main types of food packaging with their corresponding characteristics, followed by the definition of the 'Life-Cycle Assessment' and its components. Then, a small overview of case studies realized on the comparison of single-use and reusable food packaging on a wider dimension will be presented. Finally, some implementations already realized for specific reusable food containers in the public catering industry will be reviewed, as a small introduction to the case study.

2.1. Single-use versus reusable food packaging: global trends

As mentioned before, single-use plastic ban has become a trend all over the world, especially for food packaging applications used in different food services, as it can be illustrated by a few examples:

- In 2019, the World Wide Fund for nature (WWF) has announced a reduction of single-use plastics in Singapore in more than 270 businesses and restaurants among the food and beverage industry, going from small entities to large global companies such as Sodexo – which is catering food to schools, hospitals and multinational corporations –, with cost remaining the main challenge of that change (Quek, 2019).
- In Switzerland, the trend has been followed as well in the 'Centre Hospitalier Universitaire Vaudois' (CHUV) in Lausanne, where single-use plastic tableware has been banned from the staff canteen for the take-away meals. As said in a press release (2019), the CHUV distributed in 2018 "100000 plastic trays and lids, as well as 80'000 sagex bowls", which would account for 4.4 tons of plastic waste each year.
- Food industry actors have experienced a shift in mentalities, with FMCG giants such as Nestlé and Ferrero committing to actions such as making 100% of their packaging either reusable or recyclable by 2025 (Ferrero, 2019.; Nestlé, 2020).

However, when it comes to reusable containers, opinions still differ. Indeed, a big concern regarding the reusable packaging is about hygienic aspects. In order to reuse the food container, there has to be a warranty that the recipient is washed in a correct way before being reused, and the recipients might not always be fitted for the kind of food proposed in the places using the reusable system (Roosen, 2019).

The concern about the cleaning part of reusable containers is also shared by the Foodservice Packaging Institute Incorporated (2007), which stated that food borne diseases cause around “325000 hospitalizations, and 5,000 deaths in the United States each year”. A 2002 study realized in Nevada in restaurants, coffee bars, etc. showed that 18% of reusable items cleaned had more than the accepted standard of 100 colonies bacteria per item (as cited in Foodservice Packaging Institute Incorporated, 2007). Therefore, the Food and Drug Administration’s Food Code has established specific cleaning facilities requirements for any entity which wishes to turn to reusable containers, and public officials have been reported to say that “food safety and sanitation benefits of single-use foodservice products far outweigh any perceived impact on the environment” (as cited in Foodservice Packaging Institute Incorporated, 2007).

2.2. Food packaging: characteristics and applications

Food packaging holds several important roles: it maintains benefits of food processing at the end of the process – such as consistence, etc. –, it permits food to travel for more or less long distances and still be saleable at the point of consumption (Bugusu & Marsch, 2007). Apart from that, it also includes diverse other roles such as marketing, information or traceability. Bugusu & Marsh (2007) have highlighted the different materials from which food packaging are usually made, and their main characteristics. It is illustrated in the *Table 1* below.

Table 1: Overview of the materials in food packaging and their main characteristics

Material	**Main characteristics**
Glass	Good resistance, low manufacturing cost, maintains a longer freshness of period for the product, handles high processing temperature, can be easily reusable and recyclable. But: quite heavy, breakable, leads to increased transportation due to weight, and thus increased environmental impacts
Metal	Combination of good physical protection, corrosion resistance, decorative potential, recyclability, lightweight, … But: relatively expensive Main packaging metals used: aluminum and steel
Plastics	Mainly thermoplastics – which can be shaped and molded into several products –, usually recyclable even though certain types of plastics require a harder separation by resin type. Usually low-cost material with functional advantages – such as microwaveability –, but depends on the type of plastic
Paper	Main use in corrugated boxes, bags, and wrapping. Its light weight is a positive characteristic for transportation, but this material is not a good barrier for air and moisture. It usually has a low-cost
Paperboard	Higher weight than paper, usually low-cost, used mainly as a container for shipping and quite unlikely to be used for direct food contact

All of those characteristics therefore need to be taken into account when selecting the perfect material for a specific food packaging application, as well as different other factors, such as the type of food, the possible food/package interactions – like the migration of certain plasticizers, monomers, etc. from the package to the food –, the shelf-life wanted, the storage and transportation conditions, the costs throughout the different life stages of the product, and the disposal method chosen at the product end-of-life. (Bugusu & Marsh, 2007). Looking at the scale of the whole life-cycle leads to the definition of Life Cycle Analysis.

2.3. Life Cycle Analysis definition and explanations

As this thesis is comparing financial and environmental impacts for two types of food containers, the Life Cycle Analysis concept needs to be explained. The United States Environmental Protection Agency (US EPA) (as cited in Brusseau, Gerba & Pepper, 2019) defines Life Cycle Analysis – also called Life Cycle Assessment – as "a tool to evaluate the potential environmental impacts of a product, material, process, or activity". In other terms, LCA is thus a method which is considering all the different stages of the life-cycle of a specific product – such as raw materials sourcing, manufacturing, use and disposal – and evaluating their direct and indirect environmental impacts (Brusseau, Gerba & Pepper, 2019). In 2006, the U.S. EPA (as cited in Brusseau, Gerba & Pepper, 2019) highlighted the four main steps of a LCA method:

- the product or process description and context limitations
- the inventory analysis to quantify the environmental impacts
- the assessment of those impacts
- the interpretation of results and uncertainties that occurs during the assessment

Those are the steps which will be followed for the specific case study realized in the empirical part of this thesis.

2.3.1. Overview of common environmental assessment indicators

In a report realized by the Joint Research Centre of the European Commission about the environmental impact of EU consumption, Beylot, Corrado, Crenna, Sala, Sanyé-Mengual & Secchi (2019) are presenting the Environmental Footprint method which is defining sixteen different indicators quantifying the environmental impacts, as the following:

- **Climate change / global warming potential**: measures the global temperature increase due to greenhouse gas emissions (GHG). It is measured in kilogram of carbon dioxide equivalent – "kg CO_2 eq." –, which means the emissions are compared to the global warming potential of one kilogram of CO_2
- **Particulate matter**: measures the impacts caused by particulates on human health
- **Ionizing radiation**: measures different ionizing radiations on human health
- **Ozone depletion**: measures the impact of the depletion of stratospheric ozone layer, which releases ultraviolet radiation
- **Photochemical ozone formation**: measures the impact of substances contributing to the formation of photochemical ozone on the ground

- **Acidification**: measures the emissions in the air, water and soil which cause acidification, mainly due to combustion processes in electricity, heating and transport processes
- **Eutrophication, terrestrial**: designates the impact of substances containing nitrogen or phosphorus on ecosystems, which limit growth of such ecosystems
- **Eutrophication, fresh water**: designates the same kind of impact as the terrestrial eutrophication, with the exception that it applies for water context, with nitrogen and phosphorus coming mainly from fertilizers used in agriculture and causing the appearance of algae which decrease the quantity of oxygen available for fishes
- **Eutrophication, marine**: designates the same kind of impact as terrestrial and fresh water eutrophication, except that it is only caused by nitrogen emissions, mainly coming from agricultural fertilizers
- **Human toxicity, non-cancer**: measures the impact on human health caused indirectly by the absorption of substances vehiculated in the air, water and soil
- **Water use**: measures the impact of water used in an environment where it is considered as a scarce resource
- **Resource use, minerals and metals**: designates the impact of the current extraction of minerals and metals on a future extraction of the same resources
- **Ecotoxicity, freshwater**: designates the adverse impacts of some toxic substances on species and the functioning of an ecosystem
- **Human toxicity, cancer**: measures the impact on human health caused indirectly by the absorption of cancerous substances vehiculated in the air, water and soil
- **Land use**: measures the loss of organic matter content of soil, caused by use and transformation of land for different activities, such as agriculture, roads, mining, etc.
- **Resource use, fossils**: designates the impact of the current extraction of fossil matters on a future extraction of the same resource

Those indicators are very commonly used in LCA-related studies; they therefore provide a good basis for evaluation.

2.4. Food packaging life-cycle stages and observations

Nowadays, numerous companies, governments and other entities are trying to reduce their environmental impacts on certain specific life-cycle stages of products or services they are offering and consuming. Bugusu & Marsh (2007) have highlighted in their paper some actions proposed by the US EPA to better manage municipal solid waste resulting from food packaging use, in order to decrease the corresponding environmental impacts. One of these actions is the source reduction, that can be achieved for example by using bulk food packaging or reusable/refillable containers.

Another important stage of the life-cycle is the end-of-life stage, which can be mainly of three types, as described in Bugusu & Marsh (2007):

- **Recycling**, which includes different stages: collection, sorting, processing, remanufacturing and sale; all of these stages having a non-neglectable cost both financially and environmentally. Moreover, the end-application resulting from the recycling process depends on the material which is being treated, with packaging plastics very unlikely to be used again in food-contact applications due to the organic contaminants which still remain after the reprocessing stage.
- **Combustion/incineration**, which designates the controlled burning of waste in an appropriate facility and allows to reduce municipal solid waste volume up to 90%. It is a good alternative system for materials which cannot be recycled or composted. Combustion incinerators are used because the steam they produce recovers either heat or electricity.
- **Landfilling**, which is a disposal solution for any remaining waste and residues from recycling and combustion processes, and which is usually managed by state regulations. Some more technologically-advanced landfill infrastructure can have devices allowing to collect landfill gases and potentially use them as energy resource.

However, choosing a single-use or reusable alternative can be questionable from an 'end-of-life' perspective. Reusing brings its set of constraints, such as the cleaning part to remove any hazardous contaminant, which needs consequent volumes of water and the use of detergents often made of chemicals not ideal for the environment. In addition, transportation back to the point of reuse may also demand a lot of energy, and the same goes for the recycling scenario, where the wasted items need to be transported until a recycling plant. When it comes to incineration, lots of gases are emitted, such as carbon dioxide, acidic gases or other particulate matters, that must be carefully controlled as well (Bugusu & Marsh, 2007).

Finally, waste ending up in landfills tends to decrease nowadays, but one must now that this disposal method can lead to groundwater contamination and air pollution by the intermediate of landfill gases (Bugusu & Marsh, 2007).

2.5. Overview of some LCA-comparison case studies ran for food packaging

Several authors have run LCAs to compare single-use and reusable packaging, and they have identified the factors and stages of the life-cycle that are influencing the environmental impacts the most, considering the specific situations of the products being studied. Of course, the question as to whether or not it is preferable to favor reusable containers depends on the situation, as well as on several new dimensions of the life-cycle of the container which need to be taken into account – as mentioned above –, such as collecting, additional transportation and cleaning processes. Different countries also chose to favor one or the other type of container, according to different criteria, which makes the choice of the preferred container very blurry (Bugusu & Marsh, 2007).

It was noted that reusable packaging could be a good alternative to be considered in at least 20% of plastic packaging application (Ellen McArthur Foundation, 2017 & 2019, as cited in Corona, Megale Coelho, ten Klooster & Worell, 2020). The authors have highlighted that the globalization of supply chains and the simplified logistics flows associated to single-use plastics have favored the use of this alternative. However, they stated that reusable alternatives may be implemented more easily in a Business-to-Business (B2B) context rather than in a Business-to-Consumer (B2C) context, with individual consumers needing to change their habits to integrate the reverse flows into their consumption experience.

Corona et al. (2020) also mentioned that reusable alternatives should not be encouraged when the supply chain systems are complex, the materials used hardly recyclable and the transportation distances are important. A study conducted by the Waste and Resources Action Programme (WRAP) (2010b, as cited in Eatherley, Lee, Neto, Rodriguez-Quintero, Sjögren & Wolf, 2016) came to the same conclusion, adding that reusable packaging solutions must be preferred when the number of reuse is able to counterbalance the higher environmental impacts due to the manufacturing stage in the single-use scenario, as it is illustrated in *Figure 1* below.

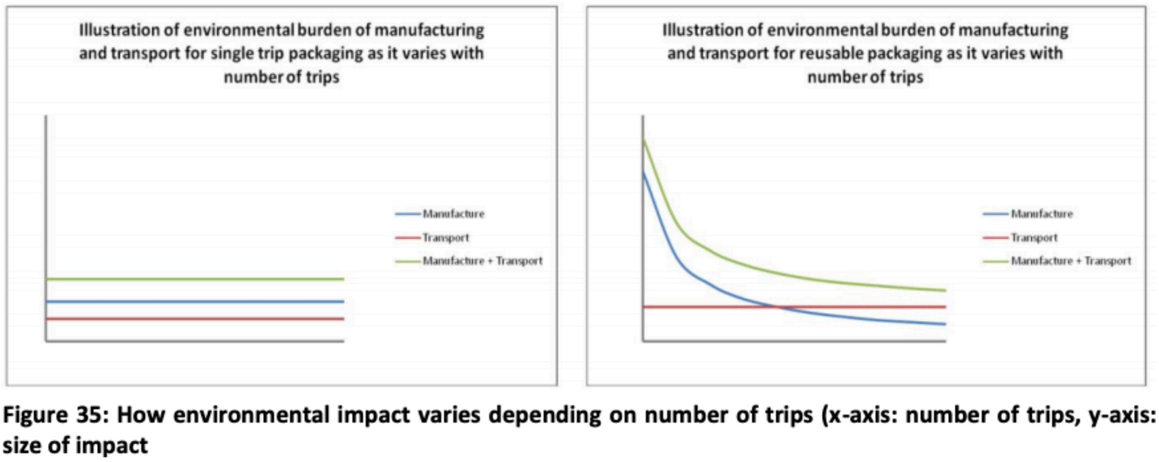


Figure 1: Influence of the number of trips on the environmental burden

(WRAP, 2010b, as cited in Eatherley, Lee, Neto, Rodriguez-Quintero, Sjögren, & Wolf, 2016)

Cortesi, Levi, Salvia & Vezzoli (2011) are also considering the number of reuse in their paper comparing disposable and reusable packaging in an Italian fruits and vegetables supply chain. The authors mention that the impacts calculated on the production and end-of-life stages of the life cycle for the reusable alternative decrease considerably when the number of uses is important, since they divided the impacts calculated at those stages by the number of uses. It is also noted that the gain in environmental impacts over the whole life cycle is very important if the number of reuse is smaller than ten, and is almost undetectable when the number of uses goes over fifty – when the number of uses is important, the change in impacts becomes asymptotical. The outcome of the study, considering the specific network observed, is that single-use cardboard boxes are more environmental-friendly on most of the indicators, except for the Acidification Potential and the Eutrophication Potential.

In terms of environmental impacts, Abejón, Aldaco, Bala, Fullana-i-Palmer & Vázquez-Rowe (2020), comparing as well single-use and reusable containers for fruit and vegetables transportation and preservation, concluded that the reusable alternative was the solution to be favored, with overall lower environmental impacts than the single-use item. Most of the impacts were occurring during the production stage for the single-use alternative, whereas the use stage counted more environmental impacts for the reusable alternative. The environmental differences between both alternatives were the least important for the Acidification Potential indicator, and the most important differences were noticed through the Ozone Depletion Potential indicator.

Accorsi, Cascini, Cholette, Manzini & Mora (2014), also studying the comparison between different single-use alternatives and a reusable alternative in the framework of fruit and vegetables transportation – but only under the Global Warming Potential indicator –, noticed the same patterns, favoring the use of reusable containers – even when smaller lifespans were assumed. The use phase caused the most important emissions due to the increase of trucks needed, resulting from the increased weight of containers transported, as well as new transportation needed to reach the washing facility. However, the authors added that the disposal phase was also extremely important in terms of CO_2-equivalent emissions for the single-use alternatives. The differences in environmental impacts resulted mainly from the choice of the disposal method and the packaging lifespan assumed for the reusable alternative.

In another study comparing reusable plastic containers and single-use corrugated boxes transporting fresh fruits and vegetables, Chonhenchob, J. Singh & S.P. Singh (2006) argued that even though the environmental savings brought by the recycling and recovery processes are quite high for the single-use scenario, the savings gained thanks to the multiple turns of containers in the reusable scenario are higher. The study concludes that the reusable alternative is better environmentally-speaking, as it results in lower greenhouse gas emissions, lower solid waste production and lower energy consumption. The authors challenged the result thanks to a sensitivity analysis, that they implemented by varying some parameters and found out that the following actions were decreasing the environmental impacts difference between both alternatives:

- Increasing the loss rate for reusable containers
- Decreasing the weight of single-use packaging

Just to cite one more example, Azapagic, Gallego-Schmid & Mendoza (2018a) have studied the environmental impacts occurring this time all along the life-cycle of reusable plastic and reusable glass food savers. Even though plastic food savers have the biggest market share thanks to their numerous advantageous properties – light weight, low cost, … –, research has stated that they might have a negative impact on health due to the potential release of a chemical molecule into the food (Duracio et al., 2013, as cited in Azapagic et al., 2018a; Earth Talk, 2008, as cited in Azapagic et al., 2018a; NRDC, 2011, as cited in Azapagic et al., 2018a). A good alternative to those plastic food savers has thus been found with glass food savers (Girling, 2003, as cited in Azapagic et al., 2018a).

In their paper, Azapagic et al. (2018a) are highlighting that, unlike the majority of other studies realized on reusable packaging, where most of the environmental impacts are happening during the transportation stage, the washing processes observed are here the most important environmentally-speaking. It can be explained by the alternative processes studied – either automatic dishwasher or hand washing, which are respectively consuming a lot of electricity, and natural gas to heat the water. As the authors observed that the glass food savers were globally having higher environmental impacts than the plastic alternative for a fixed number of uses, a sensitivity analysis was run to find out the multiplicating factors for each impact indicator which could equal the impact quantities for both alternatives. In the particular framework of this study, it was noted that glass food savers require 1.3 to 3.5 times higher lifespan to see their environmental impacts reduced at the level of those caused by the plastic containers. Moreover, varying the lifespan of the different containers did not lead to a significant change in the impacts observed, but it increased the contribution of the use stage in the total impact quantities.

Regarding the factors influencing the costs for the reusable alternative, Corona et al. (2020) have identified six main elements:

- The transportation distances
- The volumes handled in the market
- The presence of a standardized system
- The return rate of the packaging
- The cleaning dimension
- The labor dimension

Burgess, Closs, Lee, Mollenkopf and Twede (2005) have developed different cost systems approaches to help decide between different packaging alternatives, and they added that the frequency of supply and the container cost ratio – depending on the size of the container – were two other important factors to take into account in the cost evaluation of those alternatives.

Accorsi et al. (2014) also included a dimension about cost in their paper, stating that the reusable system could allow to save money on the packaging purchasing phase, whereas new requirements of that system – such as traceability, increased labor, … – would lead to a significant raise in cost. The adoption of such a system would be expected to end up in a cost increase of about six cents per kilogram of food transported.

In order to summarize the statements made on environmental and cost dimensions for the different kinds of packaging, Mahmoudi and Parviziomran (2020) have recently brought to light different factors influencing the environmental and economic costs linked to reusable packaging alternatives. Among those, Mahmoudi and Parviziomran (2020) are citing different factors identified in several other studies (Twede, 1999; Van Doorsselaer & Lox, 1999; Ross & Evans, 2003; Gonzalez-Torre et al., 2004; Lee & Xu, 2004; Mollenkopf et al., 2005; Tsiliyannis, 2005a):

- Storage space available for the empty containers
- Labor
- Washing and repair operations
- Loss rate of containers
- Geographical location
- Demand in the market
- Weight of package
- Degree of recyclability
- Percentage of reusable pieces in the whole packaging
- Amount of product being transported for each trip
- Cycle time
- Consumer discard rate
- …

A few other studies on similar subjects can be found in *Table 2* below, with their corresponding outcome.

Table 2: Overview of other LCA-studies found in the literature

Authors	**Subject discussed**	**Outcome**
Lee and Xu (2004)	Comparison of wooden pallet and reusable/recyclable plastic bulk transit packaging system used to transport empty yoghurt pottles	Reusable plastic containers cause globally less environmental impacts
Bala, Blanca-Alcubilla, Colomé, de Castro and Fullana-i-Palmer (2019)	Comparison between reusable and single-use tableware items used in the aviation catering sector	Reusable items are responsible for 73.4% of CO_2-equivalent emissions – mainly due to the heavier weight –, against 26.6% for the single-use items
Dahlbo, Judl, Korhonen, Koskela and Niininen (2014)	Comparison between reusable plastic crates and single-use recyclable corrugated cardboard boxes for product transportation	Single-use carboard boxes cause less environmental impacts than reusable plastic crates – for a quite complicated supply chain network, and for six different environmental impacts indicators
Azapagic, Gallego-Schmid and Mendoza (2018b)	Comparison between single-use food take-away containers and reusable containers	Single-use polystyrene containers are the best option environmentally-speaking, also better than the reusable options, unless they reach a certain number of uses

2.6. Introduction to the case-study: plastic trays versus stainless steel trays

2.6.1. Implementations already done in public catering services and findings

Public catering entities can be defined as entities providing food services to public infrastructures, such as hospitals, schools, nurseries, … Public catering services have always included an important logistics part in their activities, whether it is for the sourcing of food items, packaging or the delivery of meals to the final place of consumption. It is often organized around a central kitchen – as opposed to conventional 'on-site' kitchens –, distributing the food items to the different sites it serves, which usually include a smaller kitchen in which the different food items are potentially plated and warmed up. In order to ensure a good preservation and transportation of the food, adequate food containers must be chosen as packaging.

Nevertheless, catering services are also being impacted by the growing environmental concerns of the current generation. Indeed, the European Union has launched the European Union Green Public Procurement (EU GPP) initiative, which is encouraging amongst others public catering services to source food, packaging, etc. with a limited environmental impact all along their lifecycle (Commission of the European Communities, 2008, as cited in Eatherley, Lee, Neto, Rodriguez-Quintero, Sjögren, & Wolf, 2016). Some public catering services have thus decided to turn to reusable containers in their kitchen.

In 2018, France has voted a new law called 'EGAlim', which states several measures that need to be taken regarding private and public catering, covering different entities such as primary schools, nurseries and university canteens (Conseil National de la Restauration Collective, 2020). Amongst others, it prohibits single-use plastic utensils – such as glasses, plates, straws, etc. – and plastic food containers (art. 28 EGAlim law, as cited in Conseil National de la Restauration Collective, 2020). Ever since, several French canteens kitchens have shifted to reusable food containers, and more specifically stainless steel containers.

In September 2018, 42% of students in Strasbourg schools already ate in reusable food containers, and the goal was to remove 100% of single-use plastic food containers over a four-year period (Gérard, 2018). One specific action put in place to avoid useless truck transportation and hundreds of wasted meals per day was the implementation of an online booking system, to know in advance how many meals would need to be prepared, thus following a pull supply chain strategy (Buffet, as cited in Gérard, 2018).

However, in order to be able to do this shift from plastic to stainless steel containers, the infrastructure of some sites will need to be rethought – such as the purchase of new ovens and fridges fitting the size of the new containers –, which will require an additional cost of around 1.2 million euros over the four-year period (Association "Cantine Sans Plastique France", 2018), next to the increased cost caused by the additional staff needed. The four-year program is estimated to save 1.5 million non-recyclable plastic containers from waste (Gérard, 2018). Strasbourg was the first large French conglomeration to take that measure, but parents associations are trying to encourage the shift in other cities as well (Poussard, 2017).

Indeed, apart from the decreased share of plastic waste, an argument that pushed the institutions to give up on plastic containers in the school canteens was the potential presence of endocrine disruptors in such containers. The World Health Organization (WHO) has defined in 2002 an endocrine disruptor as a "substance or a mixture of substances, which alters the functions of the endocrine system, and thereby induces adverse effects in an intact organism, in its progeny or within sub-populations" (as cited in Association "Cantine Sans Plastique France", n.d.). Plastics in general may contain endocrine disruptors, and more specifically Bisphenol A, which is, amongst others, an additive giving its properties to plastic and whose use appears to have negative consequences for the health if it migrates into food – such as obesity, cancers, etc. That kind of endocrine disruptor was prohibited in France since 2015 in all food containers and replaced by substitutes, appearing to have the same issues (Association "Cantine Sans Plastique France", n.d.; Moon, 2019). It remains that its use is still very controversial, given that European law is still allowing it, not to penalize the industrial corporations.

The lack of research on the potential environmental impacts caused by a shift from plastic trays to stainless steel containers also make some entities – school canteens, etc. – reluctant to change their habits. For example, the school canteens in Thionville, France, have shifted to stainless steel food containers since February 2019, thanks to an investment of 20000 euros for around 500 stainless steel containers, but no data on transportation consumption has been calculated for the moment (Rodier, 2019). In Lyon, a two-week test has been realized for the implementation of stainless steel food containers instead of plastic trays (Ville de Lyon, 2019). The conclusion of the test highlighted advantages, such as the reduction of waste, or the decreased risk to be exposed to endocrine disruptors.

However, it also brought its set of constraints: the huge investment represented by the need to buy proper equipment to support the containers, the increase in the number of delivery trucks, additional staff needed for the cleaning operations, storage issues, the increase of water, electricity and detergent consumption, etc. (Ville de Lyon, 2019).

3. Field research : the case study of Vivalia Group

3.1. Vivalia Group: description of the context

Vivalia Group, a Belgian intermunicipal association covering mostly Luxembourg province, is composed of six hospital infrastructures, one polyclinic, a home for psychiatric patients, four rest and care homes, a safe house and three nurseries; all of sixteen sites located in the Luxembourg province. In 2018, Vivalia counted not less than 1600 authorized beds, and around 46000 annual patient admissions (Vivalia, 2018).

Concerning the organization of meals cooking and distribution, the different sites of the group are supplied by a Central Production Unit situated in Bertrix, in the north-west of Luxembourg province in Belgium. This particular structure can be understood by the will of the management to remove any production activities from the sites themselves, and optimizing the flows once the meals arrive to the different sites, so they just have to be plated and warmed in regeneration trolleys. In ten years, the number of meals prepared has been multiplied by six, with around 2000 meals cooked each day, five days a week (Mouzon, 2020). The number of Full-Time Equivalents (FTEs) has also increased, shifting from 10.56 in 2009 to 16.6 in 2018 (Vivalia, 2018).

The different food items supplied to the CPU are first stored, and then either cooked with a low-temperature process – for example for fish, chicken, meat, mashed potatoes, etc. – or just cut and put in shape – for other items such as vegetables, cheese, delicatessen, etc. They are then put in bulk volumes into polypropylene plastic trays, which are vacuum-packed and put in fridges, to ensure a better preservation of the product and increase their use-by date. Of course, other types of food, such as soups, etc. are following a different cooking process, but this thesis does not aim at citing all of them, given the specificities required for certain products.

Given that the production place is different than the consumption place, the different food items are tailored to a 'cook and chill' process, meaning that they will be preserved in a cold environment after their transformation, during transportation and before being consumed on the final site – either warm or cold.

3.1.1. Specificities of the catering containers

As the core subject of this thesis concerns the packaging trays/containers used to preserve and transport the food until the place of consumption, some additional information can be found below.

The European Standard EN 631-1:1993 has been established for each catering container, which can be defined as a "container for use in the process of storing, preparing, cooking, transporting, issuing, serving and removing foodstuffs in catering operations" (British Standards Institution, 1999). The aim of this standardization was to create a similar work routine for every catering operations, by allowing interchangeability of cooking utensils, and is "based on the Gastro-Norm (GN) modular system developed by the European Committee of Standards for Collective Housekeeping as the result of standardization activities by organizations of gastronomy, hotel business and catering trade in Austria, Germany and Switzerland" (British Standards Institution, 1999). Therefore, each container has to respect certain dimensions to be considered as a 'GN container' – no matter the material used – and those containers have a specific nomenclature according to their size. In the case of Vivalia, the containers which will be studied are the containers of types GN ½[1], for which an overview of the dimensions can be found in *Table 3* here under.

Table 3: Dimensions of the Gastro-Norm containers used for the study

Nomenclature	Length (mm)	Width (mm)
GN ½	325	265

(BSI, 1999)

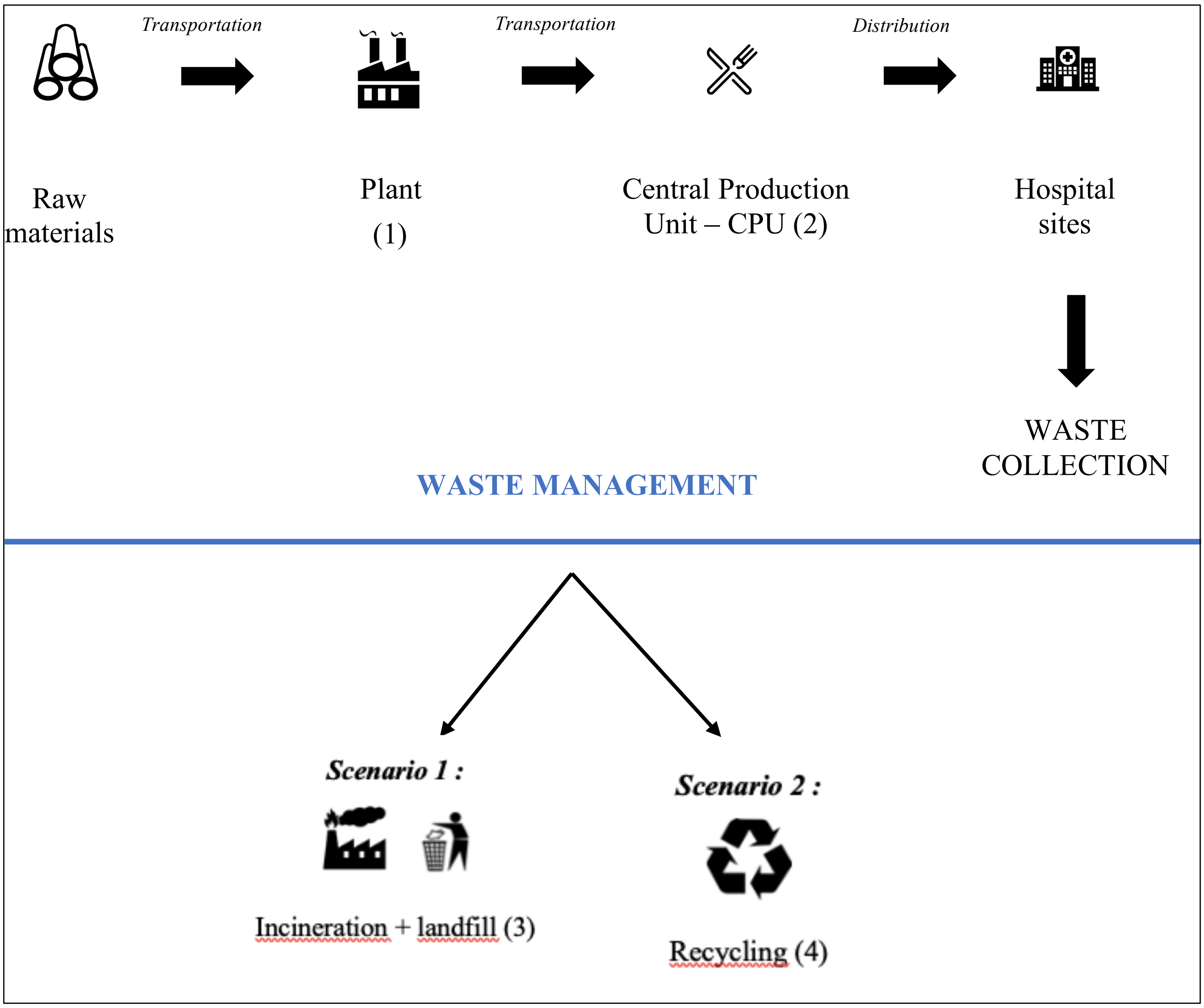
Concerning the height of those containers, different possibilities exist, which can vary according to the material used – plastic, stainless steel, aluminium, …

[1] The CPU also uses GN ¼ containers, but only the GN ½ will be considered for this study given the increased complexity of integrating them to the research, especially when using the tool measuring the environmental impacts. The data given by Vivalia about the GN ¼ trays will be converted for GN ½, knowing that the size of a GN ½ is twice the size of a GN ¼.

3.2. Supply chain network configuration

3.2.1. Current situation ‘AS IS’ – single-use trays in polypropylene

The current situation for the packaging used in the catering service of Vivalia group is depicted in *Figure 2*. The plastic trays – GN ½ – are ordered once a month to a French packaging supplier, situated in the North of France. For the purpose of the study, some data about the trays, etc. will be taken from Nutripack, a plastic food packaging manufacturer. The trays are following a specific injection molding process for the manufacturing stage, that consists in melting thermoplastic granules and injecting them under high pressure into a molding tooling, which makes the pieces with the corresponding form wanted (Office national d’information sur les enseignements et les professions, 2018; Prototech Asia, 2018). Once at the Central production Unit, the plastic trays are being used to transport bulk food to sixteen different sites, respecting the ‘cook and chill’ transport system. In order to do that, the filled trays are vacuum-packed thanks to a vacuuming machine, and put to fridge while waiting to be transported. The deliveries, done in four cycles, are following a specific predefined path to supply all sites, thanks to a single refrigerated truck, with a frequency of three days a week. Once the trays have been emptied in the sites, they are put in the municipal waste bin. Therefore, some hypotheses will be assumed, exploring the three classical disposal methods, namely landfilling, incineration and recycling. For the current situation, a first scenario with landfill and incineration will be assumed, and then a second scenario will be observed, assuming the trays are being recycled, and the wrapping part is sent to landfill and incineration, as in the first scenario.



(1) Manufacturing of the polypropylene trays and wrap
- injection molding process for trays
- extrusion process for the wrapping part

(2) Processes:
- Filling of the trays with food
- Vacuuming of the trays for preservation

(3) Waste disposal method shared between incineration and landfill

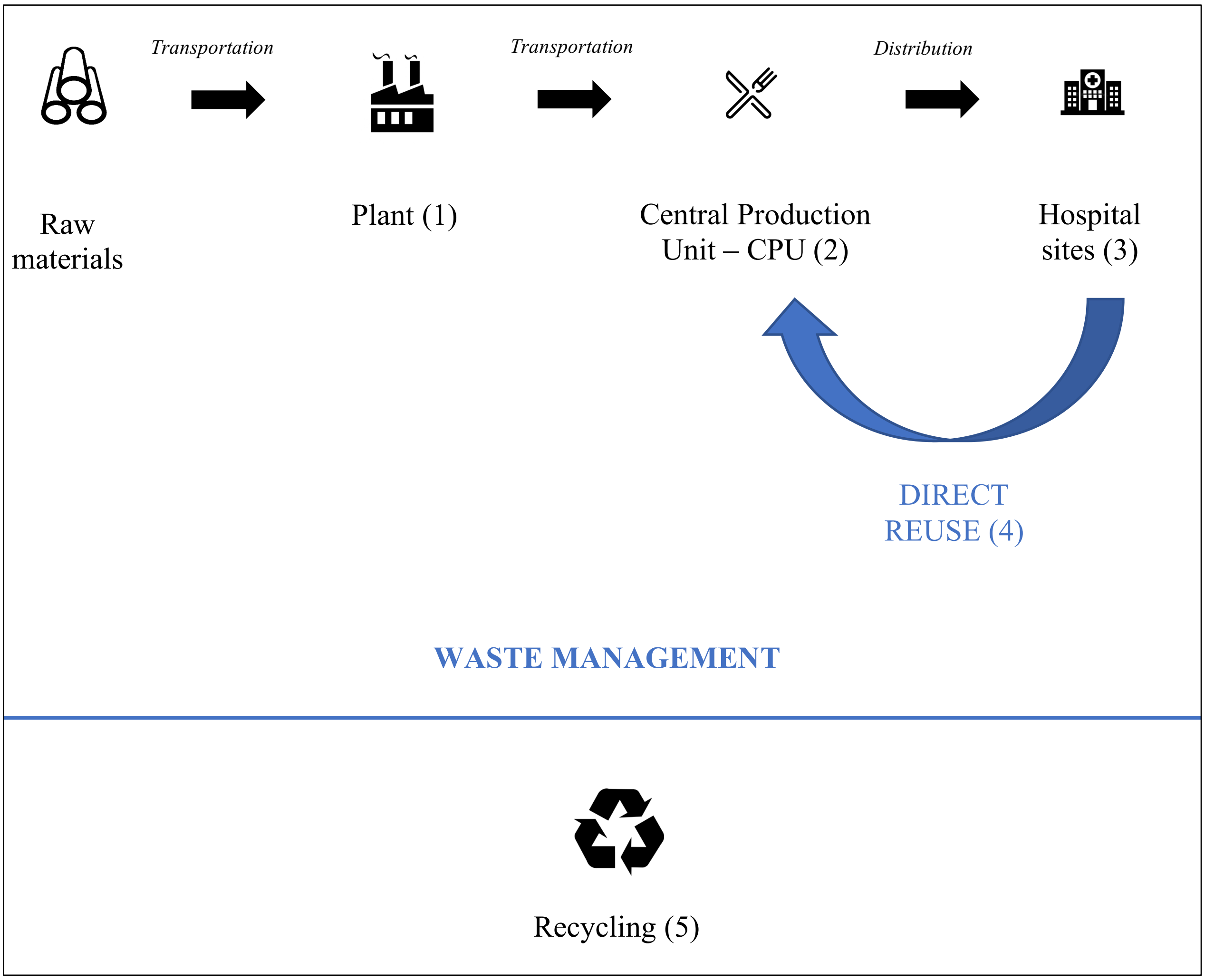
(4)Requirements:
- Cleaning of the trays
- Recycled polypropylene cannot be used in food-contact applications anymore
- Wrapping part still goes for incineration and landfill

Figure 2: Overview of the supply chain of Vivalia – single-use plastic trays alternative

3.2.2. Potential 'TO BE' situation – reusable stainless steel containers

The second situation will concern the shift to reusable stainless steel containers, closed by a stainless steel lid. The supply chain situation is represented in *Figure 3*. Several assumptions were taken for this specific situation, since there was very few information available. Moreover, given the numerous hygiene constraints needed to avoid bacterial contamination, etc., it will be considered that the same kind of food than for the plastic trays can be transported in those containers, even though some particular food such as meats with sauce, etc. might require additional protection, such as a cover with silicone to ensure a tight seal.

The stainless steel containers would be first ordered from a manufacturing plant – after a benchmark on the Internet, it was decided to choose Bourgeat Industrie, a French manufacturer in the Saône-et-Loire department, to offer a good geographical comparison basis with the plastic trays manufacturer. It is active in the manufacture of materials and equipment for professional kitchens. Then, the containers would be transported to the CPU, where they would be filled with bulk food, respecting the 'cook and chill' process, but this time, an assumption is made that the food would need to be cooked every day in the morning, and delivered every day, given that the expiry date of the food cannot be extended through a vacuum-packing process. Considering the high number of sites which need to be delivered on four cycles, and the shorter period of time for the delivery – assumption of the sites delivered before noon –, the CPU would need to invest in additional trucks to deliver the food, and reorganize the shifts, potentially leading to the hiring of new staff members. Once emptied on the different sites, the reusable containers would need to be pre-washed, and transported back to the CPU, where they would go through a second washing process. At the end of the lifespan of the container, a recycling disposal method is considered for the stainless steel, which would be first sent to a recycling branch where the containers would be crushed, and then to a steel company that could reuse the scrap metal to make new applications.



(1) Manufacturing of the stainless steel containers
  - Sheet-metal stamping process

(2) Processes:
  - Filling of the containers with food
  - Secondary cleaning of used containers – dishwasher

(3) Requirements:
  - Primary cleaning of the containers – handwashing

(4) Requirements:
  - Transportation of empty containers from the day before back to the CPU

(5) Recycling of stainless steel – it will be remanufactured for new stainless steel applications

Figure 3: Overview of the supply chain of Vivalia – reusable containers alternative

3.2.3. System boundaries

Like in every LCA-related study, the system is analyzed including some boundaries. In this case, it was chosen not to take into account the raw material sourcing, due to the high uncertainty linked to it – geographical importation, etc.

3.2.4. Packaging specifications

Table 4[2] is showing the different packaging types taken into account for both situations, as well as their characteristics.

Table 4: Dimensions of the plastic trays and reusable containers

	GN ½ plastic	**GN ½ stainless steel container**	**GN ½ stainless steel lid**
Length (mm)	325	325	325
Width (mm)	265	265	265
Height[3] (mm)	52	65	/
Weight (kg)	0.073	0.68	0.5

A picture of the different food containers can also be found in *Appendix 1*.

[2]The data obtained here were collected through Vivalia for the plastic trays and on the websites of Bourgeat (https://www.bourgeat.fr/) and one retailer for catering utensils (https://www.materiel-horeca.com/)

[3] Even though the heights of single-use and reusable containers are not exactly the same, the difference is considered as neglectable for this research

3.3. Life cycle assessment

3.3.1. Goal and scope definition

The current single-use situation includes the manufacturing process, the transportation from the trays factory until the CPU, the vacuuming process and the distribution from the CPU to the different hospital sites. For the end-of-life, the two different scenarios mentioned previously will be studied – incineration/landfill versus recycling.

The alternative situation with the reusable containers includes the manufacturing process, the transportation from the containers factory until the CPU, the distribution from the CPU to the different sites, the preliminary washing process on the site, the transportation of the containers back to the CPU and the secondary washing process. At the end of the fifteen years, it will be assumed that the containers are being recycled.

3.3.2. Functional unit

The functional unit of the present study is to make meals available at the different places of consumption, over a pre-defined period of fifteen years, which is assumed to be the average lifespan for stainless steel (International Stainless Steel Forum, n.d.). Therefore, all the flows linked to packaging will be analyzed over a fifteen-year period.

3.3.3. Data sources and quality

This case study is only a first approach to a real Life Cycle Analysis. It includes data from several sources. A part of the information is primary data, which was collected directly at the Central Production Unit site in Bertrix, or during mails exchange with Mr Gaspar and Mr Renard, from the catering department of VIVALIA. Another part of the information is secondary data, which was obtained through the review of literature, borrowed from other LCA case studies run for similar research or found on the Internet. Finally, some data considered as unreliable or missing was estimated, or stated as hypotheses, with different scenarios being observed – especially for the stainless steel containers situation.

3.3.4. Impact assessment method

Nowadays, there are plenty of LCA-software which can be used when assessing the environmental impacts of certain products or processes. Eggermont (2013) has mentioned some LCA-software commonly used, in a report written for the 'Agence Wallonne de l'Air et du Climat' (AWAC):

- SimaPRO: one of best-selling LCA-software in the world, it grants access to eight databases, among which Ecoinvent. It also allows the evaluation through different methods (CML, Impact 2002, …) and the comparison of products.
- GaBi: software developed by the University of Stuttgart, which has several databases and allows the comparison following different assessment methods.
- Umberto: Software better-suited for industrial processes, which uses a graphic interface to build flow diagrams.
- Team: Software developed by PricewaterhouseCoopers for the calculation of life-cycle inventories and corresponding environmental impacts, specifically tailored for industrial systems.
- CMLCA: Software which does not grant access to any database or assessment methods, but allows the uploading of any external database.
- Open LCA: free open source software

In the framework of the case study realized for this thesis, and after a deeper research on the software described above, it was decided that none of them would be used to run the empirical analysis, mainly due to the licensing cost they implied, and the training it required for an optimal use – which could not be done in the conditions of the Covid-19 crisis. Instead, a specific tool called 'Bilan Produit®', developed for the 'Agence de la transition écologique' (ADEME), has been selected. The ADEME has already realized environmental reviews for several different companies in France. The tool evaluates the environmental impacts – according to several indicators – based on data coming from a specific database of the ADEME, called 'Base IMPACTS®', which has been built according to European standards and is gathering data from numerous recognized life cycle inventory databases (ADEME, 2014). The whole evaluation process is composed of the manufacturing, distribution, use and end-of-life steps. It is allowing the user to choose between several materials, and to select at each step the several processes/quantities of materials needed to complete the steps. Nevertheless, due to limited use of the tool and the quite complicated supply chain configuration of Vivalia's network, the impacts occurring all along the life cycle have been evaluated step by step, taking into account the quantities necessary over the period studied.

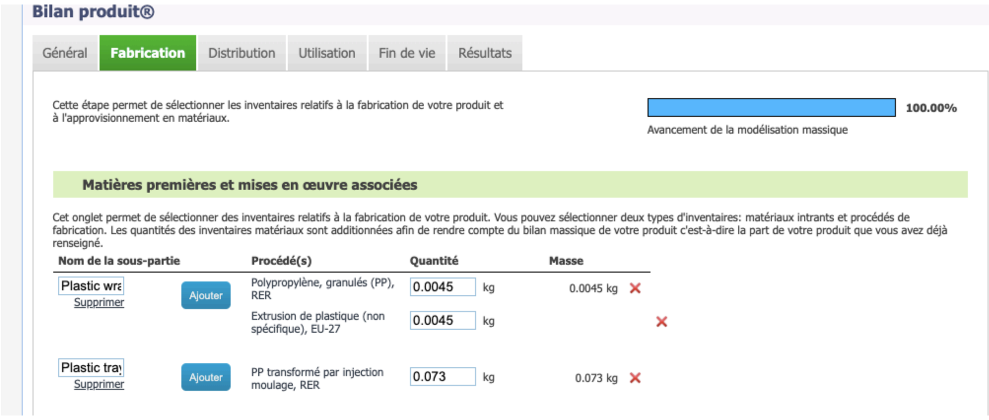


Figure 4: Example of processes and material inserted in the tool 'Bilan Produit®'

However, the accuracy of the results might be discussed, as the tool is quite limited, for example on the data available from the database. Moreover, certain processes available in the tool are taking into account too much information – for example for the transport, it includes also the infrastructure impacts, etc. – or they are not taking into account enough information – no real representation or options possible for the loading of the truck, etc.

This tool offers to study the impacts of products under several different environmental assessment indicators, which were already cited in the literature review. However, for this study, it was chosen to analyze the life-cycle of both alternative under the four following indicators: climate change - fossil, fossil resource use, photochemical ozone formation, acidification. It is important to note that climate change will be the 'flagship' indicator for this comparison study, as it is the one which is the closest to the 'carbon footprint' concept – very commonly used concept –, and is measured in CO_2-equivalent emissions. The other three indicators, which were chosen because of their frequency of appearance in other LCA-related case studies seen during the literature review investigation, will be presented more as additional information.

3.3.5. Data limitations, assumptions and hypotheses

In order to understand the limitations of the study, it must be specified that the tool 'Bilan Produit®', chosen to assess the impacts linked to each stage of the life cycle analyzed, is a tool mainly used for raising awareness to eco-design and life-cycle approaches. It therefore has limited functionalities compared to a classic LCA-software.

Moreover, for the estimation of the end-of-life impacts, some problems were encountered, due to the lack of data available from the tool to know the impacts associated with recycling processes. Therefore, those impacts were estimated thanks to secondary data found in the literature.

Given the technical aspect of the subject, the important number of information that may vary and the low data availability regarding some of that information, assumptions had to be taken all along the different steps of the life cycle, trying as much as possible to stick to reality.

However, even though the accuracy of the results can be discussed, this case study already provides a good overview for deeper future research.

Regarding the different processes, etc. used from the tool 'Bilan Produit®', a sensitivity analysis will be realized on all the steps related to transportation, in order to challenge the results obtained with the available processes, that might not be reflecting enough information from the case study. Therefore, the tool 'EcoTransIt' will be used as a second estimate of the CO_2 emissions caused by transportation. The details can be found further in this paper.

3.4. Life-cycle inventory

As stated in Chonhenchob, J. Singh & S.P. Singh (2006), Life Cycle Inventory (LCI) "quantifies material use, energy use, environmental discharges and wastes associated with each stage of a production system over its life cycle, from raw material extraction through material processing, product fabrication, use, re-use or recycling and ultimate disposal".

3.4.1. Single-use plastic trays

3.4.1.1. Manufacturing stage

It is important to highlight here that the trays delivered to the different sites of Vivalia are composed of two parts: the tray in itself and the plastic wrap which is used during the vacuuming process, in order to protect and preserve food during storage and transportation.

As said before, the PP trays are manufactured following an injection molding process. Considering the lack of information from the supplier, the injection molding will be used as the main material transformation process for this study. It will be assumed that 0.073 kilograms of PP granules are needed to build a tray weighing 0.073 kilograms by injection molding.

For the purpose of this study, it will be assumed that the plastic wrap is coming from the same supplier as the trays and is made from polypropylene. According to the product's technical sheet, the plastic wrap roll bought has a width of 330 millimeters, a length of 500 meters and weighs 8.519 kilograms (Nutripack, 2019). Thus, given that the trays have a length of 325 millimeters and a width of 265 millimeters, it is assumed that a roll can cover 1887 trays. The weight of plastic wrap per tray is 4.5×10^{-3} kilograms. It is assumed that the plastic wrap is going through an extrusion process, transforming the PP granules into plastic wrap (PlastiCompétences, 2020).

The total weight of a tray used is therefore 7.75×10^{-2} kilograms. The details of the previous calculations can be found in *Appendix 2*.

3.4.1.2. Transportation from the supplier until the CPU

For the transportation from the plastic trays manufacturer until the CPU, the data available from the 'Base IMPACTS®' database was used – transportation by truck, including road infrastructure, operation and use of truck (100%).

Given that the processes available from the database were not covering only the use of the truck, a second impact evaluation was done using the 'EcoTransIt' tool – as previously mentioned –, which calculated the CO_2-equivalent emissions, to challenge the first results.

The emissions taken into account using 'EcoTransIt' were the vehicle emissions, as done by the Tank-to-Wheels process (ifeu Heidelberg, INFRAS Berne, & IVE Hannover, 2019).

The distance between the manufacturing site and the CPU has been computed thanks to Google Maps[4], considering the shortest path, which is of 234 kilometers.

Given that an order is passed for an average of 4000 trays per month and that a plastic roll can cover 1887 trays, it is assumed that the plastic rolls are ordered monthly by 3. The total net weight in the truck is thus 317.56 kilograms. Due to some lack of information, it is assumed that the logistic packaging elements usually used to transport, protect, etc. the products are not taken into account in the calculations. The details of the calculations can be found in *Appendix 2*.

3.4.1.3. Vacuuming process

Once the trays are filled in with food, they need to be vacuumed, so their expiry date is extended, and it allows the CPU to do the deliveries only three days a week with one single truck. Following the information on the vacuum packing machine, a rhythm of 400 cycles per hour is being followed and the machine has a power of 1.8 kilowatt (Exapro, 2020; H. Renard, personal communication, May, 2020). As one cycle on the machine represents the vacuuming of one tray, it can be computed that the machine needs: $\frac{1.8}{400} = 4.5\times10^{-3}$ kilowatt-hour to vacuum one tray. The process chosen on the tool is a national average mix of electricity for Belgium.

3.4.1.4. Distribution from the CPU to the different sites

As mentioned before, the different sites are being supplied three days a week, following four different cycles. The corresponding distances are taken from Google Maps as well, and rounded up to the nearest superior integer. The path chosen is the shortest path among the different paths offered on the application.

Regarding the quantities transported to each site, the accurate allocation of trays quantities per site has been estimated based on the number of authorized beds per site for the hospital sites and homes, and the welcoming capacity for the other types of sites. Based on 2018 data, an overview of the situation on the different sites can be found in *Appendix 3* (Service Public Fédéral, n.d.; Vivalia, 2018).

[4] https://www.google.com/maps/

Moreover, the following sites distribution cycles were communicated by the CPU Head of catering, with their corresponding amount of trays[5]:

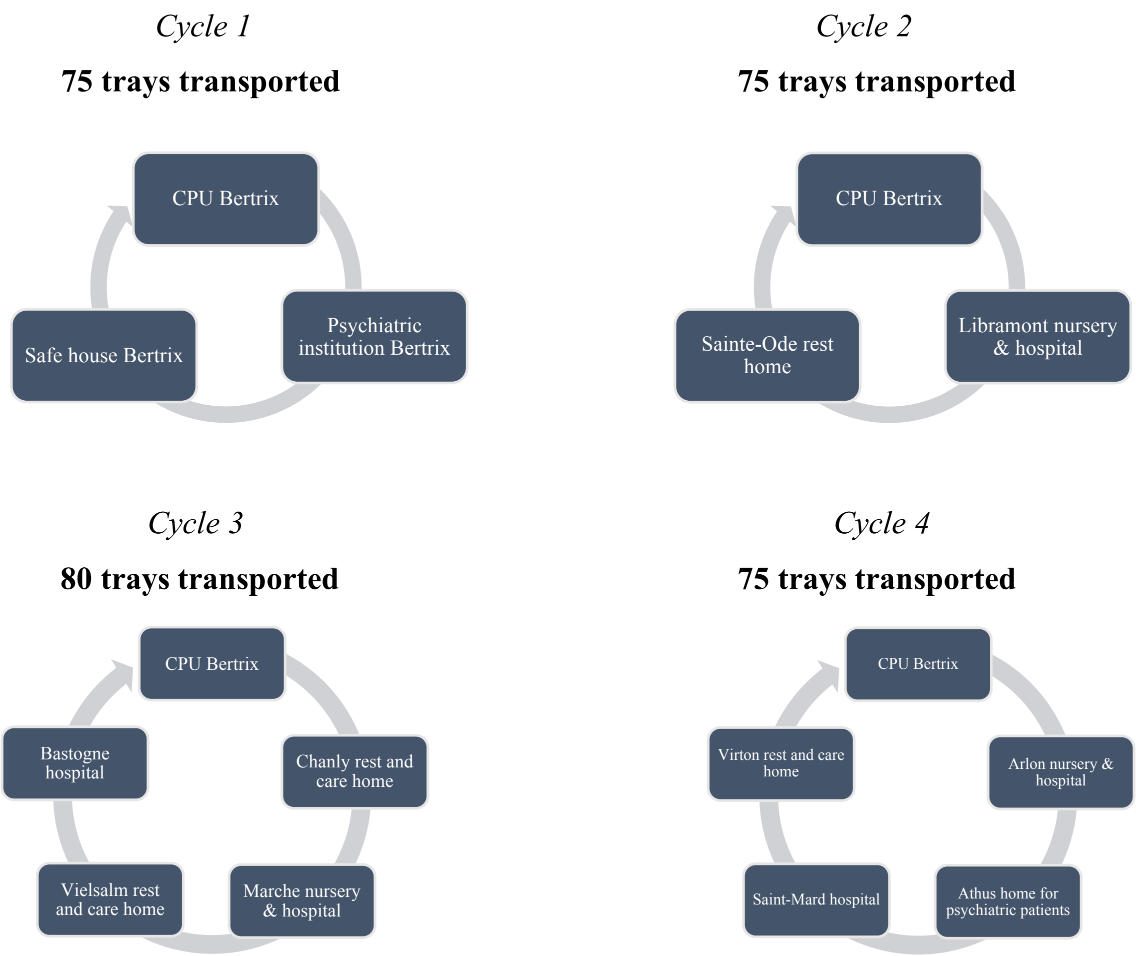


Figure 5: Delivery cycles to the different sites

Therefore, an estimation of the quantity of trays delivered per site was done based on the proportional capacity for every site, as it can be seen in *Table 5*. Some sites are delivered in the same time, given their similar location, and are therefore considered as one 'entity' just for the purpose of the study – for example for an hospital site and the nursery next to it. The calculation details can be found in *Appendix 4*.

[5] The amount written for each cycle was adjusted to only consider the type GN ½ trays. The CPU is also using GN ¼ trays, but those quantities were converted into GN ½ to ease the calculations, knowing that one GN ½ tray equals two GN ¼ in size.

Table 5: Number of trays delivered by site – single-use alternative

Site supplied	Estimated number of trays delivered per site
Psychiatric hospital Bertrix	70
Safe house Bertrix	5
Libramont nursery & hospital	63
Sainte-Ode rest home	12
Chanly rest and care home	18
Marche nursery & hospital	26
Vielsalm rest and care home	22
Bastogne hospital	14
Arlon nursery & hospital	48
Athus home for psychiatric patients	5
Saint-Mard hospital	14
Virton rest and care home	8

Another element to take into account is the weight of the food going in each tray. Given the wide variety of dishes served to the final consumer – meat, fish, chicken, vegetables, etc. – , an estimation has been made. Based on a random sample of 200 food portions from a 'weight notebook' held at the CPU, and containing the unit weight of the portions transported, the quartiles of the dataset have been computed. It appears that 50% of the unit weights are situated between 150 and 175 grams. The empirical mean was used as an estimation of the unit weight for the portions transported, and is of 166.51 grams. Based on a conversation held in December 2019 with Mr Philippe Gaspar, it was noted that a GN ½ tray could contain 15 portions. Thus, it was assumed that the total weight of the tray – plastic packaging and food – was 2.575 kilograms. The calculation details can be found in *Appendix 5*.

The accurate weight per delivery was computed according to the different cycles and trays going to the different sites, knowing that the trays were transported thanks to Returnable Transport Items (RTIs) – crates and rolls –, for which a picture can be found in *Appendix 6*. The truck used for delivery can transport 2 rolls. Each roll weighs 24 kilograms and can contain 14 crates, which have a unit weight of 1.72 kilograms. The total weight of RTIs in the truck is thus 96.16 kilograms. Knowing this, the total weight per site delivery can be computed. The calculations detailing the statements above are explained in *Appendix 7*. The distances between each site can be found in *Appendix 8*, and the weight transported per trip can be found in *Appendix 9*, with a summary in *Table 6*.

Table 6: Total weight transported in the truck until the different sites (in kilograms) – SCENARIO 1

Travel realized	Weight transported in the truck (kg)
Cycle 1	
CPU → Psychiatric institution Bertrix	Neglectable (same place)
Psychiatric institution → Safe house Bertrix	109.036
Safe house → CPU	96.16
Cycle 2	
CPU → Libramont nursery & hospital	289.297
Libramont → Saint-Ode rest home	127.062
Sainte-Ode → CPU	96.16
Cycle 3	
CPU → Chanly rest and care home	302.173
Chanly → Marche nursery & hospital	255.82
Marche → Vielsalm rest and care home	188.866
Vielsalm → Bastogne hospital	132.212
Bastogne → CPU	96.16
Cycle 4	
CPU → Arlon nursery & hospital	289.297
Arlon → Athus home for psychiatric patients	165.689
Athus → Saint-Mard hospital	152.814
Saint-Mard → Virton rest and care home	116.761
Virton → CPU	96.16

Here as well, the process available on the tool for the refrigerated truck – 'cooling truck transport (fresh) including fleet and infrastructure (100%)' – doing the deliveries also includes the road infrastructure and truck operation/utilization. That is why, in order to challenge the results obtained, the transportation data was also evaluated thanks to the 'EcoTransIt' tool, which is computing emissions directly linked to the truck – as the roads, etc. were already built.

3.4.1.5. End-of-life stage:

As mentioned before, two scenarios were considered for the disposal of wasted trays, namely:

- Landfilling and incineration
- Recycling.

The plastic trays are currently put in the bin with all the 'municipal' waste, and thus collected through the intermediary of waste collection trucks. In order to ease the comparison and the estimation, it was assumed that the trucks collecting waste on the twelve different sites studied were all managed by IDELUX Environnement, which is an intermunicipal association covering waste management activities in the province of Luxembourg and some municipalities in the province of Liège (IDELUX, n.d.). Once collected, the trucks are gathering all the waste in a waste management facility, located in Habay, where it will be either prepared for incineration or landfilled. It must be noted that the facility in Habay does not include an incineration plant, but is more a centralized facility which has an activity of preparing waste to become fuel. According to the chief operating officer on the Habay site, the waste transformed into fuel is sent every day to five different energy recovery units – Uvelia, Bruxelles Energie, Ipalle and InBw in Belgium, and Syvalome in France. (C. Dambrain, personal communication, June 23, 2020). A few years ago, part of the waste was sent for incineration to German units, but this solution is nowadays avoided, in order to shorten the environmental impacts linked to transportation and favor a national solution. For this research, it will be assumed that the prepared fuel is being sent only to Uvealia SA, a Belgian subsidiary of Intradel located in Liège (Intradel, n.d.). According to the organization Conversio Market & Strategy GmbH, around 4% of plastics are landfilled in Belgium (as cited in Plastics Europe, 2018). For this specific scenario, it will thus be assumed that 4% of the waste collected will be landfilled, and the 96% remaining will be incinerated. The associated transportation distances until the waste management facilities in Habay have been computed assuming that the collection trucks are leaving from the corresponding municipalities each week, to simplify calculations[6]. The quantities were summed up to have an estimation per municipality, and the calculations were done per week, knowing that the waste collection truck is usually coming at the end of each week.

The details of weekly quantities taken by the waste collection truck, the distances and the weight transported from the different sites to the waste management facility can be found in *Appendix 10*. For this step, the process used in the tool was once again including the road infrastructure, truck operation, etc., that is why the impacts for the transportation part will be challenged with 'EcoTransIt' as well.

[6] Of course, the trucks collecting waste are not collecting only the bags containing the trays, but the environmental impacts are calculated based on that assumption – just on the share of weight represented by the trays.

It is assumed that the fuel preparation is not taken into account in the environmental impacts evaluation, given the few information available about it.

As mentioned before with the assumptions made, 96% of the waste gathered in the facility is crushed, and then sent to the incineration facility in Liège. The distance between Habay facility and Uvelia is 131 kilometers[7]. The data which are thus taken into account for the environmental impacts evaluation are allocated according to *Table 7* – see *Appendix 10* for the detailed calculations. On the tool, the processes chosen were selected for 'residual household waste'.

Table 7: Weekly quantities of waste dedicated to landfill and incineration

Weekly waste dedicated to landfill (kg)	Weekly waste sent for incineration (kg)
2.8365	**68.076**

A second scenario was considered, given the establishment of a recycling branch within Nutripack, which is taken as example for the supplier (Centre resource du développement durable, 2016). This scenario was not chosen by Vivalia given the logistics constraints it implied, but it will be studied for this research, to estimate its impact both from an environmental and financial point of view. One of the main barriers to the recycling of polypropylene trays is the need to clean them from any fat component, food leftovers, and the need to remove any remnant of plastic wrap which was used to protect and preserve food. Therefore, it had to be assume here that the used trays would be brought back to the CPU in order to be cleaned in a dishwasher, before being collected by the supplier. The trays would be crushed on the plant site, and usually transformed back into granules as raw material for the manufacturing of other non-food-contact plastic applications (Carpentier & Rivelon, 2011). As said before, the distance from the CPU to the supplier plant is 234 kilometers. The weight transported in the truck would also vary, since it would need to go back to the CPU with the empty plastic trays. The changes were computed in *Table 8*. The detailed calculations can be found in *Appendix 11*.

[7] https://www.google.com/maps/

Table 8: Total weight transported in the truck until the different sites (in kilograms) – SCENARIO 2

Travel realized	Weight transported in the truck (kg)
Cycle 1	
CPU → Psychiatric institution Bertrix	Neglectable/same place
Psychiatric institution → Safe house Bertrix	109.036
Safe house → CPU	96.525
Cycle 2	
CPU → Libramont nursery & hospital	289.297
Libramont → Saint-Ode rest home	131.661
Sainte-Ode → CPU	101.635
Cycle 3	
CPU → Chanly rest and care home	302.173
Chanly → Marche nursery & hospital	257.134
Marche → Vielsalm rest and care home	192.078
Vielsalm → Bastogne hospital	137.030
Bastogne → CPU	102
Cycle 4	
CPU → Arlon nursery & hospital	289.297
Arlon → Athus home for psychiatric patients	169.193
Athus → Saint-Mard hospital	156.683
Saint-Mard → Virton rest and care home	121.652
Virton → CPU	101.635

Regarding the technical aspects for the washing part, the CPU owns a rack conveyor dishwasher, which allows several racks full of dishes to be washed over an hour. Given that the technical details of the model present at the CPU were not available from the technical team of Vivalia, the specificities of a similar model were taken for the estimation of the water and energy consumption. The model PROFI CN-S-A from Hobart – global market leader for commercial dishwasher and warewash systems – was thus taken as an example, and it was assumed that the dishwasher could handle 150 racks per hour, consumed 0.7 liter per rack and had a power of 29.4 kilowatt (Hobart, n.d.). The number of GN-type trays/containers per rack was assumed to be 10 (Hobart, n.d.).

It was assumed as well that the trays would be washed directly on their return from the different sites of consumption. Given that there are 305 trays which are distributed per delivery, the energy consumption of the dishwasher to wash them would be 18.228 kilowatt-hour per week and the water consumption would be 65.1 liters per week.

The detergent consumption was assumed to be 25 grams per use, and thus 75 grams per week (Ecoconso asbl, 2008). The calculation details can be found in *Appendix 12*.

For the modalities of return to the plant site in order to remanufacture the trays into non-food application, it was assumed that the truck coming to do the monthly delivery of new plastic trays would take back the old trays, offering a proportion of the buyback price for a ton of trays. The total weight taken back monthly would correspond to the use of four weeks of trays, which gives a weight of 267.18 kilograms – see *Appendix 13* for the details.

Since the tool is not updated regarding the recycling step, an assumption was made for the impacts generated. It was assumed that 0.216 kilograms of CO2-equivalent emissions were saved if one kilogram of PP was being recycled – the balance between 0.081 kilograms of emissions produced and 0.297 kilograms of emissions saved (Avenant bilan CO2 de la gestion des déchets, 2008, p.48).

However, the impacts caused by waste represented by the wrapping part also had to be taken into account. As previously mentioned, the end-of-life for the wrapping parts would be shared between incineration and landfill, and the transportation[8] until the different waste management facilities would be taken into account as well. The details of the calculations can be found in *Appendix 14*.

Regarding the processes used in the tool, electric consumption was estimated by an electric mix from Belgium – as for the vacuum-packing step –, the data for water consumption available in the tool was assumed to have a mix of origins, and the detergent used for the dishwasher was chosen as a normal 'sanitary cleaner'.

[8] Of course, the weight taken into account is not the only weight transported in the truck, but the impacts will be evaluated only based on the data from the wrapping of the trays.

3.4.2. Reusable stainless steel containers

3.4.2.1. Manufacturing stage

Given that reusable stainless steel containers are an alternative studied which has not been yet implemented within Vivalia for the preservation and transportation of the trays, lots of assumption and scenarios were used for this part of the research. First, as mentioned before, it was assumed that the containers supplier would be ‘Bourgeat Industrie’, a French manufacturer. Numerous manufacturing processes can be applied to shape a stainless steel piece. However, in the framework of this study, and given the available processes on the ‘BASE IMPACT’ database, as well as documentation found on the website of the supplier, it was considered that sheet-metal stamping would be the main process occurring in the case of the Gastro-Norm container manufacturing [9](Bourgeat Industrie, n.d.)). It was assumed that 0.68 kilograms of stainless steel sheet was needed to build a container of 0.68 kilograms and 0.5 kilograms of stainless steel sheet was needed to build a lid of 0.5 kilograms, giving a total of 1.18 kilograms[10].

3.4.2.2. Transportation from the stainless steel containers supplier until the CPU

For the transportation from the stainless steel containers manufacturer until the CPU, the same process as for the single-use alternative was taken from the tool – namely transportation by truck, including road infrastructure, operation and use of truck (100%).

The distance between the manufacturing site and the CPU is of 671 kilometers[11]. Considering the current number of plastic trays sent per week and the frequency of deliveries, the total number of containers to be used was computed by estimating the number of trays sent for delivery if the deliveries were done every day of the week. Given that there were currently 305 trays being delivered three days a week, with 75 trays per delivery for cycles 1, 2 and 4 and 80 trays per delivery for cycle 3, for a new production and delivery organization seven days a week, it was assumed that the number of trays prepared and delivered per day would be $\frac{3}{7}$ of the number of trays per delivery for the single-use alternative. *Table 9* is showing the detailed allocations per daily delivery cycle.

[9] see also https://www.youtube.com/watch?v=r7Ho9MXbu7Q & https://www.youtube.com/watch?v=j1_PlTYOy3w

[10] However, as it was written in the tool that the sheet-metal stamping process has 20% matter loss, the weight used for the process is 1.416 kilograms.

[11] https://www.google.com/maps/

Table 9: Daily number of reusable containers delivered by site

Cycle	Number of trays transported daily
Cycle 1	32
Cycle 2	32
Cycle 3	34
Cycle 4	32
Total	**130**

It was assumed that the trays were transported back to the CPU on the following day, when the truck comes for the delivery of the meals. Knowing this, the number of containers to be ordered was determined, taking into account the lead time for the return of the containers to the CPU, the time to wash them at the CPU, the containers which needed to be in circulation, and a percentage of lost/damaged containers. It was assumed that the safety stock would be two days, the trays sent for delivery would be circulating for two days and the percentage of lost/damaged containers would be 0.05%[12] of the containers transported per year.

Moreover, the International Stainless Steel Forum (n.d.) mentioned – in one of its educational modules about sustainable development and stainless steel – that the average lifetime of stainless steel used as metal product – other than in the building, automobile, machinery, etc. sectors – is 15 years. If a lifespan of fifteen years is assumed, it can be considered that the number of containers ordered to the manufacturer is 880. The number of annual reuse was estimated to be 60 for each container. Considering the lids and the containers for transportation, it was computed that the total weight in the truck was 1038.4 kilograms. The calculation details can be found in *Appendix 15*.

[12] It is not a consequent number as it is assumed that the return of the containers to the CPU will be realized by someone from Vivalia, and monitored carefully regarding the quantities. It is mainly an issue if the containers have to be returned to an external washing center, where the monitoring might not be realized as accurately. For the end-of-life steps, etc., it will be assumed that 100% of the containers ordered are going through the end-of-life process.

3.4.2.3. Distribution from the CPU to the different sites

The allocation of trays per site supplied can be done following the same methodology as for the plastic trays – same percentages –, as it can be seen in *Appendix 16*.

The total weight transported by truck cycle and by site was computed following the same method as for the plastic trays, meaning that it was assumed that the number of portions per container was 15, and each portion weighed in average 0.16651 kilograms.

The total weight of the container once closed with the lids is thus 3.678 kilograms. The containers were still transported thanks to the two previously-mentioned types of RTIs – rolls and plastic crates – which are together weighing 96.16 kilograms. However, this time, the transportation back to the CPU did not consider only the RTIs, but also the empty containers which were pre-washed on every site by hand. The weight of the empty containers with lid is 1.18 kilograms.

It must be noted that the truck was assumed to take back the empty containers from the previous day when doing a certain cycle, so that the weight to be taken into account in the calculations for the travel to the next site was the sum of the empty containers and the full containers which still need to be delivered.

The weight transported per delivery for the stainless steel containers can be found in the following *Table 10*, with the detailed calculations in *Appendix 17*[13].

[13] Once again, the same process as for the transportation of single-use trays will be taken from the tool – 'cooling truck transport (fresh) including fleet and infrastructure (100%)' –, and the results will be challenged thanks to 'EcoTransIt'.

Table 10: Total weight transported in the truck until the different sites (in kilograms) – REUSABLE ALTERNATIVE

Travel realized	Weight transported in the truck (kg)
Cycle 1	
CPU → Psychiatric institution Bertrix	Neglectable (same place)
Psychiatric institution → Safe house Bertrix	103.515
Safe house → CPU	98.52
Cycle 2	
CPU → Libramont nursery & hospital	213.845
Libramont → Saint-Ode rest home	146.408
Sainte-Ode → CPU	133.92
Cycle 3	
CPU → Chanly rest and care home	221.2
Chanly → Marche nursery & hospital	201.219
Marche → Vielsalm rest and care home	173.745
Vielsalm → Bastogne hospital	151.266
Bastogne → CPU	136.28
Cycle 4	
CPU → Arlon nursery & hospital	213.845
Arlon → Athus home for psychiatric patients	163.892
Athus → Saint-Mard hospital	158.897
Saint-Mard → Virton rest and care home	143.911
Virton → CPU	133.92

3.4.2.4. Use stage

3.4.2.4.1. Pre-washing on each site

As the use of stainless steel requires two washing phases in order to ensure a proper cleaning to avoid any microbial contamination, it was assumed that the first washing of the trays will happen on each site using such containers. It was also assumed that for this phase, dedicated staff was removing most of food leftovers, before washing them.

Regarding the quantity of liquid detergent used, no exact amount was found when reviewing the literature. The quantity of liquid detergent used was thus estimated to be 3 milliliters – or around 5 grams[14] – for each site, assuming that the food leftovers were removed as possible beforehand, thanks to brushes, etc. (Ecoconso asbl, 2008).

[14] The detergent used from the tool was here chosen as 'liquid soap for dishes'.

The quantity of water used for hand washing was estimated to be 60% more than for the dish washing technique (Galvez Martos, Schönberger & Styles, 2013). It was assumed that the dishes were washed in a sink with a corresponding capacity on every site, and that they were washed in the same water, regardless of the number of containers needed to be washed.

3.4.2.4.2. Secondary washing on the CPU site

As mentioned before, the CPU was using a rack conveyor dishwasher, handling 150 racks per hour, consuming 0.7 liter per rack and having a power of 29.4 kilowatt (Hobart, n.d.). The number of GN-type trays/containers per rack is 10 (Hobart, n.d.). As the daily number of containers and lids to be washed is 260, it was assumed that the daily energy consumption for the dishwasher was 5.096 kilowatt-hour and the daily water consumption was 18.2 liters. The quantity of detergent used was estimated to be 25 grams per day [15](Ecoconso asbl, 2008). As mentioned before, hand washing requires 60% more water than the dishwasher technique, which gives an estimated daily consumption per site of 30 liters[16]. The calculation details can be found in *Appendix 18*.

3.4.2.5. End-of-life

Theoretically, stainless steel is 100% recyclable, and the manufacturing of a new piece made with stainless steel is usually made of 25% recycled stainless steel, 35% of recycled waste stainless steel coming from the manufacturing steps, and finally 40% of new stainless steel as raw material (British Stainless Steel association, 2018; see also Patel, 2018).

The evaluation tool did not provide information on the impact of metal recycling, but assumptions were made based on the process stainless steel had to go through to be 'regenerated'.

Indeed, it was assumed that, once at the end of their life, the containers are collected, sent to a recycling branch and separated from other metal pieces. They are then crushed and sent back to a refinery, where they will be used to compose new applications.

A study on the recycling of ferrous metals has shown that recycling steel can allow to save the equivalent of 57% of CO_2 emissions and 40% of primary energy required to produce primary steel (ADEME & Fédération Des Entreprises du Recyclage, 2017).

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[15] Here, the processes taken for the water, energy and detergent consumption were the same as the one mentioned for the dishwasher use assumed for the recycling scenario of plastic trays

[16] As the flows in the tool have to be computed in kilograms for water use, it is assumed here that 1 liter of water = 1 kilogram

Therefore, it was assumed for this study that the emissions saved during the recycling of stainless steel represented 57% of the emissions occurring during the manufacturing stage. Concerning the energy consumption, it was assumed that 40% of energy needed during the manufacturing stage were saved thanks to recycling.

Nevertheless, in order to make a good comparison with the single-use alternative, the transportation to entities involved in the end of life of metal pieces had to be made. In this case, it was assumed that the stainless steel containers were transported to the company 'Sametal[17]' – situated in the province of Liège –, where the containers would be crushed and prepared to be sent to a steel company that would reuse the scrap metal to manufacture new components. In this case, the steel company was assumed to be 'John Cockerill'. The distances of the two trips travelled can be found in *Table 11* here under, and were computed thanks to Google Maps[18]. It was assumed that 100% of the weight would become crushed scrap metal.

Table 11: Distances and weight transported to the different end-of-life entities for reusable containers

Travel	**Distance between the two sites (kilometers)**	**Weight transported (kilograms)**
CPU → Sametal	120	1038.4
Sametal → John Cockerill	16	1038.4

It must be noted as well that the recycling company Sametal was assumed to take back the pieces made of stainless steel for a price of 650€ per ton[19].

[17] https://sametal.sohow.be/fr/
[18] https://www.google.com/maps/
[19] Valid price from 27/07 until 03/08 (https://sametal.sohow.be/fr/)

3.5. Impacts assessment

Given that the lifespan of the stainless steel containers has been estimated to fifteen years, a comparison between both alternatives was realized over that period. The following pages will compare both containers types – plastic and stainless steel – on each of the main life-cycle stages, for each of the four impact indicators chosen, and then on a global overview. As mentioned previously, the steps involving transportation will be evaluated thanks to the regular tool, like the other steps, but also with 'EcoTransIt', to challenge those results. The impacts evaluated with the second tool can be found in the appendices indicated, and a comparison with the general tool will be realized at the end of this section.

3.5.1. Manufacturing stage

The impacts of the manufacturing stage have been compared for 720000 plastic trays and 880 reusable containers manufactured during the fifteen years. *Table 12* is showing those impacts on the four environmental indicators chosen.

Table 12: Comparison of impacts at the manufacturing stage

	SINGLE-USE	**REUSABLE**
Climate change (Kg CO2 eq.)	162000	3879.04
Resource use - Fossil (MJ)	5117760	43823.12
Photochemical ozone formation (Kg COVNM eq.)	354.888	19.9144
Acidification (eq. Mol. H+)	600.048	29.9376

The impacts computed thanks to the 'Bilan Produit®' tool show that the reusable alternative is much more interesting environmentally-speaking than the single-use scenario, for each indicator.

3.5.2. Transportation from suppliers

The impacts resulting from the transportation from the suppliers of both alternatives have first been computed with the tool 'Bilan Produit®' in *Table 13*, and the corresponding impacts evaluated with the tool 'EcoTransIt' can be found in *Appendix 19* – this time only for the CO_2-equivalent emissions.

Table 13: Comparison of impacts at the transportation stage

	SINGLE-USE	REUSABLE
Climate change (Kg CO2 eq.)	1004.04	52.302
Resource use - Fossil (MJ)	15851.52	825.745
Photochemical ozone formation (Kg COVNM eq.)	6.3756	0.3321
Acidification (eq. Mol. H+)	6.3756	0.3321

For this step again, the reusable alternative is proven to have less impacts on all the indicators observed. This is mainly due to the monthly order that is passed for the plastic trays, compared to the single order made for the reusable containers.

3.5.3. Use step

For this step of the life-cycle, the processes happening during the use of the tray/container were presented – excluding distribution, which comes just in the next section. Therefore, the vacuuming process for the single-use trays was compared to the two washing processes needed for the reusable alternative. The impacts of the washing processes have been computed taking into account the water and detergent used both for the hand washing and dishwasher phases, adding the electricity consumption for the dishwasher phase. The impacts associated to those processes can be found in *Table 14*.

Table 14: Comparison of impacts at the use stage

	SINGLE-USE	REUSABLE
Climate change (Kg CO2 eq.)	823.6098	8992.8384
Resource use - Fossil (MJ)	28862.028	264292.392
Photochemical ozone formation (Kg COVNM eq.)	1.5480153	16.6865244
Acidification (eq. Mol. H+)	2.5257843	28.3905804

The impacts associated to the use step are more important in the case of the reusable alternative, due to the daily repetition of the cleaning processes. The dishwasher use account for 81% of the CO_2 emissions linked to the washing processes of the reusable alternative – see *Appendix 20.*

3.5.4. Distribution stage

For this step, two different scenarios were taken into account, linked to the two different assumptions made for the end-of-life methods.

First, *Table 15* represents the comparison of the environmental burden for reusable and single-use trays, if it is assumed that the plastic trays are shared between 96% of incineration and 4% of landfill at the end of their life.

Table 15: Comparison of impacts at the distribution stage – SCENARIO 1

	SINGLE-USE	REUSABLE
Climate change (Kg CO2 eq.)	14622.9408	32193.1428
Resource use - Fossil (MJ)	229393.242	504988.302
Photochemical ozone formation (Kg COVNM eq.)	95.958954	211.226652
Acidification (eq. Mol. H+)	91.806858	202.20564

For this scenario, the reusable alternative cause more than 50% higher environmental impacts than the single-use trays – that can be explained by the increase in the delivery frequency.

Then, *Table 16* shows the impacts linked to the scenario where the plastic trays are sent back to the supplier to be recycled.

Table 16: Comparison of impacts at the distribution stage – SCENARIO 2

	SINGLE-USE	REUSABLE
Climate change (Kg CO2 eq.)	14888.2734	32193.1428
Resource use - Fossil (MJ)	233550.018	504988.302
Photochemical ozone formation (Kg COVNM eq.)	97.6895244	211.226652
Acidification (eq. Mol. H+)	93.520908	202.20564

For this second specific scenario, the impacts linked to distribution are a bit higher than the previous scenario, which is explained by the slight increase in the weight being transported, since the truck has to bring back empty trays from the previous days to wash them before they can be recycled. However, the impacts linked to the reusable alternative are still more important.

The results obtained with 'EcoTransIt' can be found in *Appendix 21*.

3.5.5. End-of-life step

The two End Of Life (EOL) scenarios previously-mentioned for the single-use alternative were compared to the impacts of the reusable alternative. *Table 17* below represents the impacts for the first scenario – 96% incineration and 4% landfill –, including the transportation flows linked to the EOL step. The details can be found in *Appendix 22*.

Table 17: Comparison of impacts at the EOL stage – SCENARIO 1

	SINGLE-USE	**REUSABLE**
Climate change (Kg CO2 eq.)	114632.424	-2201.9868
Resource use - Fossil (MJ)	-525706.47	-17391.136
Photochemical ozone formation (Kg COVNM eq.)	36.05904	0.06365
Acidification (eq. Mol. H+)	11.056302	0.076493

Below, *Table 18* shows the impacts when the recycling scenario is considered for the plastic trays.

Table 18: Comparison of impacts at the EOL stage – SCENARIO 2

	SINGLE-USE	**REUSABLE**
Climate change (Kg CO2 eq.)	-41.1036	-2201.9868
Resource use - Fossil (MJ)	111337.344	-17391.136
Photochemical ozone formation (Kg COVNM eq.)	14.4269763	0.06365
Acidification (eq. Mol. H+)	17.32378833	0.076493

As it can be noticed from the numbers above, the EOL assuming incineration and landfill emits much more CO_2 emissions than the recycling scenario. However, the first scenario allows to have savings on the energy used, thanks to the process of recovery due to the incineration part.

The second scenario, on the opposite, allows to have savings on the CO_2 emissions generated with the recycling. Nevertheless, the savings have been limited because of the impacts generated by the transportation to the waste management facilities. No savings have been taken into account for the energy used regarding the second scenario because no data was found, but it is most likely that the recycling scenario allows to decrease the energy used linked to plastic pellet production. It can be noticed as well that photochemical ozone formation is less important for the recycling scenario, since less emissions are emitted, but acidification increases – due to the higher transportation distance back to the supplier, and the cleaning step which was added for the trays.

When it comes to the reusable scenario, important savings can be noticed thanks to the assumption taken, both for the CO_2 emissions generated and the energy used.

When doing a general comparison on the CO_2 emissions, it can be noticed that the current situation is the worst environmentally-speaking, and the reusable alternative would be the best. This is what can be concluded for the two last indicators as well. When the 'resource use' indicator is observed, the current situation – without any recycling – allows the biggest savings, and the recycling scenario is the worst.

The impacts linked to transportation flows have been also evaluated with 'Eco Transit', and the details can be found in *Appendix 23*.

3.5.6. Overall comparison of the environmental impacts

In order to dig deeper into the comparison of the single-use and reusable alternatives which are the subjects of this study, the weight associated to each step of the life-cycle has been computed for both items, thanks to the below figures. The indicator chosen for the comparison is the 'climate change' indicator, as it is the flagship indicator.

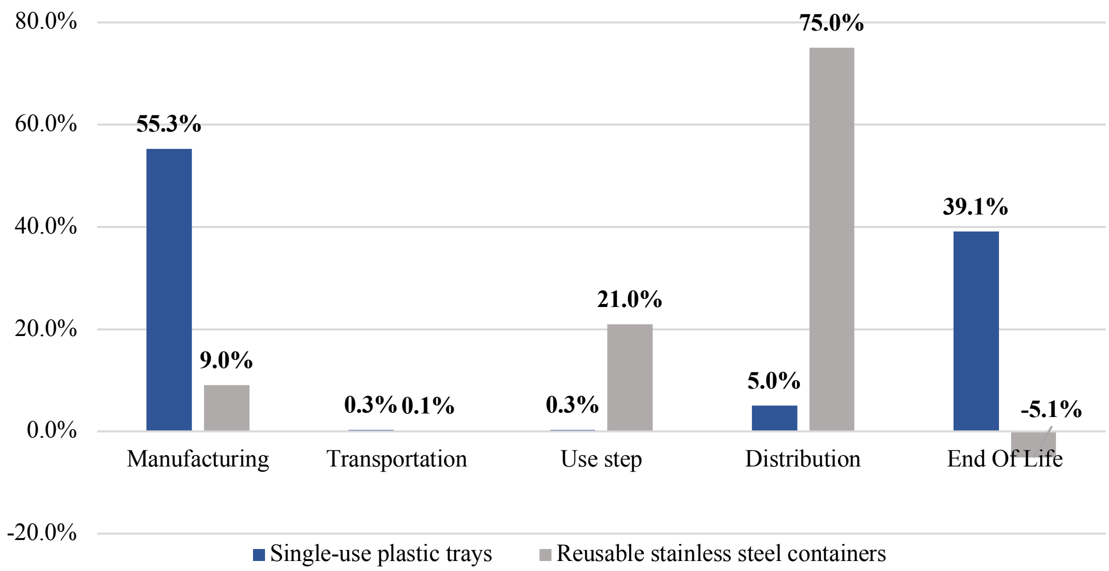

Figure 6: Distribution of climate change impacts along the steps of the life cycle

Following the first scenario studied for single-use trays – with incineration and landfill chosen as the EOL methods –, the manufacturing step accounts for the majority of impacts for climate change with 55.3% of CO_2 emissions, followed by the EOL step with 39.1% of the emissions. The distribution, use and transportation account for less than 6% of the CO_2 emissions.

When it comes to the reusable stainless steel containers, distribution is the most consuming in terms of CO_2 emissions, representing 75% of those emissions. Following the assumptions made in the beginning, the EOL step allows to realize 5.1% savings on the emissions because of the recycling process assumed for the stainless steel, which can be reused and remanufactured into several other applications. The following *Figure 7* shows the distribution of the different steps of the life-cycle assuming the second scenario for the end of life of the trays, namely recycling.

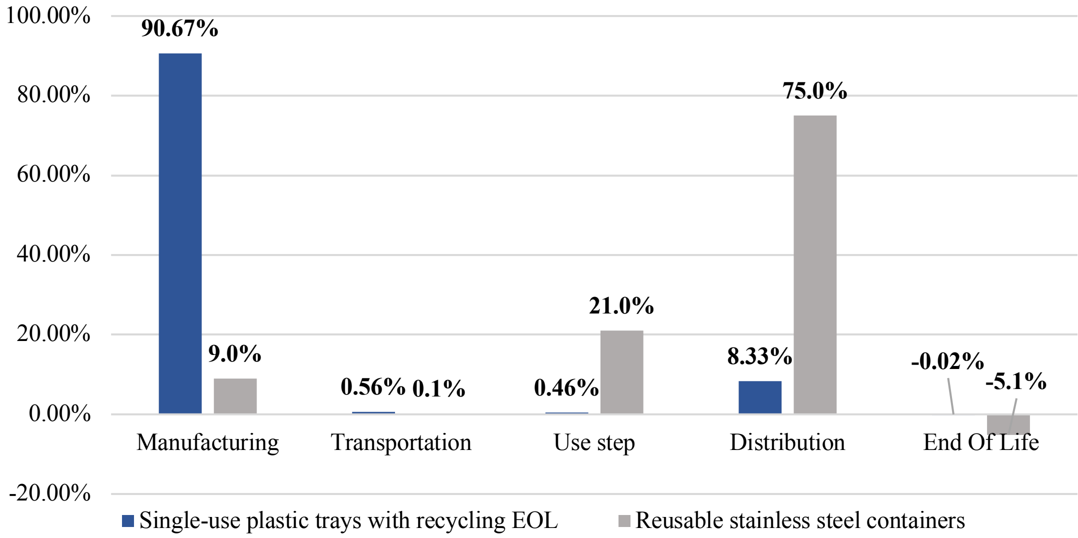

Figure 7: Distribution of climate change impacts along the steps of the life cycle – Recycling scenario for the plastic trays

As it can be noticed, using the second scenario increases to 90.67% the weight of manufacturing in the total of emissions released – given that the total of emissions decreases because of the savings due to recycling. Even though those emissions are not saved on the remanufacturing of trays with food-contact applications, they are counted as part of the life-cycle in this study to highlight their advantageous effect.

Regarding the three other environmental impact indicators, they will not be discussed in details considering that the flagship indicator for comparison is the climate change, and the EOL step for the reusable alternative has not been studied under those three other indicators due to the lack of information available.

However, for the plastic trays, it is important to highlight that the manufacturing step supports 105.2% of the 'resource use' indicator because of the energy saved from the incineration process.

When the EOL method chosen is the recycling process, the energy consumed is not compensated by the incineration process anymore, and manufacturing thus account for 92.9% of the energy consumption. Regarding the last two indicators – photochemical ozone formation and acidification potential –, they are following the same patterns, with the manufacturing of the plastic trays accounting for between 70-85% of the impacts and the distribution step accounting for 13-20% of the impacts.

If the reusable alternative is observed – provided that the EOL step is neglected –, the transportation step has the highest impact for each of the three indicators, accounting for more than 60% every time. *Table 19* below indicates the total impacts for the climate change indicator over the 15-year period studied, for the two scenarios assumed for the plastic trays, and the reusable option.

Table 19: Total CO_2 emissions for each alternative

	SINGLE-USE : SCENARIO 1	SINGLE-USE : SCENARIO 2	REUSABLE
Climate change (Kg CO2 eq.)	293083.0146	178674.8196	42915.3364

From the table above, it can thus be stated that the stainless steel containers would lead to less important CO_2 emissions, making them a better solution environmentally-speaking.

Within the framework of this study, the impact per kilogram of food handled can also be computed, as in the *Figure 8* below. The details of computation can be found in *Appendix 24*.

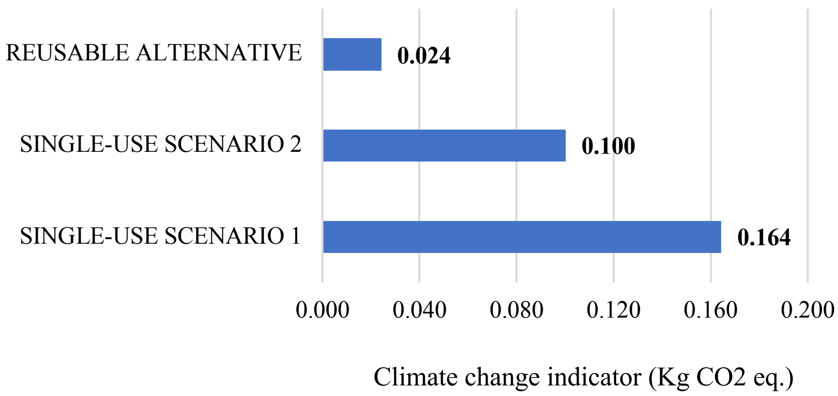

Figure 8: Impacts per kilogram of food handled (in Kg CO2-equivalent)

Thanks to the numbers computed on *Figure 8*, the ratio single-use/reusable was calculated and it appeared that the reusable stainless steel containers become a more interesting option to use when the number of reuse goes above 133 over a period of fifteen years, if the scenario 1 is being followed.

If scenario 2 is being chosen, the reusable containers become more interesting environmentally-speaking if the number of reuses is above 218 over the fifteen years. The details of computation can be found in *Appendix 25*.

3.5.6.1. Findings obtained with EcoTransIt

If the comparison is run with 'EcoTransIt', the impacts due to transportation flows are less important than the ones obtained with the tool 'Bilan Produit®', since 'EcoTransIt' is only taking into account the emissions linked to the use of the truck – nothing regarding the infrastructure, etc.

If the results are compared with what was previously obtained thanks to the first tool, it can be noticed that the weight associated to the manufacturing stage has increased for both single-use scenarios and for the reusable alternative. However, for the reusable alternative, the most important stage in terms of impacts is not anymore the distribution stage, but the use stage, accounting for 82% of the total impacts, due to the cleaning processes. The weight of each step for each alternative in the total emissions can be found in *Appendix 26*.

The impacts per kilogram of food handled has been computed as well in *Figure 9*.

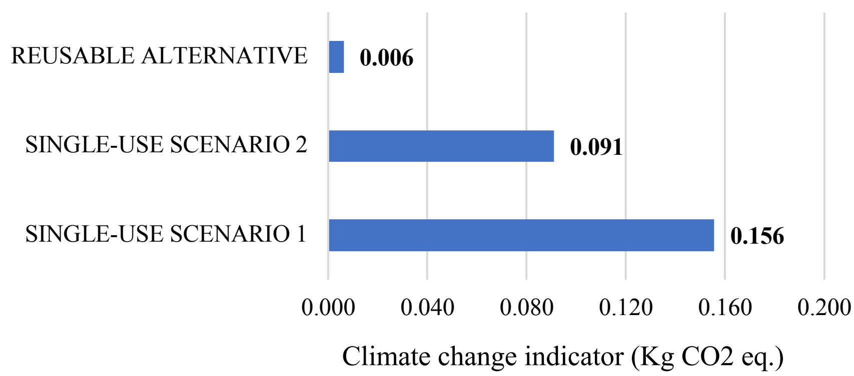

Figure 9: Impacts per kilogram of food handled (in Kg CO2-equivalent) – EcoTransIt

The ‘single-use/reusable’ ratio has been computed as well thanks to the numbers in *Figure 9*. After reassessing the situation with the numbers found thanks to EcoTransIt, the reusable containers should be chosen when the number of reuses is above 36 if the first scenario is compared to it. When looking at the second scenario, the reusable containers should be preferred when the number of uses is more than 62. The computation details can be found in *Appendix 27*.

When comparing both tools used, the factor differences between them are the following:

Table 20: Ratio ‘Bilan Produit®’/EcoTransIt for the total impacts per kilogram of food

SINGLE-USE SCENARIO 1	SINGLE-USE SCENARIO 2	REUSABLE OPTION
1.06	1.1	3.9

The difference is thus mainly noticed for the reusable option, as it was the alternative the most impacted by transportation flows.

3.6. Economic assessment

This part of the research is focusing on the financial impacts established for the hospital when choosing one or the other alternative developed above – plastic trays or stainless steel containers – used for the preservation and transportation of food to the different sites supplied by the CPU of Vivalia. The assessment will be realized following the steps which are involving a cost for Vivalia. The costs have been calculated excluding the Value-Added Tax (VAT), as it is assumed that Vivalia is exempted from VAT for the costs linked to the catering activities.

3.6.1. Single-use plastic trays: costs inventory and assessment

The costs which need to be taken into account are the following[20]:

- Purchasing cost of trays
- Cost of electricity allocated to the vacuum packing machine / dishwasher if the recycling scenario is considered
- Cost of water consumption if the recycling scenario is considered
- Renting cost for the delivery truck
- Cost of gas for the distances travelled
- Cost of staff

3.6.1.1. Purchasing cost

According to the data communicated by Vivalia, the plastic trays GN ½ cost 246€ for 1000 pieces. The unit cost is thus 0.246€. The purchase of the plastic roll for the wrapping of the trays also has to be considered in this step. As mentioned previously, the plastic rolls are ordered monthly by three units. A roll costs 40.3€ (Union des groupements d'achats publics, n.d.). *Table 21* shows the total purchasing cost over the fifteen-year period studied. Further calculations details can be found in *Appendix 28*.

Table 21: Total purchasing cost – single-use option

15-year period	
Tray cost (€)	177120
Wrapping roll cost (€)	21762
TOTAL COST (€)	**198882**

[20] The municipal waste tax is not taken into account here, given that it is assumed Vivalia – and the sites supplied – is considered as a public entity and is thus exempted from this tax (Debernardi, 2019).

3.6.1.2. Cost of electricity

3.6.1.2.1. Vacuum packing machine

According to the data from year 2019 on Eurostat (2020), the price of electricity is 0.2839€ per kilowatt-hour. As it was found before that vacuuming a tray would lead to an energy consumption of 0.0045 kilowatt-hour, *Table 22* summarizes the cost for the electric consumption due to the vacuuming activity, and *Appendix 29* gives more details about the calculations.

Table 22: Electricity cost – vacuum-packing

15-year period	
Electricity cost (€)	911.79

3.6.1.3. Renting cost for the delivery truck

According to the data communicated by Vivalia (2020), the truck used for the deliveries is a rented truck from the refrigerated truck company 'Le Petit Forestier', and has a monthly renting cost of 1850€[21]. The total cost over the period studied can be found in *Table 23* below.

Table 23: Renting cost for the delivery truck – single-use alternative

15-year period	
Truck renting cost (€)	333000

3.6.1.4. Cost of gas for the distances travelled

The truck used is a diesel refrigerated delivery van, and more specifically the 'chassis cab with platform' model from the Fiat brand. It has a combined urban and extra-urban consumption of around 5.7 liters per 100 kilometers [22](Fiat, 2019). The price of diesel – consulted on the 24th of June 2020 – is 1.08388€/liter (Service Public Fédéral Economie, 2020). The total travelled distances over the four cycles for a normal delivery day are 448 kilometers. The total cost can be found in *Table 24*, with detailed calculations in *Appendix 30*.

[21] It is assumed that the monthly renting cost includes the maintenance cost as well, etc. As no more information was available from Vivalia about the type of contract, the cost will be evaluated normally over the fifteen years.
[22] It is assumed that the diesel consumption indicated includes the refrigerated part of the truck.

Table 24: Cost of gas – single-use alternative

15-year period	
Diesel cost for transportation (€)	64766.43

3.6.1.5. Recycling scenario

3.6.1.5.1. Electric consumption for the dishwasher

As mentioned before, the weekly energy consumption due to the use of the dishwasher to clean the trays coming back from each delivery day is 18.228 kilowatt-hour. The price per kilowatt-hour is 0.2839€. The total electric cost over fifteen years is represented in *Table 25*.

Table 25: Electric cost – recycling scenario

15-year period	
Electricity cost – dishwasher	4036.44

3.6.1.5.2. Water consumption for the dishwasher

Based on data from the 'Société wallone des eaux' (2020), one cubic meter of water costs around 4.982€ in Wallonia. Given that the weekly water consumption of the dishwasher to clean the trays to be recycled is 65.1 liters – as mentioned before –, *Table 26* below summarizes the total cost.

Table 26: Cost of water – recycling scenario

15-year period	
Water cost (€)	252.98

3.6.1.5.3. Payback for the trays returned

Despite the additional costs linked to the recycling scenario, it must be noted that the recycling branch of the supplier also gives a payback per weight of plastic trays returned – for one ton of trays, the company gives back 250€ (Carpentier & Rivelon, 2011). Therefore, as it was computed before that the monthly weight of trays potentially being returned to the supplier was 267.18 kilograms, *Table 27* offers an overview of the costs being saved by the hospital using the recycling branch over fifteen years.

Table 27: Payback due to trays returned

15-year period	
Payback given (€) [23]	- 12023.1

3.6.1.6. Cost of staff

The CPU is currently employing 16 FTEs, at a gross annual cost of 44000€ per FTE – who are working five working days a week. *Table 28* represents the gross cost for staff over the studied period.

Table 28: Cost of staff – single-use alternative

15-year period	
Gross cost for staff (€)	10560000

3.6.1.7. Overall economic impacts of the single-use trays

On a global picture, it can be highlighted that the cost of staff is the most important cost dimension, as it represents around 95% of the expenses linked to the management of the CPU. However, as the cost of staff is not directly linked to the trays – people are assigned to different tasks which are not all linked to the management of the trays – it can be interesting to look at the 5% of the total costs remaining, looking at the two different end-of-life scenarios proposed.

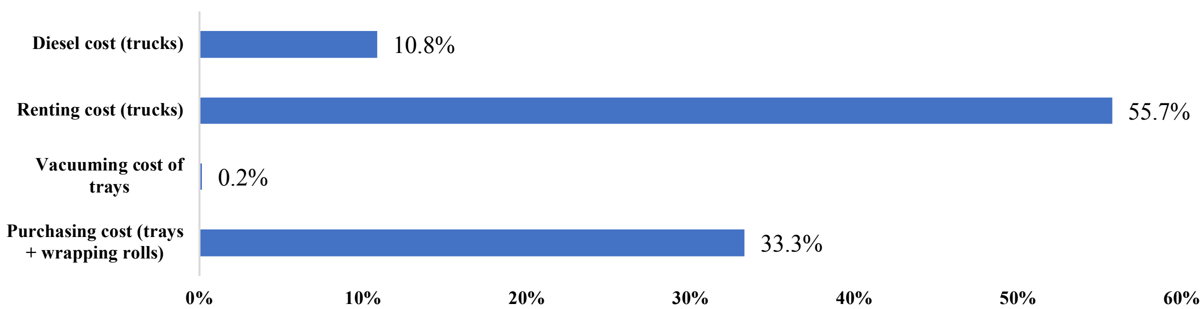

Figure 10: Distribution of the direct cost dimensions for single-use trays : Scenario 1 – No Recycling

[23] Counted as a negative value, from a cost perspective

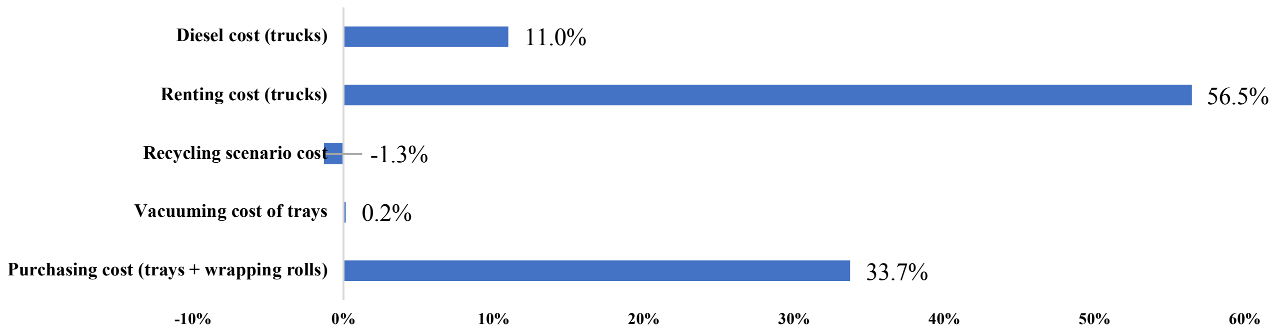

Figure 11: Distribution of direct cost dimensions for single-use trays: Scenario 2 – Recycling

From both pictures above, it can be noted that the renting cost of the truck is the most important cost dimension linked to single-use plastic trays, representing between 55 and 57% of the total cost – without taking into account the cost of staff –, depending on the end-of-life scenario chosen.

Following a logical reasoning, the percentage associated to the truck renting cost in the 'recycling scenario' is higher than for the 'no recycling scenario', as the renting cost remains equal in both scenario, but the 'recycling scenario' allows to decrease the total amount of cost thanks to a payback from the recycling branch, thus allowing the truck renting to 'weigh' more in the total cost. The purchasing cost for both scenarios is the second most important direct cost, as it represents between 33 and 34% of the total direct costs.

3.6.2. Reusable stainless steel containers: costs inventory and assessment

The cost dimensions which need to be taken into account for this alternative are the same as for the plastic trays, except that some will need to be adjusted given the additional constraints added in the supply chain.

3.6.2.1. Purchasing cost

After realizing a benchmark of companies selling professional kitchen materials in stainless steel in France – to make a comparison with the plastic trays' supplier –, it was decided to use Bourgeat Industrie as supplier example. According to the prices seen on the website of a retailer for HORECA industry materials, the price of one stainless steel container manufactured by Bourgeat Industrie is 14.95€ [24] and the price of the corresponding lid is 11.95€.

[24] https://www.materiel-horeca.com

If it is assumed that the delivery is free and the total number of containers for the fifteen-year period are bought directly, the total cost over that period is represented in *Table 29*.

Table 29: Purchasing cost – reusable alternative

15-year period	
Cost of container (€)	13156
Cost of corresponding lid (€)	10516
TOTAL	***23672***

3.6.2.2. Cost of electricity

3.6.2.2.1. Electric consumption of the dishwasher

Considering that the reusable alternative requires the dishwasher to consume daily 5.096 kilowatt-hour and considering the price of electricity as previously – 0.2839€/kWh – the cost of consumption over fifteen years can be found in *Table 30*.

Table 30: Cost of electricity – dishwasher

15-year period	
Cost of electricity (€)	7899.28

3.6.2.3. Cost of water

3.6.2.3.1. Hand washing and dishwasher consumption

As mentioned before, the daily consumption of water is of 18.2 liters for the dishwasher and 30 liters per site for the handwashing part. Considering that one cubic meter of water costs 4.982€, *Table 31* shows the costs linked to water consumption over the fifteen years studied. More details on calculations can be found in *Appendix 32*.

Table 31: Cost of water – cleaning processes

15-year period	
Dishwasher water consumption cost (€)	495.07
Hand washing water consumption cost (€)	9792.62
TOTAL	10287.69

3.6.2.4. Renting cost for the delivery truck

As the reusable alternative is being considered, additional constraints and adaptations in the supply chain need to be thought through. In the case of Vivalia, the delivery of meals to the different sites would need to happen in the morning before lunch. It was thus assumed that the cooking of food items is happening earlier in the morning. In order to deliver all the sites approximately at the same time, additional trucks need to be rented out and additional staff need to be hired – this subject will be discussed further in this paper. Given the distances and the high number of sites to be supplied, it does not seem doable to deliver them with only one truck while respecting the timings. Therefore, it will be assumed that the CPU is renting not one but four trucks, each truck delivering the sites being included in one of the four cycles.

If it is assumed that the four trucks would be rented, as before, for 1850€ per month, *Table 32* below represents the total renting cost over the fifteen years.

Table 32: Renting cost for the trucks – reusable alternative

15-year period	
Renting cost for the trucks (€)	1332000

3.6.2.5. Cost of gas for the distances travelled

Considering again that the truck is consuming 5.7 liters of diesel per 100 kilometers travelled, the consumption of the four trucks together over the period studied can be found in *Table 33*. The calculations are detailed in *Appendix 33*.

Table 33: Cost of diesel – reusable alternative

15-year period	
Diesel cost (€)	191293

3.6.2.6. Cost of staff

As mentioned before, the new constraints implied by the use of stainless steel containers would require to redistribute tasks and arrange shifts in a different way. The current situation includes 16 FTEs employed, assuming that FTEs work 8 hours per day, 5 days a week on a schedule Monday-Friday and 52 weeks a year, for a total of 2080 hours per year and a gross income of 44000€ per FTE (P. Gaspar, personal communication, May, 2020). Using the stainless steel containers would lead to a change of shifts, given that staff would need to work seven days a week, instead of five.

However, it was assumed that the weekly number of hours worked would remain the same, and so would the number of FTEs working at the CPU, given that the daily working hours would have decreased – since the quantity of production per day would be less important, and split over seven days instead of five. Therefore, as a FTE is considered to be working 40 hours per week, on the new shifts of seven days, employees would be assumed to work 5.71 hours per day.

As the gross cost per hour and per FTE is known to be 21.15€, it can be used as a basis to compute the cost per hour for the Saturday and Sunday, which are not working days, and are thus counted respectively as being 26% and 56% more costly (P. Gaspar, personal communication, December, 2020). Those costs can be found in *Table 34* below.

Table 34: Personal cost per hour and per FTE

	Week day	**Saturday**	**Sunday**
Cost per hour and per FTE (€)	21.15	26.65	33

The total cost for staff using the reusable alternative can be found in *Table 35*, and the calculation details have been computed in *Appendix 34*.

Table 35: Total gross cost for staff

15-year period	
Gross cost of staff (€)	11797029

Remark: Another element that can be discussed when identifying the increased in staff cost is the hand washing part of the containers on each site after the use, which would need to be handled by staff working in the kitchens there, in addition to their regular tasks. As some sites would only receive five or six containers per day, it would not impact a lot their working period, since the operation would not be time-consuming given that the containers would go to a secondary washing in the dishwasher once on the CPU site. However, for the sites which receive a more important daily quantity of containers, there might be a need to increase their income, or to put it in the form of bonuses or overtime hours performed. It will not be considered here, but was worth mentioning.

3.6.2.7. *Payback received from the recycling of reusable containers*

As mentioned in the life cycle inventory part, the company which is recycling the metal pieces is offering a payback price – 650€ per ton – for the weight collected. As it was assumed that the 880 containers would need to be replaced after 15 years, *Table 36* below shows the payback received by using a recycling branch for the EOL process.

Table 36: Payback received from the recycling company Sametal

15-year period	
Payback received (€)	-674.96

3.6.2.8. *Overall economic impacts of the reusable containers*

Once again, the cost of staff represents the biggest part in the total cost, but this time for 88.29%. As before, since this cost is not directly linked to the management of containers, the remaining 11.71% representing the other cost dimensions will be observed more carefully.

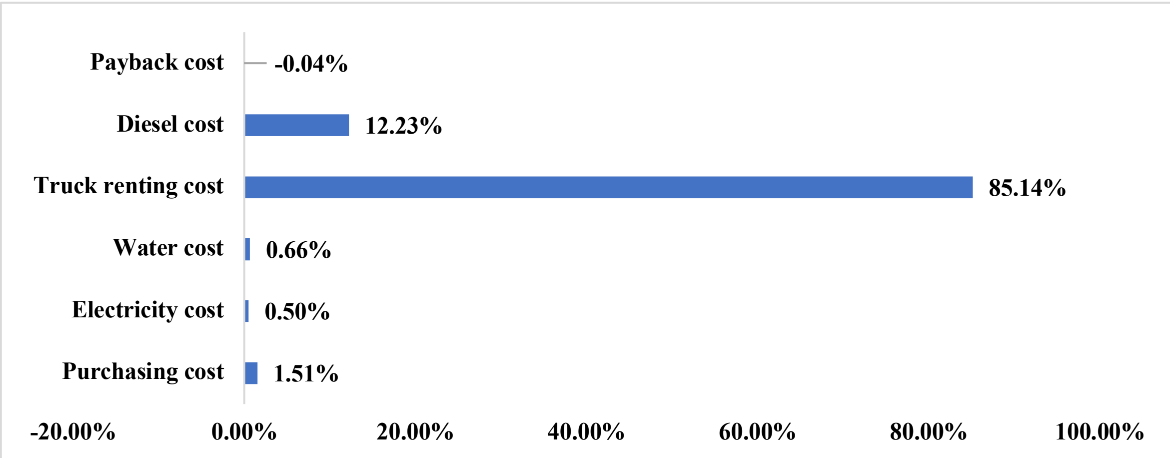

Figure 12: Distribution of direct costs for reusable stainless steel containers

From the picture above, it can be noticed that the truck renting is still the highest cost dimension, representing 85.14% of the total cost – without taking into account the cost for staff – as the assumption was taking into account that the number of trucks rented increased to four. The costs linked to the transportation flows are therefore the most important costs.

3.6.3. Comparison financial burden single-use vs reusable GN ½ containers

Table 37: Total cost for each alternative studied

15-year period			
	SINGLE-USE SCENARIO 1	***SINGLE-USE SCENARIO 2***	***REUSABLE ALTERNATIVE***
Total cost (€)	11157560.21	11149826.53	13361505.82

Over the period studied, it can be noticed that shifting to reusable stainless steel containers would lead to close to 20% increase in the costs, mainly due to the increased cost related to staff, and the renting investment in three new trucks. When looking only at the purchasing cost, Vivalia would have to make a direct investment in reusable containers, while using the plastic trays allows them to distribute the costs along the years.

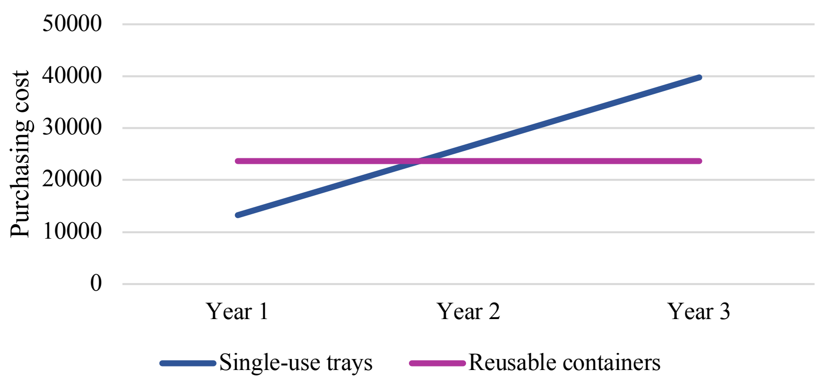

Figure 13: Comparison of the cumulated purchasing costs for both alternatives

Figure 13 above shows that if Vivalia choose to purchase reusable containers, it would take them less than two years to recover the same expenses as for the purchase of single-use trays.

The different total costs obtained can also be computed per kilogram of food handled over the period of fifteen years.

Table 38: Total cost per kilogram of food handled for each alternative

	Reusable alternative	**Single-use alternative – scenario 1: No recycling**	**Single-use alternative – scenario 2: Recycling**
Cost per kilogram of food handled (€)	7.54	6.26	6.25

Following those findings, turning to the reusable alternative would thus be around 1.3€ more costly than the single-use alternative for each kilogram of food handled, over a period of fifteen years. Regarding the two scenarios studied for the end-of-life, including a recycling dimension into the supply chain would be around 1 cent cheaper for each kilogram of food managed – mainly thanks to the payback received from the recycling branch. The details of the above calculations can be found in *Appendix 35*.

4. Discussions on the findings

4.1. Field of application for both alternatives

Within the network configuration of Vivalia, the reusable containers have been found to cause less important environmental impacts than the single-use trays. However, from a cost point of view, this option is considerably more expensive. A tradeoff must therefore be made to know which option must be favored. A summary of the pros and cons stated for each alternative has been established below.

Table 39: Pros and cons for each alternative considered

	Reusable alternative
PROS	- Less environmental impacts - Fits into current consumption modes and trends – reverse logistics, … - Likely to fit better in the context of expected raising ecological taxes – for example taxes on single-use plastics, etc.
CONS	- Musculo-skeletal disorders can appear due to the handling of heavier containers - Higher risk of microbial contamination if cleaning processes are not strictly respected - Require more time-consuming operations – deliveries on weekends, preparation earlier in the morning - Storage of empty containers might be difficult given the high number concerned - Risk of food loss if issue during transportation, since the containers are not sealed

	Single-use alternative
PROS	- Less time-consuming operations in the kitchen - Safer transportation and better preservation of food - Extended shelf-life for products being vacuum-packed – average of 5 days (H. Renard, personal communication, May, 2020)
CONS	- Increased environmental impacts - Risk of endocrine disruptor migration form plastic into food when hot food is packed (Association "Cantine Sans Plastique France", n.d.) - Management and collection of used trays to be recycled might be difficult

4.2. Recommendations

The current context of the health care sector in Belgium, with the centralization of hospitals, can help understanding which could be the future solutions and improvements to make regarding the question of food packaging. Indeed, Vivalia, which is planning to centralize most of its hospital structure in two different locations in the Luxembourg province by 2025, could for example use a mix of reusable and single-use containers. Given that the supply network for the deliveries would be reduced in terms of trips, it could be interesting to use reusable containers supplying the two big hospitals, and keep using single-use trays for the smaller-sized entities which are dispersed in different locations – rest and care houses, etc. Moreover, the type of food which need to be delivered also has an influence on the kind of packaging to use. For example, for food items which have lower risks – in terms of microbial contamination, transportation safety, etc. – such as starchy food, cooked vegetables, etc., it might be interesting to start handling them until the point of consumption in reusable containers, whereas other items such as meat in sauce, etc. should remain in the vacuum-packed trays. Of course, those suggestions should be studied further in order to have a real estimation of their feasibility.

An additional point linked indirectly to the food packaging is food waste left from the bulk packaging delivered. Indeed, it is hardly possible to have no leftovers from the food transported in bulk packaging. A mean to address this constraint would be to install an online booking system for regular patients – with a similar functioning as the system implemented for the schools in Strasbourg –, which could allow them to choose between several options and neglect the food they do not want. In this way, a kind of 'just-in-time' meal preparation service would be established.

Looking at the cost dimension, however, even if a mix of single-use trays and reusable containers were used in order to make savings on the environmental part, using such a mix is not guaranteed to result in significant cost decrease, since the monthly investment in the trucks would still need to be paid for the every-day deliveries using reusable containers, in addition to the cost for staff preparing the meals seven days a week. It could be possible to reduce the cost over the long run, for example by investing directly into trucks, instead of paying a monthly rent.

4.3. Improvement areas

Since a lot of assumptions have been taken along the steps of the life cycle for both alternatives studied, it is interesting to identify the key points on which further reflection and research could be pursued.

One of the main point which needs further investigation is the calculation of the impacts linked to the transportation flows. Indeed, even though the analysis was challenged with two different tools – 'Bilan Produit®' and EcoTransIt –, the important gap between both impacts computed indicates that it could be more accurate to calculate them thanks to a 'real' LCA-software, which might allow to choose more options for the loading, the type of truck, etc. – here, the fact that Vivalia is using a refrigerated delivery van could not really be taken into account.

Then, regarding the cost calculations, it could be interesting to take into account the inflation rate for some dimensions as the study is realized over fifteen years – electricity cost, water cost, staff cost, etc. A sensitivity analysis regarding the different costs taken as assumptions could be done, to obtain a price range for both alternatives.

More attention could be drawn to the specificities of the different sites – for example, this research assumed that the nurseries were opened on weekends too, etc. The question of food safety could also be digged, as some specific food items might not be fitted to stainless steel containers transportation. An alternative option that could be studied is the use of stainless steel containers with a specific lid containing a silicone mouthpiece, which could allow the vacuuming of the container, thus extending the shelf-life of food and permitting Vivalia to keep on doing the deliveries at the same rhythm as they are currently being done.

The recycling scenarios for both alternatives could be reviewed, taking different assumptions for the quantities, the percentage recycled, etc., and the impacts could be calculated with a 'real' LCA-software, to have more accurate results. The quantities of detergent needed at the use stage could be increased, and adapted to the number of containers to be washed, which is not always homogenous among the sites.

The lifespan of the containers could be challenged, modifying the number of uses to understand the change of impacts it induces.

The transportation of raw materials until the factories could also be part of a new research, which would therefore have a wider scope.

5. Conclusion

In a world where awareness is increasingly being raised towards environmental matters, new concepts and ideas have emerged to limit the adverse effects of pollution. In the packaging industry, plastic ban is little by little becoming a new trend and actors of the supply chains need to find alternative ways to transport and protect their products. Nevertheless, even though it is common knowledge that single-use plastic applications have non neglectable environmental impacts, case studies from the scientific literature have shown that the choice between single-use and reusable options widely depends on the supply chain configuration and specificities of the life cycle steps.

The research realized for this thesis has shown that Life Cycle Analysis can quickly become very difficult to realize, given the numerous dimensions and constraints which need to be taken into account. The technical aspects of some stages and the uncertainty of data leads to the adoption of assumptions, which need to be challenged.

This paper aimed at analyzing the single-use polypropylene food trays used in the framework of the catering services supplied by the Belgian hospital intermunicipal association Vivalia, and confronting it to the implementation of a reusable alternative of stainless steel containers, observing both environmental and financial impacts over a period of fifteen years.

The main outcome of this study is that the reusable stainless steel container causes less CO_2 emissions than the polypropylene tray, mainly due to the lower impacts caused during the manufacturing, directly linked to the high number of uses for the container. However, from a cost point of view, the single-use tray is cheaper, given the specific deliveries organization – frequency, etc. – which allows Vivalia to make savings on the transportation trips and do not require additional investment in trucks. The single-use alternative also allows to save staff-related costs.

To conclude, the reusable stainless steel containers have turned out to be a better option environmentally-speaking, but the higher cost associated to them may still be a barrier for decision-makers. A mean to change opinions could be to find ways to reduce costs all along the supply chain, while still respecting the environment. However, each situation is different and need to be examined carefully when choosing the best packaging option, and this is even more true in the current fast-moving world. The coronavirus pandemic, which led to a step back to single-use plastics to increase food protection, is the living proof of it.

6. Appendices

Appendix 1 : Overview of the GN ½ single-use and reusable packaging

<u>Polypropylene GN ½ tray</u>

<u>Stainless steel GN ½ reusable container</u>

Appendix 2: Calculations computed for the manufacturing and distribution steps – single-use alternative

Table 40: Data of single-use trays

Single-use alternative		
TRAYS		
Weight	0.073	kg
Length	365	mm
Width	265	mm
PLASTIC WRAP		
Width 1 roll	330	mm
Length 1 roll	500000	mm
Weight of 1 roll	8.519	kg
TRAYS PER DELIVERY		
Cycle 1	75	
Cycle 2	75	
Cycle 3	80	
Cycle 4	75	
TOTAL	**305**	trays per delivery day

Table 41: Calculation of additional data for single-use trays

Data to be computed	Value	Calculations
Number of trays wrapped with 1 roll	1887 trays	$\frac{Length\ 1\ roll}{Width\ 1\ tray} = \frac{500000}{265}$
Weight of 1 portion of wrapping film	4.5×10^{-3}kg	$\frac{Weight\ 1\ roll}{Nb\ trays\ wrapped\ with\ 1\ roll} = \frac{8.519}{1887}$
Total weight single-use packaging	7.75×10^{-2}kg	$Weight\ tray + weight\ wrapping\ film = 0.073 + 4.5 \times 10^{-3}$
Total of trays ordered per month	4000 trays	$305 \times 3 \times 4 = 3660$[25]
Number of rolls ordered per month	3 rolls	$\frac{Nb\ trays\ ordered\ monthly}{Nb\ trays\ wrapped\ with\ 1\ roll} = \frac{4000}{1887} = 2.12 \approx 3$
Net weight transported in the truck of the trays supplier during delivery	317.56 kg	$(Nb\ trays\ by\ order \times Unit\ weight\ of\ trays) + (Nb\ rolls\ per\ order \times Unit\ weight\ of\ rolls) = (4000 \times 0.073) + (3 \times 8.519)$

Appendix 3: Number of beds/places per site

Table 42: Calculation of additional data for single-use trays

Site considered	Quantity in beds/welcoming places
Chanly rest and care home	135 beds
Vielsalm rest and care home	155 beds
Virton rest and care home	54 beds
Sainte-Ode rest home	66 beds
Athus home for psychiatric patients	30 beds
Psychiatric hospital site Bertrix	199 beds
Libramont hospital	317 beds
Marche hospital	175 beds
Bastogne hospital	96 beds
Arlon hospital	307 beds
Saint-Mard hospital	96 beds
Bertrix safe house	16 places
Marche nursery	18 places
Libramont nursery	18 places
Arlon nursery	18 places

[25] Trays are only ordered per 1000 units, so it is rounded up to the nearest multiplicator of 1000, and it is assumed that there is a safety stock for the trays

Appendix 4: Computation of the trays quantities being delivered per site

Table 43: Estimation of the trays quantities delivered by site – single-use alternative

Specific cycle	Site supplied	Proportion of beds & places per site and per cycle	Estimated number of trays delivered per site
Cycle 1	*Psychiatric hospital Bertrix*	$\frac{199}{(199+16)} = 93\%$	0.93 × 75 = 70
	Safe house Bertrix	$\frac{16}{(199+16)} = 7\%$	0.07 × 75 = 5
Cycle 2	*Libramont nursery & hospital*	$\frac{[317+18]}{([317+18]+66)} = 84\%$	0.84 × 75 = 63
	Sainte-Ode rest home	$\frac{66}{([317+18]+66)} = 16\%$	0.16 × 75 = 12
Cycle 3	*Chanly rest and care home*	$\frac{135}{([175+18]+135+155+96)} = 23\%$	0.23 × 80 = 18
	Marche nursery & hospital	$\frac{[175+18]}{([175+18]+135+155+96)} = 33\%$	0.33 × 80 = 26
	Vielsalm rest and care home	$\frac{155}{([175+18]+135+155+96)} = 27\%$	0.27 × 80 = 22
	Bastogne hospital	$\frac{96}{([175+18]+135+155+96)} = 17\%$	0.17 × 80 = 14
Cycle 4	*Arlon nursery & hospital*	$\frac{[307+18]}{([307+18]+30+96+54)} = 64\%$	0.64 × 75 = 48
	Athus home for psychiatric patients	$\frac{30}{([307+18]+30+96+54)} = 6\%$	0.06 × 75 = 5
	Saint-Mard hospital	$\frac{96}{([307+18]+30+96+54)} = 19\%$	0.19 × 75 = 14
	Virton rest and care home	$\frac{54}{([307+18]+30+96+54)} = 11\%$	0.11 × 75 = 8

Appendix 5: Calculations of the food weight per tray

Table 44: Quartiles of unit weight per portion

	Unit weight of one portion (in grams)[26]
Minimum	100
Quartile 1	150
Median	150
Quartile 3	175
Maximum	350

Table 45: Unit weight for a sample of 200 portions

Sample of portions unit weights (in grams) transported in the food containers									
200	200	200	130	150	150	150	150	150	112
100	240	120	120	150	150	150	150	300	106
100	240	200	110	150	150	150	150	300	150
200	100	100	240	150	150	150	300	150	150
240	200	100	100	150	150	150	150	300	150
300	200	100	150	150	150	150	300	150	150
240	120	100	110	150	150	150	150	300	160
200	100	150	100	150	175	150	150	150	160
150	100	150	120	150	150	150	150	300	160
240	100	150	110	150	150	150	150	300	175
100	240	150	240	175	150	150	150	175	150
100	240	150	240	175	150	150	150	150	150
120	240	350	200	150	150	300	150	250	150
240	240	120	240	175	175	175	150	150	300
300	110	135	240	150	175	150	175	175	150
240	100	120	240	175	150	150	175	150	150
100	110	120	150	175	150	150	150	150	150
100	100	175	150	150	150	150	150	150	144
240	240	100	150	175	150	175	150	150	250
150	150	140	150	150	160	150	150	150	150

- *Size of the sample*: n = 200
- *Empirical mean*: $\frac{1}{n} \times \sum_{i}^{n} x_i = \frac{33302}{200} = 166.51g$
- *Total weight of a full plastic tray*: $(0.16651 \times 15) + 0.0775 = 2.575$ kg[27]

[26] *The data were computed via Excel formulas on quartiles*
[27] The result is rounded with three numbers after the comma, to be comparable from kilograms to grams

Appendix 6: RTIs used for the transportation of trays/ containers

Appendix 7: Total weight of the RTIs elements in the truck

Table 46: Data on RTIs used

RTI data	
Number of rolls per truck	2
Number of crates per roll	14
Weight 1 roll (kg)	24
Weight 1 crate (kg)	1.72
Total weight of RTIs in the truck (kg)	**96.16**

Appendix 8: Distances between the different sites

Table 47: Distances travelled during cycle 1

	CPU Bertrix	Psychiatric institution Bertrix	Safe house Bertrix
CPU Bertrix	/	Neglectable (same place)[28]	/
Psychiatric institution Bertrix	/	/	3
Safe house Bertrix	3	/	/

Table 48: Distances travelled during cycle 2

	CPU Bertrix	Libramont nursery & hospital	Sainte-Ode rest home
CPU Bertrix	/	16	/
Libramont nursery & hospital	/	/	23
Sainte-Ode rest home	41	/	/

[28] The CPU is situated on the same site as the psychiatric institution in Bertrix

Table 49: Distances travelled during cycle 3

	CPU Bertrix	Chanly rest and care home	Marche nursery & hospital	Vielsalm rest and care home	Bastogne hospital
CPU Bertrix	/	41	/	/	/
Chanly rest and care home	/	/	30	/	/
Marche nursery & hospital	/	/	/	54	/
Vielsalm rest and care home	/	/	/	/	43
Bastogne hospital	51	/	/	/	/

Table 50: Distances travelled during cycle 4

	CPU Bertrix	Arlon nursery & hospital	Athus home for psychiatric patients	Saint-Mard hospital	Virton rest and care home
CPU Bertrix	/	57	/	/	/
Arlon nursery & hospital	/	/	15	/	/
Athus home for psychiatric patients	/	/	/	23	/
Saint-Mard hospital	/	/	/	/	2
Virton rest and care home	46	/	/	/	/

Appendix 9: Total weight in the truck for each trip (in kilograms) – single-use alternative scenario 1

Table 51: Weight transported during cycle 1 – single-use alternative scenario 1

	CPU Bertrix	Psychiatric institution Bertrix	Safe house Bertrix
CPU Bertrix	/	/	/
Psychiatric institution Bertrix	/	/	96.16 + (5 × 2.575) = **109.036**
Safe house Bertrix	**96.16**	/	/

Table 52: Weight transported during cycle 2 – single-use alternative scenario 1

	CPU Bertrix	**Libramont nursery & hospital**	**Sainte-Ode rest home**
CPU Bertrix	/	96.16 + (75 × 2.575)= **289.297**	/
Libramont nursery & hospital	/	/	289.297 – (63 × 2.575) = **127.062**
Sainte-Ode rest home	**96.16**	/	/

Table 53: Weight transported during cycle 3 – single-use alternative scenario 1

	CPU Bertrix	**Chanly rest and care home**	**Marche nursery & hospital**	**Vielsalm rest and care home**	**Bastogne hospital**
CPU Bertrix	/	96.16 + (80 × 2.575) = **302.173**	/	/	/
Chanly rest and care home	/	/	302.173 – (18 × 2.575) = **255.82**	/	/
Marche nursery & hospital	/	/	/	255.82 – (26 × 2.575) = **188.866**	/
Vielsalm rest and care home	/	/	/	/	188.866 – (22 × 2.575) = **132.812**
Bastogne hospital	**96.16**	/	/	/	/

Table 54: Weight transported during cycle 4 – single-use alternative scenario 1

	CPU Bertrix	**Arlon nursery & hospital**	**Athus home for psychiatric patients**	**Saint-Mard hospital**	**Virton rest and care home**
CPU Bertrix	/	96.16 + (75 × 2.575) = **289.297**	/	/	/
Arlon nursery & hospital	/	/	289.297 – (48 × 2.575) = **165.689**	/	/
Athus home for psychiatric patients	/	/	/	165.689 – (5 × 2.575) = **152.814**	/
Saint-Mard hospital	/	/	/	/	152.814 – (14 × 2.575) = **116.761**
Virton rest and care home	**96.16**	/	/	/	/

Appendix 10: Overview of the distances and weight transported until the waste management facility of Habay/Weekly waste dedicated to landfill and incineration

Table 55: Single-use scenario 1 – Transportation until the waste management facility

Municipality[29]	Distance to Habay waste management facility (km)	Quantity of trays put to waste per week	Weight of the trays in the different trucks (kg)
Bertrix	37	(70 + 5) × 3 = **225**	225 × 0.0775 = **17.4375**
Libramont	34	63 × 3 = **189**	189 × 0.0775 = **14.6475**
Sainte-Ode	54	12 × 3 = **36**	36 × 0.0775 = **2.79**
Wellin	68	18 × 3 = **54**	54 × 0.0775 = **4.185**
Marche	79	26 × 3 = **78**	78 × 0.0775 = **6.045**
Vielsalm	80	22 × 3 = **66**	66 × 0.0775 = **5.115**
Bastogne	38	14 × 3 = **42**	42 × 0.0775 = **3.255**
Arlon	17	48 × 3 = **144**	144 × 0.0775 = **11.16**
Aubange	27	5 × 3 = **15**	15 × 0.0775 = **1.1625**
Virton	20	(14 + 8) × 3 = **66**	66 × 0.0775 = **5.115**
	Total :	**915**	**70.9125**

Table 56: Distribution of weekly waste between landfill and incineration – scenario 1

Weekly waste dedicated to landfill (kg)	Weekly waste sent for incineration (kg)
0.04 × 70.9125 = **2.8365**	70.9125 - 2.8365 = **68.076**

Appendix 11: Total weight in the truck for each trip (in kilograms) – single-use alternative with recycling scenario

Table 57: Weight transported during cycle 1 – single-use alternative scenario 2

	CPU Bertrix	Psychiatric institution Bertrix	Safe house Bertrix
CPU Bertrix	/	Neglectable (same place)	/
Psychiatric institution Bertrix	/	/	96.16 + (5 × 2.575) = **109.036**
Safe house Bertrix	96.16 + (5 × 0.073) = **96.525**	/	/

[29] The waste is collected by municipalities, that is why some trays quantities from sites in the same municipality were summed up.

Table 58: Weight transported during cycle 1 – single-use alternative scenario 2

	CPU Bertrix	**Libramont nursery & hospital**	**Sainte-Ode rest home**
CPU Bertrix	/	96.16 + (75 × 2.575) = **289.297**	/
Libramont nursery & hospital	/	/	96.16 + (63 × 0.073) + (12 × 2.575) = **131.661**
Sainte-Ode rest home	96.16 + (75 × 0.073) = **101.635**	/	/

Table 59: Weight transported during cycle 3 – single-use alternative scenario 2

	CPU Bertrix	**Chanly rest and care home**	**Marche nursery & hospital**	**Vielsalm rest and care home**	**Bastogne hospital**
CPU Bertrix	/	96.16 + (80 × 2.575) = **302.173**	/	/	/
Chanly rest and care home	/	/	96.16 + (18 × 0.073) + (62 × 2.575) = **257.134**	/	/
Marche nursery & hospital	/	/	/	96.16 + (44 × 0.073) + (36 × 2.575) = **192.078**	/
Vielsalm rest and care home	/	/	/	/	96.16 + (66 × 0.073) + (14 × 2.575) = **137.030**
Bastogne hospital	96.16 + (80 × 0.073) = **102**	/	/	/	/

Table 60: Weight transported during cycle 4 – single-use alternative scenario 2

	CPU Bertrix	**Arlon nursery & hospital**	**Athus home for psychiatric patients**	**Saint-Mard hospital**	**Virton rest and care home**
CPU Bertrix	/	96.16 + (75 × 2.575) = **289.297**	/	/	/
Arlon nursery & hospital	/	/	96.16 + (48 × 0.073) + (27 × 2.575) = **169.193**	/	/
Athus home for psychiatric patients	/	/	/	96.16 + (53 × 0.073) + (22 × 2.575) = **156.683**	/
Saint-Mard hospital	/	/	/	/	96.16 + (67 × 0.073) + (8 × 2.575) = **121.652**
Virton rest and care home	96.16 + (75 × 0.073) = **101.635**	/	/	/	/

Appendix 12: Calculation details – water and energy consumption of the dishwasher for the recycling scenario

Table 61: Computation of water consumption data – scenario 2

Dishwasher	
TECHNICAL DATA	
Number of racks/hour	150
Water consumption (liter/rack)	0.7
Number of containers/rack	10
VIVALIA SITUATION	
Number of containers for one day	305
Number of racks/day	$\frac{305}{10} \approx 31$
Water consumption/day (liter)	0.7 × 31 = 21.7
Frequency of deliveries	3 days a week
Water consumption/week (liter)	21.7 × 3 = 65.1

Energy consumption for the dishwasher

- *Power of the dishwasher*: 29.4 kilowatt for 150 racks/hour
- *Energy consumption for 31 racks*: $\frac{29.4}{150} \times 31 = 6.076$ kilowatt-hour
- *Energy consumption for 1 week*: 6.076 × 3 = 18.228 kilowatt-hour

Appendix 13: Calculations of the weight taking back the trays to the recycling branch of the supplier

- *Number of trays per delivery day:* 305
- *Number of deliveries per week:* 3
- *Number of trays taken back per month:* 305 × 3 × 4 = 3660
- *Weight of a plastic tray (kg):* 0.073
- *Total weight in the truck returning to the plant for the recycling scenario (kg):*

$$3660 \times 0.073 = 267.18$$

Appendix 14: Calculations details – End-of-life of the wrapping plastic due to Scenario 2

The distances and quantity of trays were computed in the same way as what was done for *Appendix 10*.

- *Weight of the wrapping part on the tray*: 0.0045 kilogram

Table 62: Single-use scenario 2 – Transportation until the waste management facility for the wrapping parts

Municipality[30]	**Distance to Habay waste management facility (km)**	**Quantity of trays put to waste per week**	**Weight of the trays in the different trucks (kg)**
Bertrix	37	(70 + 5) × 3 = **225**	225 × 0.0045 = 1.0125
Libramont	34	63 × 3 = **189**	189 × 0.0045 = 0.8505
Sainte-Ode	54	12 × 3 = **36**	36 × 0.0045 = 0.162
Wellin	68	18 × 3 = **54**	54 × 0.0045 = 0.243
Marche	79	26 × 3 = **78**	78 × 0.0045 = 0.351
Vielsalm	80	22 × 3 = **66**	66 × 0.0045 = 0.297
Bastogne	38	14 × 3 = **42**	42 × 0.0045 = 0.189
Arlon	17	48 × 3 = **144**	144 × 0.0045 = 0.648
Aubange	27	5 × 3 = **15**	15 × 0.0045 = 0.0675
Virton	20	(14 + 8) × 3 = **66**	66 × 0.0045 = 0.297
	Total :	**915**	**4.1175**

- *Weight transported until Uvelia for incineration (96%)*:

  4.1175 × 0.96 = 3.9528 kilograms

Appendix 15: Computation of the quantity of stainless steel containers to be ordered

Illustration of the reusing system:

Nb of trays out of the CPU every day: $2 \times 130 = 260 \begin{cases} 130 \text{ transported} \\ 130 \text{ waiting to be returned to the CPU} \end{cases}$

Safety Stock in trays (assumption): If issues, 1 day to be aligned with the washing lead-time at the CPU, 1 day for the lead-time of the return and a percentage coverage for potential damaged/lost containers

[30] The waste is collected by municipalities, that is why some trays quantities from sites in the same municipality were summed up.

Table 63: Illustration of the reusing system

Day	**Containers at the CPU**	**Containers on the hospital sites (total of containers on all sites)**	**Containers going back to the CPU**
Day 1	3 × 130 + coverage	130	/
Day 2	2 × 130 + coverage	130	130
Day 3	2 × 130 + coverage	130	130
Day 4	2 × 130 + coverage	130	130
...			

- *Coverage/percentage of lost/damaged containers assumed during a year*: 0.05%
- *Number of containers circulating during a year*: 130 × 7 × 52 = 47320
- *Number of lost/damaged containers during a year*: 0.0005 × 47320 = 24
- *Number of lost/damaged containers assuming 15 years of lifespan for the containers*: 24 × 15 = 360
- *Total number of containers to be ordered* = *Number of containers out of the CPU + Safety Stock in the CPU* = 260 + 260 + 360 = 880
- *Total number of annual use per container*: $\frac{880}{130}$ = 6.76

  It means that a container is used in average every 6 days. Therefore, the annual number of uses is $\frac{360}{6}$ = 60

<u>Total weight in the truck from the supplier</u>

- *Nb containers to be ordered × (Unit weight of a container + Unit weight of a lid)* =

  880 × (0.68+0.5) = 1038.4 kilograms

Appendix 16: Number of trays supplied per site – reusable alternative

Table 64: Estimation of the trays quantities – reusable alternative

Specific cycle	Site supplied	Proportion of beds & places per site and per cycle	Estimated number of trays delivered per site
Cycle 1	*Psychiatric hospital Bertrix*	93%	0.93 × 32 = 30
	Safe house Bertrix	7%	0.07 × 32 = 2
Cycle 2	*Libramont nursery & hospital*	84%	0.84 × 32 = 27
	Sainte-Ode rest home	16%	0.16 × 32 = 5
Cycle 3	*Chanly rest and care home*	23%	0.23 × 34 = 8
	Marche nursery & hospital	33%	0.33 × 34 = 11
	Vielsalm rest and care home	27%	0.27 × 34 = 9
	Bastogne hospital	17%	0.17 × 34 = 6
Cycle 4	*Arlon nursery & hospital*	64%	0.64 × 32 = 20
	Athus home for psychiatric patients	6%	0.06 × 32 = 2
	Saint-Mard hospital	19%	0.19 × 32 = 6
	Virton rest and care home	11%	0.11 × 32 = 4

Appendix 17: Total weight in the truck for each trip (in kilograms) – reusable alternative

- *Weight of the full container*: (15 × 0.16651) + 0.68 + 0.5 = 3.678 kilograms
- *Weight of an empty container*: 0.68 + 0.5 = 1.18 kilograms

Table 65: Weight transported during cycle 1 – reusable alternative

	CPU Bertrix	Psychiatric institution Bertrix	Safe house Bertrix
CPU Bertrix	/	Neglectable (same place)	/
Psychiatric institution Bertrix	/	/	96.16 + (2 × 3.678) = **103.515**
Safe house Bertrix	96.16 + (2 × 1.18) = **98.52**	/	/

Table 66: Weight transported during cycle 2 – reusable alternative

	CPU Bertrix	**Libramont nursery & hospital**	**Sainte-Ode rest home**
CPU Bertrix	/	96.16 + (32 × 3.678) = **213.845**	/
Libramont nursery & hospital	/	/	96.16 + (27 × 1.18) + (5 × 3.678) = **146.408**
Sainte-Ode rest home	96.16 + (32 × 1.18) = **133.92**	/	/

Table 67: Weight transported during cycle 3 – reusable alternative

	CPU Bertrix	**Chanly rest and care home**	**Marche nursery & hospital**	**Vielsalm rest and care home**	**Bastogne hospital**
CPU Bertrix	/	96.16 + (34 × 3.678) = **221.2**	/	/	/
Chanly rest and care home	/	/	96.16 + (8 × 1.18) + (26 × 3.678) = **201.219**	/	/
Marche nursery & hospital	/	/	/	96.16 + (19 × 1.18) + (15 × 3.678) = **173.745**	/
Vielsalm rest and care home	/	/	/	/	96.16 + (28 × 1.18) + (6 × 3.678) = **151.266**
Bastogne hospital	96.16 + (34 × 1.18) = **136.28**	/	/	/	/

Table 68: Weight transported during cycle 4 – reusable alternative

	CPU Bertrix	Arlon nursery & hospital	Athus home for psychiatric patients	Saint-Mard hospital	Virton rest and care home
CPU Bertrix	/	96.16 + (32 × 3.678) = **213.845**	/	/	/
Arlon nursery & hospital	/	/	96.16 + (20 × 1.18) + (12 × 3.678) = **163.892**	/	/
Athus home for psychiatric patients	/	/	/	96.16 + (22 × 1.18) + (10 × 3.678) = **158.897**	/
Saint-Mard hospital	/	/	/	/	96.16 + (28 × 1.18) + (4 × 3.64) = **143.911**
Virton rest and care home	96.16 + (32 × 1.18) = **133.92**	/	/	/	/

Appendix 18: Water and energy consumption for the hand washing and dishwasher phases – reusable alternative

Table 69: Water consumption data – reusable alternative

Dishwasher technique			
TECHNICAL DATA			
Nb racks/hour	150		
Water consumption (liter/rack)	0.7		
Nb of containers/rack	10		
VIVALIA SITUATION		**Hand washing technique**	
Nb containers + lids/day	130 + 130 = 260	VIVALIA SITUATION	
Nb of racks/day	$\frac{260}{10} = 26$	*Increased water consumption compared to dish washer technique*	60%
Water consumption/day (liter)	0.7 × 26 = 18.2	*Water consumption/day for each site (liter)*	18.2 × (1+0.6) = 29.12 → rounded to 30 liters

Energy consumption for the dishwasher

- *Power of the dishwasher*: 29.4 kilowatt for 150 racks/hour
- *Energy consumption for 26 racks*: $\frac{29.4}{150} \times 26 = 5.096$ kilowatt-hour

Appendix 19: Sensitivity analysis – transportation stage evaluated with 'EcoTransIt'

The sensitivity analysis realized with the 'EcoTransIt' tool will allow to choose more accurate parameters to estimate the emissions released. For this transportation step, the computations were made assuming a truck with between 7.5 and 12 tons capacity, using diesel, with the norm 'EURO 4' for the emissions – as stated by Nutripack, taken as example (Carpentier & Rivelon, 2011) –, and 0% empty trips, given that only a one-way travel was taken into account.

The load factor of the trucks transporting the trays/containers has been computed according to the following formula:

$$\textit{Load factor (\%)}^{31} = \frac{\textit{Weight in the truck}}{\textit{Loading capacity of the truck}} \times 100$$

- *Single-use option*: $\frac{317.56}{7500} = 5\%$
- *Reusable option*: $\frac{1038.4}{7500} = 14\%$

Table 70 below represents the CO_2 emissions associated to the transportation step over the 15-year period.

Table 70: Climate change impact for the transportation step – EcoTransIt

	SINGLE-USE	REUSABLE
Climate change (Kg CO2 eq.)	19.8	0.34

[31] The percentage obtained was rounded up to the nearest superior integer

The difference in those numbers compared to what was previously established with the 'Bilan Produit®' results from the scope of evaluation which is taken into account in the different tools, with 'EcoTransIt' presenting lower numbers, as it takes into account the emissions directly coming from the truck use, while the first tool also takes into account the infrastructure of the road, use of truck and park management, which explains the higher impacts noticed.

Appendix 20: Distribution of the two washing phases in the total use stage of the reusable alternative – Climate change indicator

Table 71: distribution of impacts between cleaning processes – reusable alternative

	Hand washing	**Dishwasher**
Climate change (Kg CO2 eq.)	1714.6584	7278.18

- *Percentage allocated to the dishwasher technique in total use stage impacts – reusable*: $\frac{7278.18}{8992.8384} = 81\%$

Appendix 21: Sensitivity analysis – distribution stage evaluated with 'EcoTransIt'

Specifications of the parameters used:

Given that the refrigerated truck used by Vivalia has a maximum payload of 0.78 ton, for a maximum total weight with payload of 2.48 tons, the vehicle type chosen in the tool was the minimum weight available, which was 'vehicles with less than 3.5 tons of capacity'[32]. The rest of the parameters needing to be specified were fixed as the following:

- *Weight in the truck*: as calculated before
- *Place of origin and destination fixed thanks to the coordinates of the addresses*
- *Fuel type*: diesel
- *Emission standard*: Euro 5: fixed in an arbitrary way
- *Percentage of empty trip*: 0% – as each trip is taken into account
- *Load factor*: calculated depending on each weight, according to the formula below:

[32] It must be noted as well that selecting both 'vehicles with less than 3.5 tons of capacity' and 'cooled box' – in reference to the refrigerated truck – was not possible on the tool, so the impacts were calculated as for a 'normal' truck, thus not taking into account the fact that the 'truck' used was actually a delivery van.

$$Load\ factor\ (\%) = \frac{Weight\ in\ the\ truck}{Maximum\ payload\ of\ the\ truck} \times 100$$

The load factors corresponding to each trip done by the truck for the deliveries can be found here under:

Table 72: Load factors for the distribution step – single-use scenario 1

Travel realized	Load factor (%)
Cycle 1	
CPU → Psychiatric institution Bertrix	Neglectable (same place)
Psychiatric institution → Safe house Bertrix	$\frac{109.036}{780} = 14\%$
Safe house → CPU	$\frac{96.16}{780} = 13\%$
Cycle 2	
CPU → Libramont nursery & hospital	$\frac{289.297}{780} = 38\%$
Libramont → Saint-Ode rest home	$\frac{127.062}{780} = 17\%$
Sainte-Ode → CPU	$\frac{96.16}{780} = 13\%$
Cycle 3	
CPU → Chanly rest and care home	$\frac{302.173}{780} = 39\%$
Chanly → Marche nursery & hospital	$\frac{255.82}{780} = 33\%$
Marche → Vielsalm rest and care home	$\frac{188.866}{780} = 25\%$
Vielsalm → Bastogne hospital	$\frac{132.212}{780} = 17\%$
Bastogne → CPU	$\frac{96.16}{780} = 13\%$
Cycle 4	
CPU → Arlon nursery & hospital	$\frac{289.297}{780} = 38\%$
Arlon → Athus home for psychiatric patients	$\frac{165.689}{780} = 22\%$
Athus → Saint-Mard hospital	$\frac{152.814}{780} = 20\%$
Saint-Mard → Virton rest and care home	$\frac{116.761}{780} = 15\%$
Virton → CPU	$\frac{96.16}{780} = 13\%$

Table 73: Load factors for the distribution step – single-use scenario 2

Travel realized	Load factor (%)
Cycle 1	
CPU → Psychiatric institution Bertrix	**Neglectable/same place**
Psychiatric institution → Safe house Bertrix	$\frac{109.036}{780} = 14\%$
Safe house → CPU	$\frac{96.525}{780} = 13\%$
Cycle 2	
CPU → Libramont nursery & hospital	$\frac{289.297}{780} = 38\%$
Libramont → Saint-Ode rest home	$\frac{131.661}{780} = 17\%$
Sainte-Ode → CPU	$\frac{101.635}{780} = 14\%$
Cycle 3	
CPU → Chanly rest and care home	$\frac{302.173}{780} = 39\%$
Chanly → Marche nursery & hospital	$\frac{257.134}{780} = 33\%$
Marche → Vielsalm rest and care home	$\frac{192.078}{780} = 25\%$
Vielsalm → Bastogne hospital	$\frac{137.03}{780} = 18\%$
Bastogne → CPU	$\frac{102}{780} = 14\%$
Cycle 4	
CPU → Arlon nursery & hospital	$\frac{289.297}{780} = 38\%$
Arlon → Athus home for psychiatric patients	$\frac{169.193}{780} = 22\%$
Athus → Saint-Mard hospital	$\frac{156.683}{780} = 21\%$
Saint-Mard → Virton rest and care home	$\frac{121.652}{780} = 16\%$
Virton → CPU	$\frac{101.635}{780} = 14\%$

Table 74: Load factors for the distribution step – reusable alternative

Travel realized	Load factor (%)
Cycle 1	
CPU → Psychiatric institution Bertrix	Neglectable (same place)
Psychiatric institution → Safe house Bertrix	$\frac{103.515}{780} = 14\%$
Safe house → CPU	$\frac{98.52}{780} = 13\%$
Cycle 2	
CPU → Libramont nursery & hospital	$\frac{213.845}{780} = 28\%$
Libramont → Saint-Ode rest home	$\frac{146.408}{780} = 19\%$
Sainte-Ode → CPU	$\frac{133.92}{780} = 18\%$
Cycle 3	
CPU → Chanly rest and care home	$\frac{221.2}{780} = 29\%$
Chanly → Marche nursery & hospital	$\frac{201.219}{780} = 26\%$
Marche → Vielsalm rest and care home	$\frac{173.745}{780} = 23\%$
Vielsalm → Bastogne hospital	$\frac{151.266}{780} = 20\%$
Bastogne → CPU	$\frac{136.28}{780} = 18\%$
Cycle 4	
CPU → Arlon nursery & hospital	$\frac{213.845}{780} = 28\%$
Arlon → Athus home for psychiatric patients	$\frac{163.892}{780} = 22\%$
Athus → Saint-Mard hospital	$\frac{158.897}{780} = 21\%$
Saint-Mard → Virton rest and care home	$\frac{143.911}{780} = 19\%$
Virton → CPU	$\frac{133.92}{780} = 18\%$

The two tables here under represent the CO_2 emissions related to distribution if the calculations are run with 'EcoTransIt'.

Table 75: Climate change impact for the distribution step – scenario 1 with EcoTransIt

	SINGLE-USE	REUSABLE
Climate change (Kg CO2 eq.)	152.0532	354.7362

Table 76: Climate change impact for the distribution step – scenario 2 with EcoTransIt

	SINGLE-USE	REUSABLE
Climate change (Kg CO2 eq.)	150.8832	354.7362

Here again, the numbers vary quite importantly from the ones obtained with the first tool, as they also include the road infrastructure, manufacturing and end-of-life of the truck used in addition to the truck utilization.

Appendix 22: Detailed overview of the EOL impacts – single-use versus reusable

Table 77: Impacts for the EOL stage – scenario 1

	Impacts linked to transportation until Habay	Impact linked to transportation until Uvelia	Impacts linked to incineration/landfill
Climate change (Kg CO2 eq.)	38.142	116.802	114477.48
Resource use - Fossil (MJ)	581.04	1779.12	-528066.63
Photochemical ozone formation (Kg COVNM eq.)	0.26784	0.8199	34.9713
Acidification (eq. Mol. H+)	0.32184	0.98532	9.749142

Table 78: *Impacts for the EOL stage due to the wrapping parts – scenario 2*

	Impacts linked to transportation until Habay	**Impacts linked to transportation until Uvelia**	**Impacts linked to incineration/landfill**
Climate change (Kg CO2 eq.)	2.2212	6.7824	6645.9744
Resource use - Fossil (MJ)	33.822	103.302	-30689.1
Photochemical ozone formation (Kg COVNM eq.)	0.0155898	0.04761	2.0304765
Acidification (eq. Mol. H+)	0.018738	0.057222	0.56602833

Table 79: Impacts for the EOL stage due to the trays– scenario 2

	Impacts linked to transportation until the trays' supplier	**Impact linked to dishwasher use**	**Impacts linked to recycling[33]**
Climate change (Kg CO2 eq.)	844.74	3712.8	-11253.6216
Resource use - Fossil (MJ)	13336.74	128552.58	/
Photochemical ozone formation (Kg COVNM eq.)	5.364	6.9693	/
Acidification (eq. Mol. H+)	5.364	11.3178	/

<u>*Reusable alternative*</u>

The impacts directly linked to recycling – without the transportation flows – have been computed for the 'climate change' and 'resource use – Fossil' indicators only, given the availability of information. As mentioned previously, the impact of recycling on climate change has been assumed to save 57% of emissions generated during the manufacturing stage, and the impact on resource use has been assumed to save 40% of energy used during the manufacturing stage.

Table 80: Impacts for the EOL stage – reusable alternative

	Impacts linked to transportation – Habay & Uvelia	**Impacts linked to recycling**
Climate change (Kg CO2 eq.)	9.066	-0.57 × 3879.04 = -2211.0528
Resource use - Fossil (MJ)	138.112	-0.4 × 43823.12 = -17529.248
Photochemical ozone formation (Kg COVNM eq.)	0.06365	
Acidification (eq. Mol. H+)	0.076493	

[33] Information only available for 'climate change' indicator

Appendix 23: Sensitivity analysis – EOL stage evaluated with 'EcoTransIt'

For this EOL step, the computations were made assuming a truck with between 7.5 and 12 tons capacity, using diesel, with the norm 'EURO 4' for the emissions, and 0% empty trips, given that only a one-way travel was taken into account.

The load factor of the trucks has been computed according to the following formula:

$$Load\ factor\ (\%)^{34} = \frac{Weight\ in\ the\ truck}{Loading\ capacity\ of\ the\ truck} \times 100$$

The transportation flows to take into account in this step are the following:

Single-use – scenario 1:

- Transport until Habay and Uvelia for landfill and incineration

Single-use – scenario 2:

- Transport until Habay and Uvelia for landfill and incineration concerning the wrapping plastic which is not recycled
- Transport until the trays's supplier for the trays to be recycled

Reusable:

- Transport until Sametal to crush the containers
- Transport until John Cockerill to remanufacture the scrap metal

Load factors and impacts for each flow:

- *Scenario 1: transport until Habay for the trays and wrapping plastics*

As it was stated previously, the weight calculated corresponding to the quantity of wrapping plastic which is put to the bin weekly is not representative of the total weight which can be transported by a garbage truck. It will thus be assumed that the load factor is 20%, which represents 1500 kilograms.

Table 81: Impacts for the EOL stage – reusable alternative

	SINGLE-USE
Climate change (Kg CO2 eq.)	0.87282

- *Scenario 1: transport until Uvelia for the trays and wrapping plastics*

[34] The percentage obtained was rounded up to the nearest superior integer

For this scenario, a load factor of 40% – 3000 kilograms – will be assumed.

Table 82: Climate change impact for the transport until the incineration facility – scenario 1 with EcoTransIT

	SINGLE-USE
Climate change (Kg CO2 eq.)	1.404

- *Scenario 2: transport until Habay for the wrapping plastic which cannot be recycled*

Here as well, the loading factor will be assumed to be 20%.

Table 83: Climate change impact for the transport of the wrapping parts until the waste management facility – scenario 1 with EcoTransIT

	SINGLE-USE
Climate change (Kg CO2 eq.)	0.0515268

- *Scenario 2: transport until Uvelia for the wrapping plastic which cannot be recycled*

For this scenario, a load factor of 40% – 3000 kilograms – will be assumed.

Table 84: Climate change impact for the transport of the wrapping parts until the incineration facility – scenario 2 with EcoTransIT

	SINGLE-USE
Climate change (Kg CO2 eq.)	0.1014

- *Scenario 2: transport until the trays' supplier for recycling*

For this flow, the load factor is $\frac{267.18}{7500} = 4\%$

Table 85: Climate change impact for the transport of the trays back to the recycling branch of the supplier – EcoTransIt

	SINGLE-USE
Climate change (Kg CO2 eq.)	19.8

- *Reusable alternative: transport from the CPU until Sametal*

For this flow, the load factor is $\frac{1038.4}{7500}$ = 14%.

Table 86: Climate change impact for the transport of reusable containers until the recycling branch Sametal – EcoTransIt

	REUSABLE
Climate change (Kg CO2 eq.)	0.075

- *Reusable alternative: transport from Sametal until John Cockerill*

For this flow, the load factor is $\frac{1038.4}{7500}$ = 14% – as it is assumed that the weight crushed will be the same.

Table 87: Climate change impact for the transport of reusable containers crushed into pieces from Sametal to John Cockerill – EcoTransIt

	REUSABLE
Climate change (Kg CO2 eq.)	0.0081

Appendix 24: Computation of the total impacts per kilogram of food handled

- *Weight of food per tray/container*: 2.49765 kilograms
- *Number of plastic trays being transported per week*: 915
- *Number of reusable containers being transported per week*: 130 × 7 = 910
- *Total number of trays being handled over 15 years*: 915 × 52 × 15 = 713700
- *Total number of trays being handled over 15 years*: 910 × 52 × 15 = 709800
- *Total weight being handled over 15 years in the trays:*

  713700 × 2.49765 = 1782572.805 kilograms
- *Total weight being handled over 15 years for the containers:*

  709800 × 2.49765 = 1772831.97 kilograms
- *Impacts for 1 kilogram of food handled – single-use scenario 1(Kg CO_2 equivalent):*

$$\frac{293083.0146}{1782572.805} = 0.164$$

- *Impacts for 1 kilogram of food handled – single-use scenario 2 (Kg CO_2 equivalent):*

$$\frac{178674.8196}{1782572.805} = 0.1$$

- *Impacts for 1 kilogram of food handled – reusable option (Kg CO_2 equivalent):*

$$\frac{42915.3364}{1772831.97} = 0.024$$

Appendix 25: Computation of ratio and minimum number of reuse over 15 years

- *Ratio single-use/reusable scenario 1*: $\frac{\text{Impacts single-use alternative}}{\text{Impacts reusable alternative}} = \frac{0.164}{0.024} = 6.79$
  - *Minimum number of reuse to equal impacts for both alternatives*:

$$\frac{\text{Number of uses assumed for 15 years}}{\text{Ratio single-use/reusable}} = \frac{900}{6.79} = 133$$

- *Ratio single-use/reusable scenario 2*: $\frac{0.1}{0.024} = 4.14$
  - *Minimum number of reuse to equal impacts for both alternatives*:

$$\frac{900}{4.14} = 218$$

Appendix 26: Weight of impact per stage of the life cycle – EcoTransIt

Table 88: Weight of impacts per stages and per alternative observed – EcoTransIT

	Single-use scenario 1	**Single-use scenario 2**	**Reusable scenario**
Manufacturing	58.38%	99.93%	35.213%
Transportation	0.01%	0.01%	0.003%
Use step	0.30%	0.51%	81.634%
Distribution scenario 1	0.05%	/	3.220%
Distribution scenario 2	/	0.09%	/
EOL scenario 1	41.26%	/	-20.071%
EOL scenario 2	/	-0.54%	/

Appendix 27: Impacts per kilogram of food handled, ratio and minimum number of reuses – EcoTransIt

Table 89: Total impacts for each alternative – EcoTransIt

	SINGLE-USE : SCENARIO 1	**SINGLE-USE : SCENARIO 2**	**REUSABLE**
Climate change (Kg CO2 eq.)	277475.2198	162119.3987	11015.9849

- *Impacts for 1 kilogram of food handled – single-use scenario 1(Kg CO_2 equivalent):*

$$\frac{277475.2198}{1782572.805} = 0.156$$

- *Impacts for 1 kilogram of food handled – single-use scenario 2 (Kg CO_2 equivalent):*

$$\frac{162119.3987}{1782572.805} = 0.091$$

- *Impacts for 1 kilogram of food handled – reusable option (Kg CO_2 equivalent):*

$$\frac{11015.9849}{1772831.97} = 0.006$$

- *Ratio single-use/reusable scenario 1*: $\frac{0.156}{0.006} = 25.05$
  - Minimum number of reuse to equal impacts for both alternatives:

$$\frac{900}{25.05} = 36$$

- *Ratio single-use/reusable scenario 2*: $\frac{0.091}{0.006} = 14.64$
  - Minimum number of reuse to equal impacts for both alternatives:

$$\frac{900}{14.64} = 62$$

Appendix 28: Purchasing cost calculation – single-use

- *Monthly order of trays: 4000*
- *Monthly order of wrapping rolls: 3*

Table 90: Computation of the purchasing cost per year – single-use option

	Unit cost (€)	Number of items in 1 year	Cost per year (€)
Tray	0.246	4000 × 12 = 48000	11808
Wrapping roll	40.3	3 × 12 = 36	1450.8

Appendix 29: Electricity cost – vacuuming of trays

- *Energy consumed by the vacuuming of 1 tray*: 0.0045 kWh
- *Cost of electricity*: 0.2839€/kWh
- *Cost of 1 tray vacuumed*: 1.27755×10^{-3}€
- *Number of trays delivered/week*: 915

The annual cost can be computed by doing the following calculations:

$$1.27755 \times 10^{-3} \times 915 \times 52 \text{ weeks in a year} = 60.79€$$

Appendix 30: Diesel cost computation – single-use alternative

- $\sum$ *distances for the four cycles*: 448 kilometers
- *Consumption of diesel for the refrigerated truck*: 5.7 liters/100 kilometers travelled
- *Cost of 1 liter of diesel*: 1.372€ VAT included at 21% – 1.08388 VAT excluded
- *Frequency of delivery*: 3 days/week

The annual diesel cost can thus be computed as:

$$\left(\frac{448}{100}\right) \times 5.7 \times 1.08388 \times 3 \times 52 \text{ weeks in a year} = 4317.76€$$

Appendix 31: Water cost due to dishwasher use – recycling scenario

- *Weekly water consumption for the dishwasher:* 65.1 liters
- *Cost of 1 cubic meter :* 5.3 € – VAT included 6% / 4.982€ – VAT excluded
- *Annual water consumption due to dishwasher use*:

$$65.1 \times \frac{4.982}{1000} \times 52 \text{ weeks in a year} = 16.87€$$

Appendix 32: Water cost due to the cleaning processes – reusable alternative

- *Daily water consumption for the dishwasher:* 18.2 liters
- *Daily water consumption per site for hand washing technique:* 30 liters
- *Cost of 1 cubic meter :* 5.3 € – VAT included 6% / 4.982€ – VAT excluded
- *Nb of sites where handwashing happens:* 12
- Annual water consumption due to dishwasher use:

$$18.2 \times \frac{4.982}{1000} \times 7 \times 52 \text{ weeks in a year} = 33€$$

- Annual water consumption due to hand washing phase:

$$30 \times 12 \times \frac{4.982}{1000} \times 7 \times 52 \text{ weeks in a year} = 652.84€$$

Appendix 33: Diesel cost computation – reusable alternative

- $\sum$ *distances for the four cycles*: 448 kilometers
- *Consumption of diesel for the refrigerated truck*: 5.7 liters/100 kilometers travelled
- *Cost of 1 liter of diesel*: 1.372€
- *Frequency of delivery*: 7 days/week

The annual diesel cost can thus be computed as:

$$\left(\frac{448}{100}\right) \times 5.7 \times 1.372 \times 7 \times 52 \text{ weeks in a year} = 12753€$$

Appendix 34: Gross cost of staff – reusable alternative

- *Current annual gross cost per FTE (€):* 44000
- *Current nb of FTEs :* 16
- *Number of hours worked per week:* 40
- *Total number of hours worked per year:* $40 \times 52 = 2080$
- *Cost per hour (€):* $\frac{44000}{2080} = 21.15$
- *Updated number of days worked per week:* 7
- *Updated daily number of hours worked:* $\frac{40}{7} = 5.71$
- *Cost increase on Saturday*: 26%
- *Cost increase on Sunday*: 56%
- *Cost per hour (week day) (€):* 21.15
- *Cost per hour (Saturday) (€):* $21.15 \times (1 + 0.26) = 26.65$
- *Cost per hour (Sunday) (€):* $21.15 \times (1 + 0.56) = 33$
- *Updated weekly cost per FTE (€):*

  $$(21.15 \times 5.71 \times 5) + (26.65 \times 5.71) + (33 \times 5.71) = 945.27$$
- *New annual cost per FTE – reusable alternative*: $945.27 \times 52 = 49154$ €

Appendix 35: Cost comparison of each alternative per kilogram of food handled

- *Weight of food per tray/container*: 2.49765 kilograms
- *Number of plastic trays being transported per week*: 915
- *Number of reusable containers being transported per week*: 130 × 7 = 910
- *Total number of trays being handled over 15 years*: 915 × 52 × 15 = 713700
- *Total number of trays being handled over 15 years*: 910 × 52 × 15 = 709800
- *Total weight being handled over 15 years in the trays:*

  713700 × 2.49765 = 1782572.805 kilograms
- *Total weight being handled over 15 years for the containers:*

  709800 × 2.49765 = 1772831.97 kilograms

Table 91: Computation of the cost per kilogram of food handled for each alternative

OVER 15 YEARS	**Reusable alternative**	**Single-use alternative – scenario 1: No recycling**	**Single-use alternative – scenario 2: Recycling**
Total cost (€)	13361505.8	11157560.21	11149826.53
Cost per kilogram of food transported (€)	$\frac{13361505.8}{1772831.97} = 7.54$	$\frac{11157560.21}{1782572.805} = 6.26$	$\frac{11149826.53}{1782572.805} = 6.25$

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8. EXECUTIVE SUMMARY

In a world where environmental concerns are growing, the single-use plastics issue is becoming more and more important. Cities, governments and companies are integrating sustainable practices in their daily activities; without, however, putting aside the financial aspect linked to those practices. This paper, under the form of a case study, aims at comparing the environmental and financial impacts of single-use plastic trays – assumed according two different end-of-life scenarios – and reusable stainless steel containers used to transport and preserve food from a Central Production Unit, until different sites part of a Belgian hospital intermunicipal association. The analysis realized is a first approach to a Life Cycle Analysis and has been examined following different steps of the life cycle, taking assumptions for the data which was not easily available. A period of fifteen years was taken into account – given the lifespan of the reusable container –, and the environmental impacts were computed according to different indicators, however taking the 'climate change – fossil' as flagship indicator, measured in CO_2-equivalent emissions generated. The tool used to evaluate the environmental impacts is called 'Bilan Produit®', and was developed by the ADEME – 'Agence de la transition écologique'.

From the study realized, it was found that the reusable alternative causes the lowest environmental impact, with 0.024 kilograms of CO_2-equivalent emissions per kilogram of food handled, but has the highest financial impacts, with 7.54€ per kilogram of food handled. Most of the environmental impacts are occuring during the distribution stage to the different sites, due to the increased frequency of delivery compared to the single-use option.

On the opposite, the single-use option with the end-of-life scenario assumed to be shared between 96% incineration and 4% landfill causes the worst environmental impacts, with 0.156 kilograms of CO_2-equivalent emissions per kilogram of food handled, with most of the impacts occuring during the manufacturing and end-of-life stages. Nevertheless, the cost per kilogram of food handled is 6.26€, thus lower than the one obtained for the reusable option.

The cheapest option found is the single-use alternative with a recycling end-of-life, which costs 6.25€ per kilogram of food handled. This alternative gives an environmental impact between the two other options, with 0.1 kilograms of CO_2-equivalent emissions per kilogram of food handled, and impacts happening mostly during the manufacturing stage.

Of course, the results obtained above depend on the assumptions taken for the study, which could be challenged for potential further research to come. A sensitivity analysis was realized for the transportation flows, using 'EcoTransIt' to challenge the results obtained with the first tool.