Bewertung des Potenzials und der Nachhaltigkeit von Mehrwegbehälter-Konzepte für den e-Commerce

Sustainability and viability assessment of returnable transport item approaches in e-Commerce

Wissenschaftliche Arbeit zur Erlangung des Grades
M.Sc. Maschinenwesen an der Fakultät für Maschinenwesen der
Technischen Universität München

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Eingereicht am:	01.09.2020 in Garching
Inventarnr. fml:	2020034

Vorwort

Die vorliegende Arbeit entstand unter der wissenschaftlichen und inhaltlichen Anleitung von **Josef Xu**, wissenschaftlicher Mitarbeiter am Lehrstuhl für Fördertechnik Materialfluss Logistik (fml) der Technischen Universität München.

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München, 31.08.2020

Ort, Datum, Unterschrift

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List of abbreviations

Abbreviation	Meaning
3PL	Third-party logistics
4IR	Fourth Industrial Revolution
B2B	Business-to-business
B2C	Business-to-customer
CBM	Circular business model
CCB	Corrugated cardboard box
CE	Circular economy
CEP	Courier-express-parcel
CLSC	Closed-loop supply chain
CSR	Corporate social responsibility
DC	Distribution center
EoL	End of life
EPA	Environmental Protection Agency
EPLCA	European Platform on Life Cycle Assessment
EPR	Extended producer responsibility
FSC	Forward supply chain
GDP	Gross domestic product
GPP	Green Public Procurement

ILCD	International Reference Life Cycle Data System
KPI	Key performance indicator
LCA	Life cycle assessment
LCC	Life cycle costing
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
IoT	Internet of Things
ISO	International Organization for Standardization
OEM	Original Equipment Manufacturer
PaaS	Product as a service
PE	Polyethylene
PP	Polypropylene
RFID	Radio-frequency identification
RL	Reverse logistics
RPC	Reusable plastic container
RSC	Reverse supply chain
RTI	Returnable transport item
RTLS	Real-time locating system
SCM	Supply chain management
SDG	Sustainable development goal
UN	United Nations
UNEP	United Nations Environmental Programme
WFD	Waste Framework Directive

1 INTRODUCTION

Chapter 1 provides an introduction to the general context of this master's thesis. The first section sets out the research framework for the study upon which the research aim is formulated in section 1.2. Finally, section 1.3 elucidates the methodology and structure for the remaining chapters.

1.1 Research framework

Amidst the paradigm shift brought about by the Fourth Industrial Revolution, e-Commerce is progressively becoming an established means of conducting business operations across all industry sectors. The adoption of new business models is having a profound impact on supply chain design and logistic operations. Customer expectations regarding delivery experience are increasing drastically. Both businesses and individual customers expect faster and more flexible delivery times, at low or no delivery cost and the possibility of returning the product [Tip-2016].

From a producer's point of view, e-Commerce offers two main advantages compared to traditional businesses [Laz-2019]:

- Low entry barriers: Starting a brick-and-mortar business requires a large initial cash outlay in order to rent out real estate and acquire the initial inventory. This places significant risk on the entrepreneurial activity, whereas an e-Commerce business can be operated and managed from anywhere and launched without initial stock.

- Unlimited audience reach: While the customer market that can be reached by a brick-and-mortar store is usually limited to the immediate vicinity of the business, e-Commerce retailers can target any market segment worldwide, without regard to its geographical location. This enables businesses to focus on their niche independently of how specific or segregated it is.

According to industry experts, the e-Commerce sector is expected to reach $5.695 trillion worldwide by 2022, accounting for 1 out of every 5 dollars spent on total retail sales worldwide. Moreover, the sector is expected to experience double-digit growth in the foreseeable future. [Sta-2020; Lip-2019] Adding up the aforementioned characteristics results in the logistics sector being under intense and growing pressure of delivering a higher-quality service at an even lower cost than before. [Tip-2016]

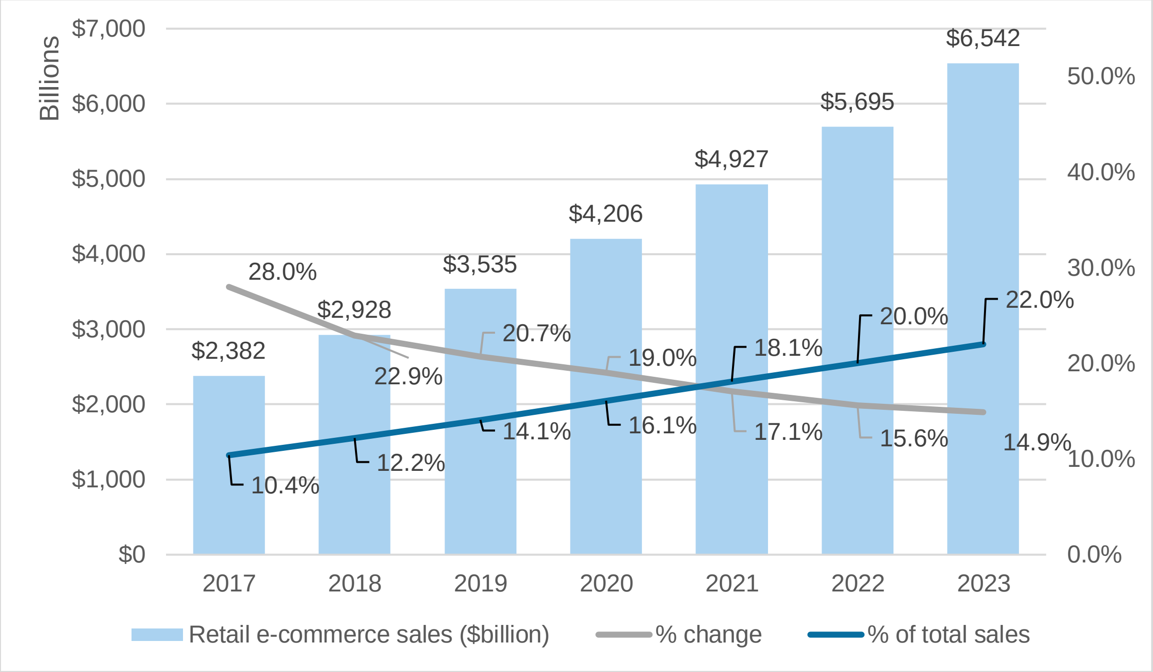


Figure 1-1: Retail e-Commerce sales worldwide, 2017-2023 [Lip-2019]

However, this increase in convenience for the customers is achieved at the cost of incurring other externalities. An increase in e-Commerce volume implies an increase in deliveries, which in turn results in higher transport-related pollution in both long-distance shipping and last-mile delivery as well as growing amounts of one-way packaging waste that end up in landfills [Kno-2019].

According to the Pitney Bowes Parcel Shipping Index, there were a total of 87 billion parcels shipped in 2018. This represents a 104 percent increase compared to 2014, most of which can be directly attributed to the surge of e-Commerce [Buc-2019]. As reported by the Environmental Protection Agency of the United States, freight is the fastest growing source of greenhouse gases and a major source of air pollution on a global scale. [Env-2019].

Another consequence of increased e-Commerce transactions is the increment in urban traffic congestion and commute times in areas with high population densities. According to a recent report published by the World Economic Forum, traffic congestion in the 100 most populated cities is projected to rise by over 21% until 2030 if nothing is done to counteract it. This would translate into an additional 11 minutes of daily commute time for each passenger due to last-mile double-parking and blockage of bike and bus lanes in e-Commerce deliveries [Kra-2020].

Additionally, e-Commerce has been plagued by overpackaging issues, consequently facing serious backlash from different political and social sectors. Compared to traditional retail, e-Commerce has approximately four times as many touch-points, resulting in shipments being split in many individual packages for delivery. [Fis-2017]. One of packaging’s main roles is protecting the delivered goods from any potential damage they could sustain along the way. The average package is dropped 17 times before it reaches its final destination. This induces retailers to ship a relatively small package inside an oversized box filled with air-bags [Bir-2018].

Generally speaking, three different categories of packaging can be distinguished [Jön-2006]:

- Primary packaging: Layer of packaging in immediate contact with the product that is designated to protect and contain the product as well as communicate marketing, product, brand, and other relevant attributes.

- Secondary packaging: Layer of packaging surrounding primary packaging designed to enable safe and efficient handling of goods and minimize damage by grouping several pre-packaged products.

- Tertiary packaging: Groups secondary packaging together to create efficient unit loads for shipment.

As social awareness about packaging waste and e-Commerce-derived emissions becomes more widespread, several approaches have emerged in order to tackle this issue. According to the waste hierarchy defined in the EU Waste Framework Directive (WFD) (2008/98/EC), the highest priority of waste management is assigned to preventing waste from being generated in the first place [Eur-2008]. Additionally, the European Directive on Packaging and Packaging Waste as well as the Circular Economy Action Plan by the European Commission give instructions and recommendations that place special emphasis on “reducing (over)packaging and packaging waste”, “driving design for reuse and recyclability of packaging” and “reducing the complexity of packaging materials, including the number of materials and polymers used” [Eur-2004; Eur-2020a; Eur-2004].

One such approach that has been gaining traction over the last years consists in transforming traditional supply chains into closed-loop supply chains (CLSC) and using returnable transport items (RTIs) as reusable secondary and tertiary packaging approaches that can be reused over many delivery cycles [Joh-2007]. As a result, many of the processes and flows within the supply chain need to be adapted or modified. Aside from delivering goods to the end-customer, returnable packaging must be recovered and transported back to distribution centers. Managing the reverse logistics of a large fleet of RTIs entails considerable complexity and requires that logistics system design and network be adapted to cope with the reverse flows. Instead of being discarded after their first use, RTIs need to undergo maintenance procedures and be refurbished before they can be used in another delivery cycle. Finally, manufacturing and end-of-life (EoL) treatment processes also differ significantly between single-use and reusable packaging alternatives.

The advantages of implementing a circular packaging economy are not limited to environmental benefits, but also often offer cost reductions and an improvement of commercial brand through CSR for companies that implement these systems. According to several recent studies, around seventy five percent of customers support the idea of introducing RTIs for e-Commerce delivery and retail shopping as an alternative to traditional corrugated cardboard boxes and plastic bags. Seven out of every ten people surveyed stated their willingness to pay an additional deposit of 2.5€ on average per reusable package [Bov-2018]. As customers are clearly becoming environmentally aware, these initiatives are expected to progressively obtain more penetration in the packaging and shipment industry in order to satisfy the demand for more sustainable delivery practices.

Although RTIs have the potential to deliver substantial economic and environmental benefits, their establishment as an alternative to traditional single-use packaging faces implementation barriers. These obstacles revolve around economic and environmental uncertainties, such as:

- Increased complexity and operational costs of required logistics systems.
- Unknown one-off transition and implementation costs.
- Uncertain room for improvement in terms of economies of scale and environmental impacts.
- Unknown adoption rate and acceptance among end-customers and logistics companies.

The overarching question to be answered in this research study deals with determining how much e-Commerce sustainability and profitability can be affected through the introduction of RTIs, potentially alleviating some of the aforementioned hurdles and providing quantifiable data to support RTI CLSC introduction in e-Commerce.

1.2 Research aim

The following research study seeks to define an approach that will contribute towards improving the sustainability of e-Commerce. Within this field, the focus is set on assessing the benefits that can be realized by replacing traditional single-use packaging with returnable transport items on the path to a true circular economy (CE). The fulfilment of this goal will ultimately result in the development of guidelines for a delivery system that is regenerative by design and aims to maintain components at their peak utility value for the longest-possible period of time.

In order to achieve the full potential of a circular economy, closed-loop supply chains need to be implemented on a sufficiently large scale and supported by a perpetuating technical infrastructure and social mindset. To ensure self-sustainability of circular systems, it is necessary to both prove their advantages from an environmental perspective as well as guarantee their economic viability by determining the critical size required to reach a breakeven point and/or introducing additional legislative obligations and restrictions to encourage the transition of all stakeholders to a circular approach.

Based on the aforementioned goal, the thesis will revolve around providing an answer to the following questions:

1. What are the general hurdles to overcome towards the implementation of a circular economy in e-Commerce delivery and which enabling factors can pave the way?
2. Which are the main parameters and decisions that should be considered during the conception and implementation processes of such a system?
3. How well do RTIs perform against traditional single-use packaging alternatives from an environmental standpoint?

1.3 Methodology and thesis structure

In order to provide an answer for each of the questions formulated in section 1.2, chapter 2 presents an in-depth overview into the current state of circular economy, reverse logistics and closed-loop supply chains. The overview is generated by reviewing documents from the most relevant authorities in the field, as well as the action plans that are being put forward in order to drive the transition towards a true circular economy. Furthermore, it offers an outlook into state-of-the art methodology for assessing the environmental impact and the economic viability of a product by taking a life cycle approach.

Chapter 3 defines the approach and core decisions that have to be considered when designing an RTI system by sequentially characterizing management functions and system parameters on the strategic, tactical and operational levels. The information is obtained through literature research and expert interviews on the field. Some concrete cases are presented in order to exemplify how companies have already implemented these systems as well as to show where there might be room for improvement.

Chapter 4 begins by defining the parameters of a generic e-Commerce supply chain in terms of both logistics system design as well as packaging characteristics based on the design choices introduced in chapter 3. The study then develops and introduces several potential models for an RTI system in e-Commerce and performs an analysis in terms of environmental impact to establish a performance comparison with a traditional disposable packaging approach. The Life cycle assessment is carried out with the help of an open source software program (openLCA), as well as databases and impact assessment methods introduced in chapter 2.

Subsequently, the obtained results are evaluated in order to gain insight into the optimal implementation procedure for such a system and determine the critical phases of these systems. Additionally, a sensitivity analysis is performed on some of the design parameters to observe how the obtained results would be affected by design modifications and determine which parameters are most influential. The last section of this chapter briefly examines some of the models' limitations due to both simplifying hypotheses as well as lack of accurate data.

Finally, chapter 5 summarizes conclusions reached through this study and explores possible future lines of research to expand and improve the obtained results.

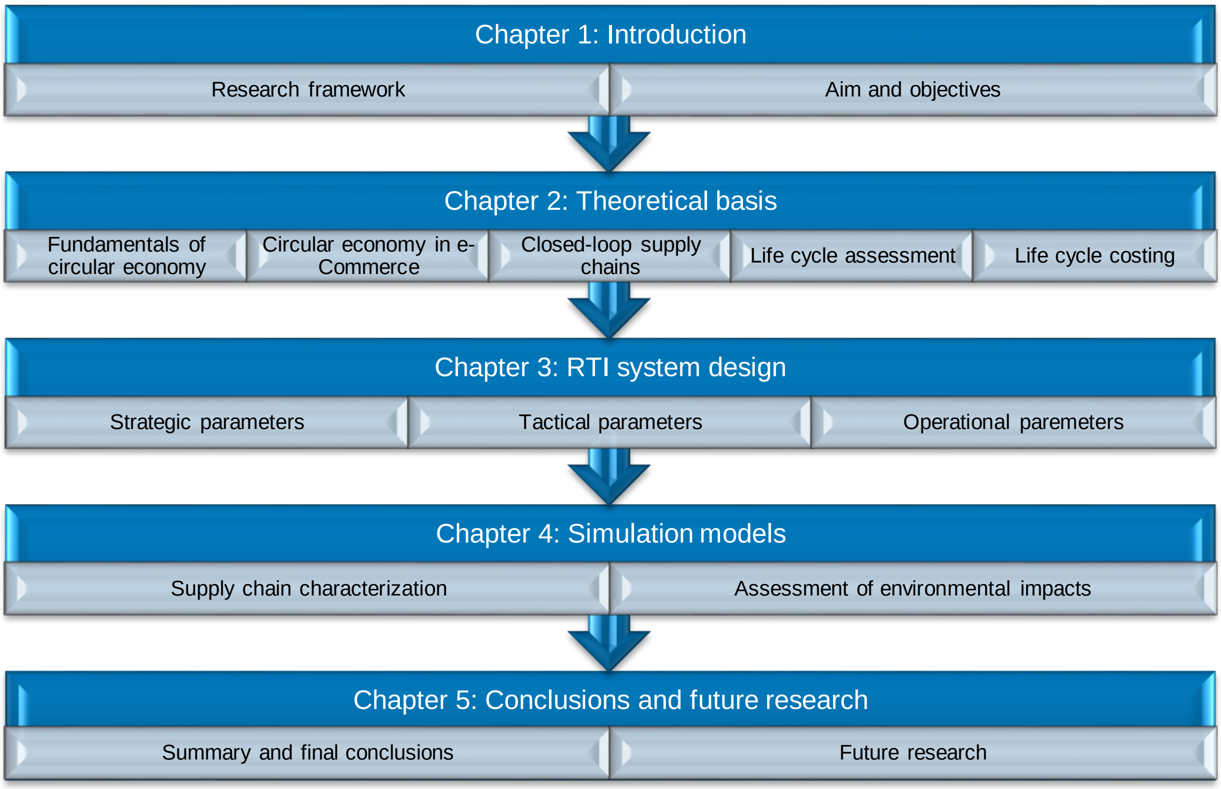


Figure 1-2: Structure of the research study

2 THEORETICAL BASIS

Chapter 2 provides an in-depth overview into the central topics of this research study. It introduces the concepts and explains the state-of-the-art of circular economy, as well as reverse logistics and closed-loop supply chains. Finally, it gives insight into the methodology of life cycle assessment in order to evaluate the impacts of a product throughout its life cycle.

2.1 Fundamentals of circular economy

The contemporary global economic system is grounded on a linear economic system that became prevalent as the First and Second Industrial Revolutions introduced the concepts of mass production and assembly lines into society. This linear model is based on a take-make-waste approach with business models centered around the extraction of resources and later transformation of resources into finished goods by processing them with energy and labor. The underlying expectation is that, once used, the customers will dispose of the products and buy new ones. Therefore, for the past two centuries, the focus of production lines has been set on developing economies of scale that enable faster and cheaper production of goods.

The advancements delivered by the linear model have brought forth enormous growth on an economic and societal welfare level. It enabled the creation and subsequent enlargement of a stable middle class, retirement and the decline of child labor, among others. However, it also resulted in the development of a consumption-centered culture. Many studies over the past decades have come to the conclusion that global growth is happening in a resource intensive way, i.e. natural resource depletion accounts for a considerable portion of global gross domestic product (GDP) growth over the last decades.

Measures of societal development that include natural capital have been growing at a much slower rate than GDP. The Inclusive Wealth Index, a metric developed by the UN Environment Programme, reported that inclusive wealth grew at a rate of 1.8% per year between 1980 and 2014, whereas GPD grew at an average rate of 3.4% in the same period. Moreover, natural capital saw a decline of 0.7% per annum [Bar-2018]. Other metrics such as the Genuine Progress Indicator (GPI), a metric that takes into account externalities incurred by the economy, instead of just measuring raw economic activity like GDP, go as far as showing a decline after the 1970s. For instance, GDP increases twice when pollution is emitted, once upon creation and once upon carrying out the cleaning activities, whereas GPI counts the emission as a cost, as well as the impact the pollution will have over time. Figure 2-1 shows a comparison of GDP and GPI growth per capita from 1950 to 2004.

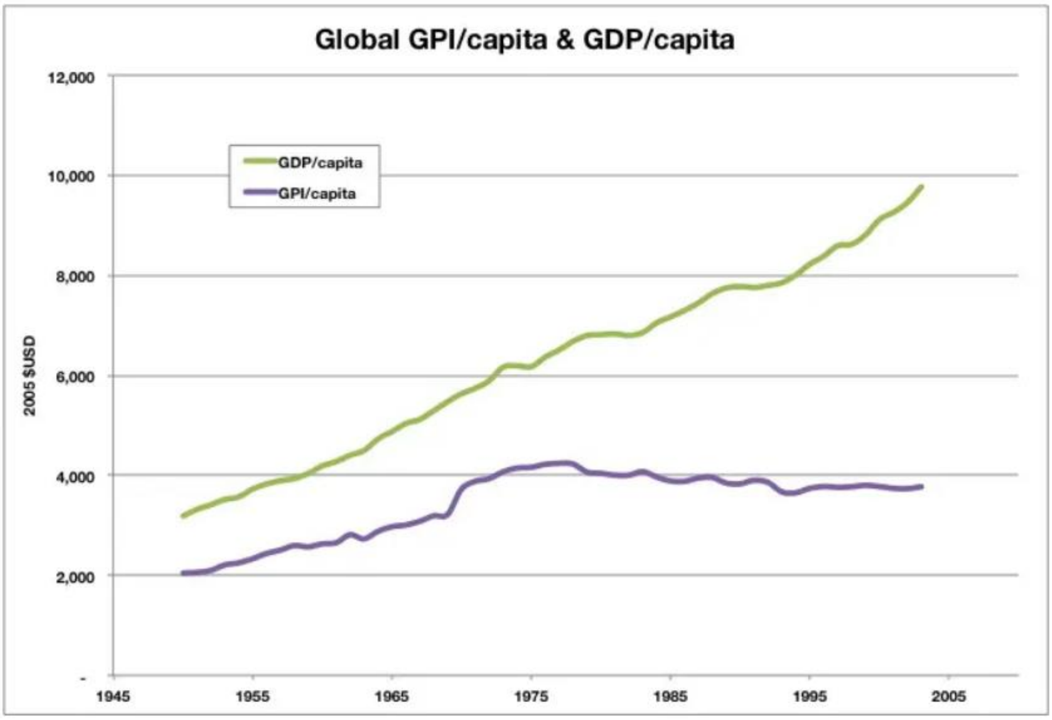


Figure 2-1: GDP vs. GPI growth per capita 1950-2004 [Kub-2013].

In contrast to the linear model, the concept of circular economy is defined as an economic model that revolves around decoupling economic growth from resource consumption and environmental impacts. According to the Ellen MacArthur Foundation, a global think tank devoted to accelerating the transition towards a circular economy model, this concept is characterized as an “economy that is restorative and regenerative by design and aims to keep products, components and materials at their highest utility and value at all times” [Mac-2015]. This means that products and materials are intended to remain productive as long as possible and, when they reach the end of their lives, they are effectively looped back into the system.

The concept of circular economy can be subdivided into two different loops, a technical and a biological loop. In a true circular economy, consumption happens only at the biological level, where resources are regenerated over time through biological processes without human intervention. In the technical loop, (re)use replaces consumption and products go through one of the different sub-loops where they are restored/recovered through human intervention by consuming renewable energy. Figure 2-2 shows the outline of a circular economy, its elements and loops.

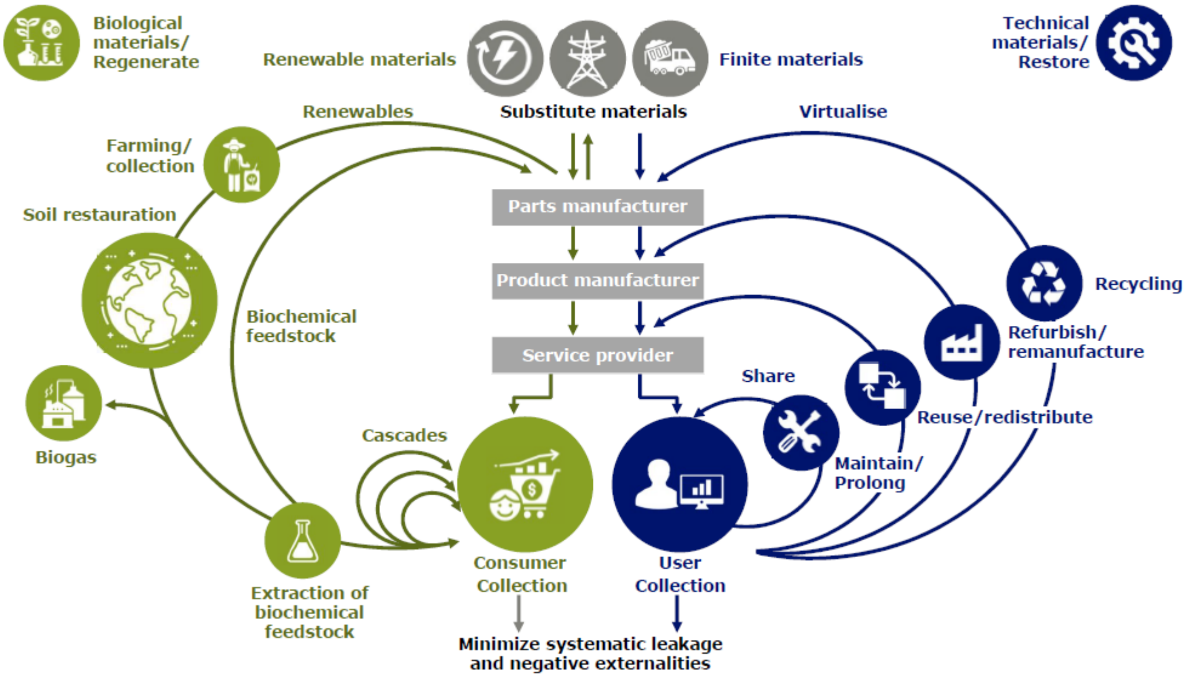


Figure 2-2: Outline of a circular economy [Mac-2015]

Recent studies have concluded that a transition to a true circular model would yield sizable benefits across every industrial and societal sector. According to experts, the transition would increase resource productivity in Europe by 3% annually, resulting in a primary resource benefit of €0.6 trillion per year by 2030 and an additional €1.2 trillion in non-resource benefits and externalities. Compared to the current linear development baseline, this would translate into a relative GDP increase of 7 pp. [Mac-2015]. Moreover, existing studies correlate the implementation of a circular economy with positive developments in employment rates [Hor-2015]. Nevertheless, such a disruptive economic transformation entails a considerable implementation cost that encompasses R&D, acquisition of new assets, depreciation of assets that become outdated as a result of the transition, investments in physical and digital infrastructure, facilities and logistic systems and subsidies to incentivize transition, among others. Even though giving an approximate order of magnitude is nearly impossible at this stage, a study carried out by the British government gauged that the implementation of a full-fledged reutilization and reuse system would amount to €14 billion, which translates to approximately €108 billion on a European level [Mac-2015; Hay-2013]

Transitioning to a true circular economy would contribute to the achievement of several of the UN Sustainable Development Goals (SDGs). Circular economy is arguably the most promising lever towards the fulfillment of SDG 12 – Responsible consumption and production. Additionally, it can assist in making progress of many other SDGs, such as Affordable and clean energy (SDG 7); Industry, innovation and infrastructure

(SDG 9); Sustainable cities and communities (SDG 11); as well as Climate action, Life on water and Life on land (SDGs 13-15).

According to the Ellen MacArthur Foundation, the circular economy is based on three principles [Mac-2015]:

1. Preserve and enhance natural capital: By monitoring finite stocks and balancing renewable flows. When resources need to be used, a circular approach carefully evaluates and chooses renewable and/or more environmentally efficient resources. An example would be replacing fossil energies with renewable energy sources.
2. Optimize resource yields: By looping products, materials and components, keeping them at their highest utility values at all times in both the technical and the biological cycles. The most common approach to fulfilling this principle consists of designing products with circularity in mind, i.e. so they can be reused, remanufactured and recycled. This also includes cascading loops between industries in order to extend the life period of products, as well as asset sharing to increase utilization rate.
3. Foster system effectiveness: By revealing and designing out negative externalities inherent to existing processes, products, materials and components, including air, water and soil pollution, releases of toxic substances and damages to human health.

The three principles of circular economy can be further refined into four different strategic sources of circular value creation [Ell-2013]:

- Inner circles: Embodies the concept that the tighter the cycle within the technical loop, the more value the strategy creates. According to this approach, prolonging a product’s life through reuse and redistribution is always environmentally preferable to other operations, as a bigger portion of the product’s embedded value, labor, natural and energy resources are retained. Should this not be possible, the next-best step consists of remanufacturing and refurbishing individual components or products as a whole, which in turn retains more value than recycling the products.
- Longer circles: Refers to the idea of maximizing the duration of each loop and/or the number of loops a product can realize during its use phase before having to undergo any of the operations described in the prior paragraph. This is achieved through adequate maintenance and reparations, as well as sharing of products between stakeholders.

- Cascaded loops: Relates to the concept of interconnecting reuse operations along the value chain or across several complementary industries in such a way that the product partially or totally substitutes the inflow of virgin materials in other supply chains before undergoing any other value recovery operations. In products that consume energy however, it is imperative to continuously assess the advancements in energy efficiency, as the benefits of new, more efficient products might outweigh those of cascading existing products.
- Pure inputs: Refers to the fact that uncontaminated materials, products and components can be recovered more efficiently while maintaining the qualities and properties of the original object, increasing long-term resource productivity.

These approaches are complementary to each other and should be tackled in parallel in order to fully harness the benefits of circular economy. Figure 2-3 provides a visualization of the four aforementioned circular value creation approaches:

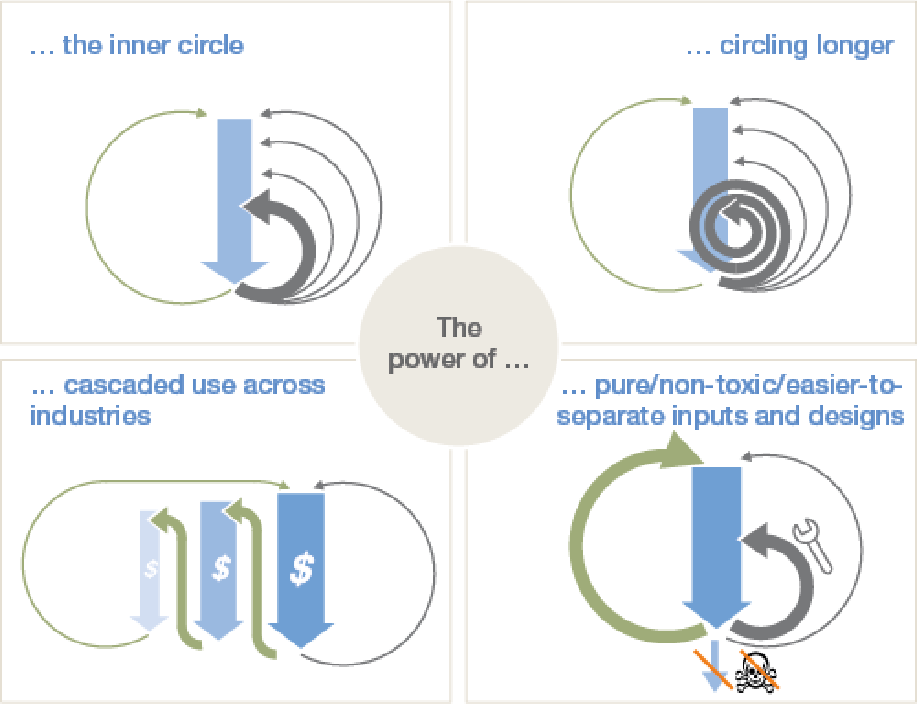


Figure 2-3: Circular value creation sources [Ell-2013]

To implement the three principles of circular economy by fully leveraging every circular value creation source, these approaches can be translated into five scalable business models. Each of these models has already been successfully implemented across different organizations, industries and geographies and substantiated by private and public entities in terms of economic, technical, and environmental viability. However, the adoption rate has been rather disparate across the models. These business models are not mutually exclusive, but rather are intended to be applied simultaneously at the different stages of the value loop in order to achieve the true impact of a circular economy. An overview of the five circular business models as well as the supply loop phases they target is given in Figure 2-4.

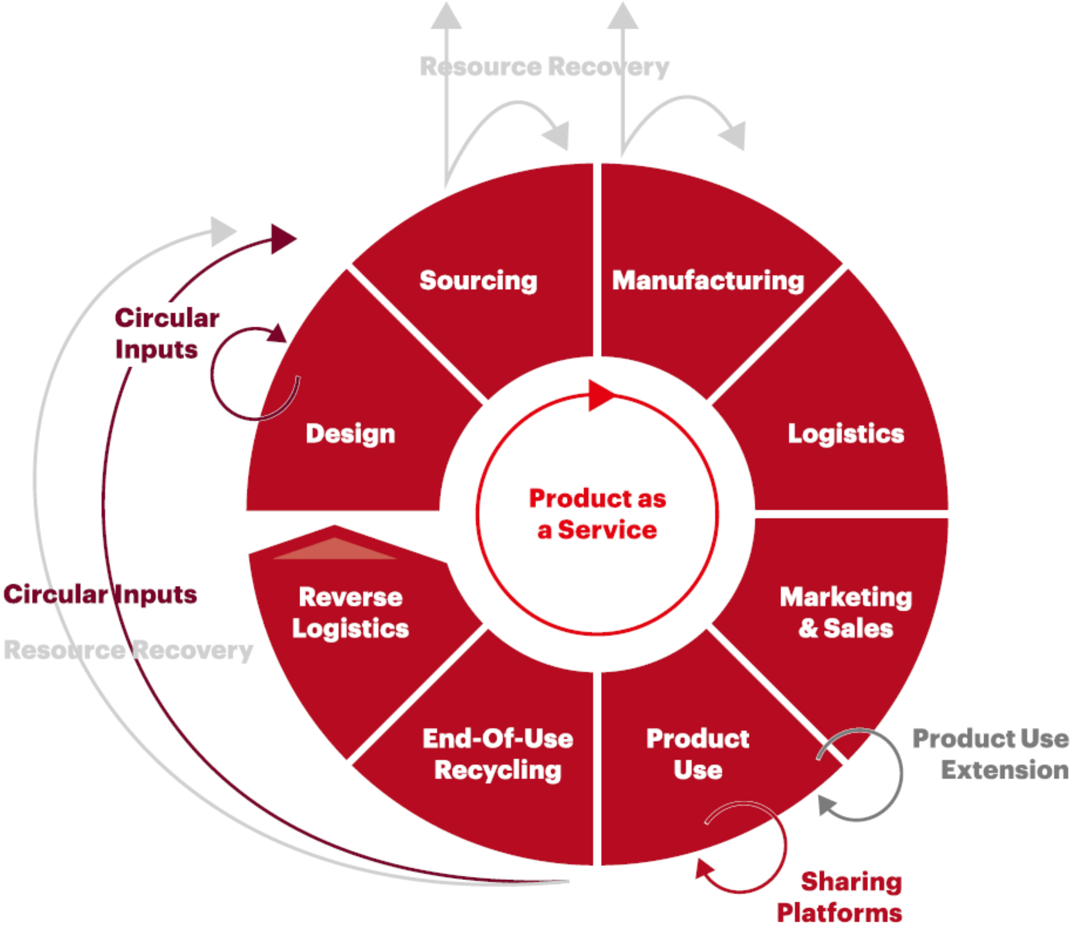


Figure 2-4: Circular value loop – The five business models [Lac-2020]

The different business models are described in the following:

Circular Inputs:

A “Circular Inputs” or a circular supply chain model is one of the most established circular business models to date. Conceptually, it revolves around replacing a linear resource with a circular counterpart in order to partially or totally design out waste in the supply chain. Circular resources comprise naturally renewable, recyclable or recycled resources such as renewable raw materials that replenish naturally, renewable energy sources that can be harvested without significant environmental impact or renewable man-made resources that can be recycled/reused infinitely without any perceivable change of quality and/or properties. In order to be viable on a business scale, it does not suffice for a resource to be circular and able to maintain its qualities across multiple loops, it also needs to be able to achieve cost parity compared to linear alternatives. The main requirements necessary to guarantee cost parity are:

- Minimum number of (re)usability cycles.
- Critical volume of the circular resource that needs to be surpassed for it to be economically viable.

These criteria should be evaluated during the design/decision phase of a circular business model.

A prominent example of Circular Inputs are glass containers/bottles used in the food/beverage industries. Contrary to most other materials, glass used in these products is 100% recyclable and can be recycled endlessly without any loss in properties or purity. Thanks to its impermeability and lack of porosity, there are virtually no interactions between packaging and products that might affect their flavor/aroma [Gla-2020].

Sharing Platforms:

A “Sharing Platforms” business model offers product owners the possibility to maximize utilization rate of their products while offering their customers affordable and convenient access to them. In these approaches, utilization is augmented by sharing access and ownership of assets between several companies/users, which has been largely enabled by the development of new technologies and platforms over the past few decades. Sharing ownership offers the advantage of also sharing costs among users. For this reason, this business model has found high acceptance in sectors where initial investments and fixed entry costs are rather high. Some examples include:

- Vehicles
- Housing
- Energy grids
- Digital platforms
- Buildings/infrastructures

Product as a Service (PaaS):

Contrary to the “Shared Platforms” approach, the PaaS business model revolves around ownership retention by the company while granting access to its users on a leasing/subscription or a pay-per-use basis. While a Sharing Assets business only focuses on the use phase of the value loop, PaaS covers every phase, from design to EoL management. In return for the subscriptions/fees, the owner also remains responsible of maintaining/repairing the assets and the EoL treatments when the products cannot be looped anymore.

In addition to the use fees, the owners can obtain supplementary revenue streams and benefits by developing long-term relationships with customers, offering complementary services (up-selling and/or cross-selling), as well as leveraging usage data in order to gain insights to refine/develop further product and service offerings or to monetize them in multi-sided business models.

Nevertheless, implementing this business model also entails some complications in comparison to the traditional approaches. For example, it requires deploying additional services and business capabilities, such as managing returns, collections and the whole reverse logistics chain or subcontracting them to a third-party logistics (3PL) provider. In doing this, the total cost of ownership might increase. Additionally, the balance sheet and income statement might need to be adapted as a result of the new structure of incoming cash flows. Since payments in this model are more spread out and of lesser amounts per payment instead of a lump sum at the moment of the acquisition, companies might need to recur to third-party financing in order to survive the first business stages until a critical customer mass has been reached in order to ensure economic viability.

All in all, this business approach is one of the fastest growing business models, not just within circular business, but in the global economy overall, with the B2C subscription industry having grown at an average annual rate of 200% since 2011 [McC-2017]. A pre-eminent example of PaaS business models can be found in the music industry, where consumers pay subscription fees on a regular basis in order to gain access (but not ownership) to the content offered by these platforms. Likewise, cloud storage services replace traditional storage devices, such as CDs or pen drives by enabling customers to upload data to storage clusters, whose ownership is retained by the service provider.

Product Use Extension:

The “Product Use Extension” business model consists of applying a series of operations during or at the end of a product’s life to extend its life time within its original market or in a secondary market for used products, instead of being landfilled, allocated to energy recovery or recycled. These operations range from repairing, reselling, redistributing and refurbishing to cascading the materials to other industries and can require the setup of dedicated sub-business models.

Similar to the previously introduced approaches, Product Use Extension poses organizational challenges that have to be overcome prior to and during implementation.

The biggest hurdle to product use extension revolves around creating customer engagement to the point where the users feel compelled to take care of the products as if they were their own. Many users tend to treat products with less care when they do not own them, leading to irreparable or permanent damage, while others will forget to return products for life extension operations or fail to recognize that the product is not single-use in the first place and discard them. Analogously to asset sharing, product use extension also requires the acquisition of new capabilities as well as making changes to product designs and business models.

Product life extension business models are exemplified by second life programs across many industries. For instance, fashion companies such as H&M are launching initiatives with the aim to sell second-hand clothing [Edi-2019]. Similarly, IKEA is currently trialing the viability of selling refurbished furniture in a step towards transitioning to a more circular business model [But-2019]. Other examples of Product Use Extension include modular designs of products, such as furniture, where broken parts or elements that reach the end of their life cycles are simply replaced by newer ones instead of buying another completely new product.

Resource Recovery:

Resource Recovery operations focus on the final phases of a products life with the aim to recover valuable resources or components once the product cannot carry out its original purpose anymore. Ideally, companies and individuals should prioritize operations higher up in the hierarchical pyramid of waste treatment. The recovery operations should be carried out in such a way that the recovered resources/materials maintain their value for the longest possible period of time. The next best alternative consists of upcycling into higher-value products, while solutions that reduce quality/value should only be employed as a last resort to keep the product in the loop. The hierarchy of waste treatment is depicted in Figure 2-5:

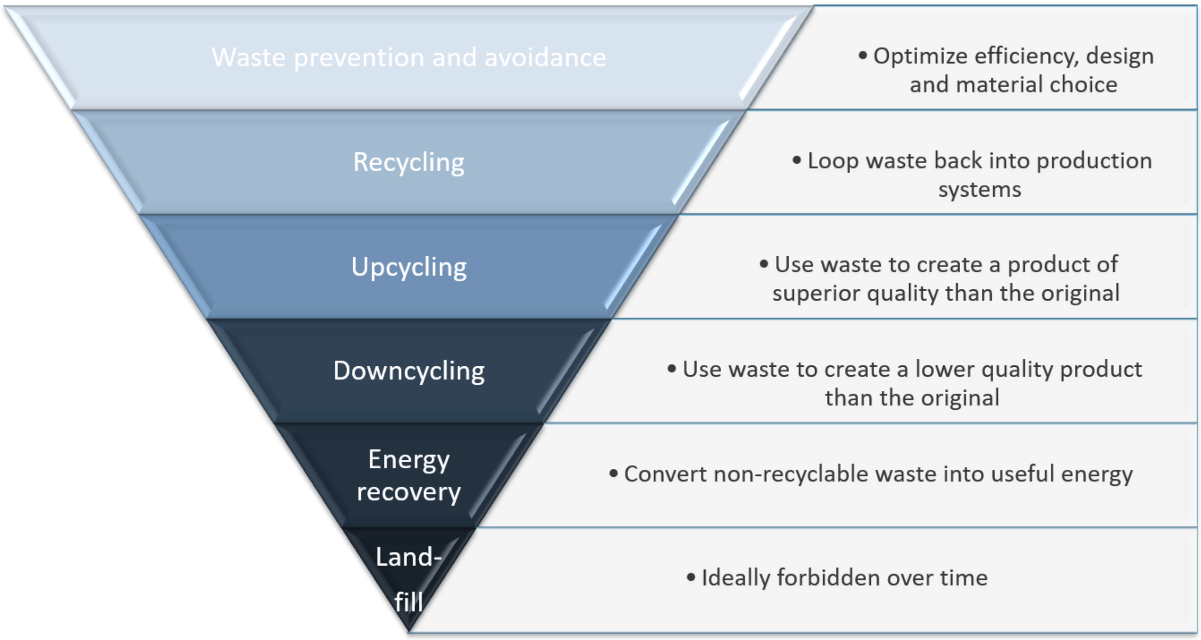


Figure 2-5: Hierarchy of waste treatment. Adapted from [Lac-2020]

At this point in time, most companies have implemented at least some form of resource recovery processes in their business models, either voluntarily or as a result of the WFD [Eur-2008]. Out of the five business models that have been introduced in the previous paragraphs, resource recovery is the one that requires less investments and infrastructural adaptation and the less disruptive with regard to existing business models. Therefore, it can be expected that this approach to circularity will continue gaining traction as recovery processes become cheaper, as well as a result of regulatory changes, levied waste taxes, resource shortages and increasing customer pressure to take responsibility of waste issues.

Out of the five business models depicted in Figure 2-5, three of them focus on the production/supply side of the economic model (Circular inputs, Product use extension and Resource recovery), while the other two are rather centered around the consumption/demand portion, as well as the relationship between the product and the users (Product as a Service and Sharing platforms). As stated in Section 1.2, one of this study's key objectives is to determine which business models are most appropriate for introducing RTIs in e-Commerce, as well as the main barriers and enabling factors to the transition from a linear to a circular economy. Many studies have attempted to hone in on the main hindrances that are slowing down or blocking a transition towards the circular economy by grouping them into several categories, such as cultural, regulatory and economic barriers [Jes-2018; Kir-2018]. However, most of the carried-out research has a broad focus, but sectors and products differ, and if circularity is to be achieved, a more tailored understanding and approach is necessary. The following subsections explore these aspects by focusing on the RTI sector for e-Commerce packaging.

2.2 Circular economy in e-Commerce

2.2.1 Circular business models for e-Commerce packaging

All the aforementioned circular business models (CBMs) can be adapted to the e-Commerce packaging sector in a straightforward manner. In fact, many circular start-ups are already scaling up different initiatives, many of which focus on the concept of adapting packaging design for reuse and disassembly. Some examples of successful approaches are illustrated in the following paragraphs as well as in Section 3.1. According to a recent study by National Geographic, 40% of produced plastic is used for packaging, most of which is only used once and then discarded [Par-2018]. Since packaging is ubiquitous, turning packaging waste streams into loops can quickly enable the development of a circular market around reusable packaging, because the critical size will be easily reached provided the adoption rate is acceptable.

From a circular inputs point of view, several materials come into question as the main component of RTIs which, coupled with renewable energies, build a strong foundation for the viability of circular economy:

- Cardboard and other paper-based materials: They are already collected globally for reutilization, traded as commodities, and can be recycled using mature technologies, achieving a global collection rate of 49% [Cir-2015]. The challenge in recycling cellulose-based materials resides in minimizing the loss of fiber and fiber quality during reprocessing operations, since their properties tend to quickly degrade as the number of cycles increases. Another disadvantage of using these materials is that they are less shock-resistant than other alternatives such as plastic and are not appropriate for transporting certain goods, such as liquids.
- Polymer-based materials: Among the four common categories of polymers used currently on an industrial level, polypropylene (PP) and polyethylene (PE) are the material candidates with the highest potential for reuse chains. They are considerably more durable and can be reused across many cycles. Especially PP is already consumed in high volumes (50 million tons in 2010 across different sectors), it can be cleaned easily and does not lose properties over time. The biggest barriers to the implementation of PP reside in the need to refine technologies for separating and reprocessing the different variations of PP. Also, standardizing the number and type of additives used in polymer

manufacturing would help in overcoming implementation barriers. All in all, PP presents itself as the most promising material and is currently being used by many packaging start-ups, some of which will be briefly introduced at the end of this subsection. For this reason, the rest of this section is focused on business models that use polymer-based packaging.

- Biodegradable packaging: It is produced from biopolymers, which are molecules found in living organisms, such as cellulose and proteins. They can be consumed, which makes them promising as food packaging materials and degrade naturally. Their main disadvantage lies in the fact that most biopolymers are currently in early stages of research and manufacturing them is both expensive and time consuming.

Product use extension operations for PP-based RTIs tend to be very simple and usually involve minor repairs as well as washing between reuses. Resource recovery operations of PP-based RTIs are manifold, but currently tend to focus on up- and recycling. In 2017, P&G and Purecycle formed a partnership that a technology for recycling PP that removes “color and odor, producing a recycled flake with ‘virgin-like’ quality” [Tot-2017]. The technology is currently being scaled up and expected to start commercial-scale production later this year. Other manufacturers of reusable packaging, like RePack, apply a mixture of upcycling to make new prototypes and samples for new reusable packaging designs and recycling into new products.

One key characteristic of an RTI system revolves around asset ownership, i.e. responsibility for cleaning, controlling, maintaining, and managing EoL operations. While an Asset Sharing approach, where supply chain actors share ownership and costs of assets is definitely viable within members of industrial supply chains, a PaaS CBM is much more convenient for e-Commerce packaging due to the following reasons:

- Relatively low asset-value per unit: Asset Sharing models are especially advantageous when fixed costs are high and can be shared among partners, while e-Commerce packaging has a comparably low cost per unit. Having one entity in the supply chain centralize the servitization of packaging offers opportunities to develop economies of scale and gives access to more visibility regarding stocks and flows.
- Customer convenience: The most important participant in the e-Commerce supply chain is arguably the customer. Customers that purchase through online channels are very sensitive to convenience. They expect their products to be delivered quickly to their doorstep and without any additional endeavors on their behalf. In order to foster adoption of RTI among customers, a PaaS CBM where

a corporation takes ownership, manages the inventory and provides additional services, is much more favorable.

As a result, most companies implementing a circular packaging system operate on a PaaS CBM either managing the stocks and flows by themselves, or by partnering with 3PL providers that implement the RTIs into their own supply chains and handle both the forward and the reverse logistics.

To sum up, most CBMs introduced in Section 2.1 are economically and technically viable in the e-Commerce packaging sector, especially for B2C segments. Some success stories are briefly introduced in the following:

- Loop is an online and physical store chain developed by TerraCycle that sells products in specifically designed premium reusable packaging from popular brands. The company handles the logistics of the whole system by offering door-to-door delivery and pickup of products and empty RTIs, creating a convenient delivery model for both the manufacturers and the customers. Additionally, they act as a pooler of RTIs by taking care of storing, cleaning, sanitizing, and redistributing the items.
- RePack is a Finnish company that operates under a PaaS CBM aimed at online retailers and web stores. When a customer places an order, they can opt to receive it in RePack's reusable packaging. The order is delivered with a prepaid return label so that the packaging can be dropped into any mailbox and returned to RePack without any additional effort by the customers. Each RTI has a unique ID-code that triggers a reward for subsequent purchases upon return of the item.
- Liviri is a US-based start-up that has designed reusable containers with the purpose of keeping meals and other perishable goods in optimal conditions. The containers incorporate a specially designed insulation layer, as well as reusable ice packs that are returned with the container. The start-up offers two business models: Either a company purchases the RTIs for their own supply chain and handles the logistics or they sell directly to customers who then return the shippers back to Liviri via a prepaid label.

2.2.2 Barriers to CE in e-Commerce packaging

The CE concept has recently attracted increasing attention from scholars, policy makers and businesses as indicated by the growth of research publications on this topic or by the adoption of an EU Action Plan for the Circular Economy in order to accelerate transition towards CE [Eur-2020a]. Other well-known corporations have announced intentions or major steps towards implementing CBMs [Ell-2017]. Despite all the proclaimed support, CE implementation still appears to be in its early stages, with limited progress having been accomplished thus far. Looking at the root causes of the issue, it becomes apparent that there must exist barriers fostering the entrenchment of linear economy. Analogously to how CBMs can be subdivided according to whether they focus on the production or consumption side of the economic model, barriers can also be categorized on the same approach. Subsequently, CE barriers to production can be subdivided into four groups: cultural, regulatory, market/financial and technology/product barriers. Each group presents interdependencies to the other four. For instance, a lack of appropriate technologies to process products at the end of their lives will result in companies being more hesitant to undertake the necessary operations to transition towards CE. Likewise, obstructing laws, regulations and taxes regarding material reprocessing will increase the price advantage of virgin raw materials over recyclables. Since barriers in one category can produce a chain effect across other categories, it is necessary to analyze and develop measures for each individual category. Figure 2-6 gives a brief definition of the five types of existing barriers.

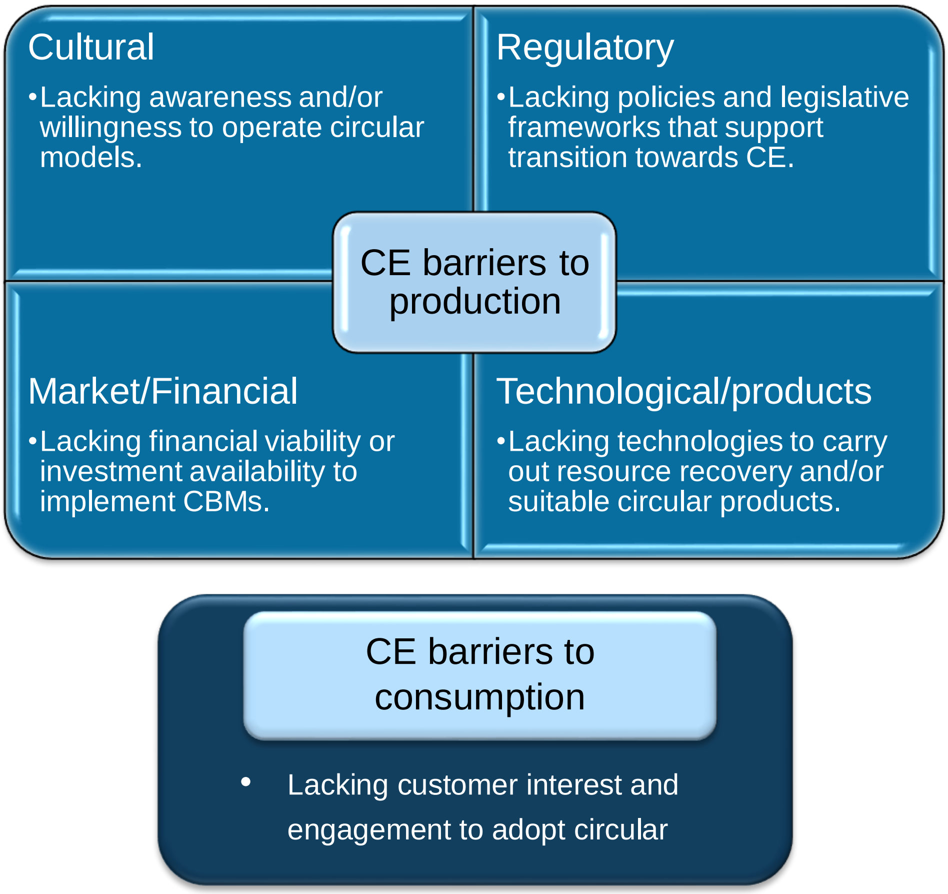


Figure 2-6: CE barriers to consumption and production

Cultural barriers: According to previous studies based on data research and interviews of businesspeople, policy makers and academia, cultural barriers are among the most pressing hindrances to a transition towards CE.

Traditionally, packaging has followed a pronounced linear take-make-waste approach with limited to non-existent concern for sustainability. Said mentality has become deeply ingrained in companies' cultures across the value chain, to the point where most corporations are hesitant to undertake business-model-disruptive actions. This often results in a silo attitude, i.e. a lack of collaboration between business functions, where CE is restricted to niche discussions among members of the CSR department and more irrelevant in other operationally/financially crucial departments.

Another prominent cultural barrier resides in the potential absence of necessary collaboration between supply chain participants. As shown in the previous subsection, almost all successful implementations of reusable packaging to this date require collaboration of several business partners, to design and manufacture packaging, produce the actual goods, provide the touch point to the general customer, handle system logistics, etc. If a circular approach is to thrive in the e-Commerce packaging sector, it is essential that a considerable proportion of participants adopt this model, especially players with a bigger market shares who might exhibit particular cultural reluctance or experience no sense of urgency.

Some companies are still under the impression that, with recycling alone, a successful circular economy can be implemented when, in reality, recycling corresponds to one of the less tight loops in the technical cycle, thus retaining a much lower amount of value/labor/energy than other alternatives such as refurbishing and reusing.

Stemming from all the previous barriers emerges the overarching crux of overcoming the potential lack of interest, engagement and knowledge about CE both across the supply chain participants as well as within the own company is one of the most urgent and pressing barriers to address.

Regulatory barriers: Regulatory barriers revolve for the most part around deficient regulatory frameworks, misaligned incentives, obstructing laws, and limited circular procurement.

Environmental policies that regulate the definition of waste might limit the operations that can be carried out on certain flows, hindering the range of circular activities for certain materials. Since current governmental regulation is designed for linearity, if a material flow is labeled as “waste”, it becomes an administrative ordeal to move it across international borders, even within the EU. As a result of waste management industry regulations, turning a waste stream into a resource for recycle/reuse becomes economically unprofitable if crossing borders is required. Since reprocessing facilities are quite scarce at the moment due to the novelty of the technologies and the upfront investment costs, this drastically reduces the amount of materials that can be recycled, especially those more structurally complex, like polymers [Phe-2017].

In most countries, there is an absence of regulatory incentives that stimulate the implementation of more CBMs, while large environmentally damaging industries periodically receive tax exemptions and subsidies. A prime example for misaligned incentives is the oil/fossil fuels sector. While these companies have a direct impact on climate change and global warming, they receive tax incentives and subsidies that amount to $1.9 trillion globally [Win-2014].

The public sector represents the biggest consumer in most countries' economies. OECD countries report to spend on average 12% of their GDP on public procurement [Org-2017]. Since public procurement represents such a big portion of demand for goods, it can be leveraged to encourage creation of circular markets and circular value loops instead of subsidizing and perpetuating linear models.

Market/financial barriers: Market and financial barriers tend to focus on the investment costs and cash-flow streams required to make CBMs viable from an economic standpoint.

One of the most common barriers among industry sectors stems from the absence of necessary reverse supply chain (RSC) infrastructure. While most companies have a highly optimized forward supply chain, they lack the required circular capabilities to recover and take back products in different stages of their life cycles. In a sector such as e-Commerce, where customers are extremely sensitive to convenience and thus many touchpoints would be required to provide satisfactory services, the lack of appropriate infrastructure hinders the development of economies of scale and standardized approaches. In fact, companies and handling approaches are extremely fragmented in the reusable packaging sector. Some companies have decided to develop their own reverse logistics systems, others rely on courier-express-parcel (CEP) providers to return the packaging from the customer to their facilities while others resort to conventional post mail.

Many shareholders focus on short-term ROI and reduction of capital expenditures. This mentality favors short-term investments in detriment of longer-term projects. CBMs require long-term value propositions, since circular products have high residual values and therefore the payback period will be longer than for linear products, since the cash-flow is spread over longer periods. Consequently, the high upfront investment costs (CAPEX) required for R&D, development of circular infrastructures and certifications deter many investors from betting on CE, even if it offers the potential for lower operational costs (OPEX) in case of successful implementation.

Analogously, the uncertainties in cash-flow structure inherent to the PaaS CBM, with no asset sales to repay initial manufacturing of RTI stocks while having to rely on unforeseeable customer behavior to receive subscriptions of unknown length, forces many startups to resort to external funding. However, the longer cash-to-cash cycles and demand uncertainties increases the cost of capital obtained from banks which in turn decreases the economic viability of funding circular packaging initiatives through external debt.

Other barriers relate to the low acquisition cost of virgin raw materials. For instance, virgin fossil-fuel-based polymers are much cheaper than bioplastics or recycled polymers, such as PP or PE. Since the bulk of customers tend to be very-cost sensitive, higher costs detract producers from attempting to recycle/reprocess and extend the life of many materials in the first place.

Technological and product barriers: While technological and product barriers might seem at first sight as the crux of the circular economy challenges, recent studies have shown that it is not perceived as such by companies, who have indicated that the required technology is in place [Kir-2018]. This statement has already been backed up for the packaging sector in previous subsections where the existence of recycling and reprocessing technologies for circular materials was introduced. Although most technologies have not reached maturity or cost parity yet, the fact that their technical viability has been proven is a considerable milestone in itself. Since technological development tends to be slow, the transition to a circular economy would need to be delayed by several decades. While other barriers, such as cultural barriers, might be deeply ingrained in society at this moment, cultural changes among new generations can quickly drive change and accelerate the transition.

The other common technological barrier relates to the lack of data and subsequent insufficient transparency in the supply chain. A lack of data results in the inability to track items in the supply chain. As such, RTI companies have a high degree of uncertainty as to the supply of RTIs that will arrive at a point in time through the reverse flow and needs larger stocks which reduce liquidity. Additionally, products with complex materials are difficult to manage due to uncertainty as to the exact type of material present and its reprocessing necessities. Such is especially true when sourcing reprocessed materials from different suppliers on a global scale. This is the case for most polymer-based materials, such as PP, that present a high variety of additives to modify their properties, which complicates the looping of materials.

Product barriers are mostly centered around their inappropriate design, having been conceived for linear economies and thus not being designed for longevity, ease of repair and disassembly at the end of their lives, such as many packaging and void materials which are designed to be discarded after being opened. Many packaging alternatives tend to cause what is known as “wrap rage”, resulting from the inability to open certain primary and secondary packages, such as clamshells and blister packs. These packages are difficult to open, but even more difficult to disassemble in most cases.

The last product issue in the packaging sector relates to the absence of standardization in secondary and tertiary packaging. Usually, each market participant develops their own packaging with different sizes, materials, and weight capacities. This tendency impedes the development of economies of scale, as well as the cross-integration of packages in different supply chains. Especially in e-Commerce, where most delivered goods tend to fall within a restricted range of dimensions, determining standard international sizes seems like a feasible approach if adopted by the main participants.

CE barriers to consumption: From a consumer perspective, most CE barriers pertain to cultural and behavioral aspects. These barriers have been assigned to a separate category, as their root-causes as well as the ways to address them are fundamentally different from barriers to production.

Convenience and price are the top two reasons why consumers of all generations choose to buy online instead of a traditional brick-and-mortar store [Wal-2018]. Therefore, any CE characteristics that contravene these principles will emerges as barriers to its implementation.

Sometimes consumer psychology can be contradictory. Most people state that they are very concerned about global warming and climate change. Recent research shows that around 75% percent of people are willing to pay a ~5-10% premium for green packaging. In fact, consumers have stated to be willing to pay the biggest premium for green packaging among several other industries such as automotive, electronics, building and furniture, probably due to its relatively cheaper costs [Kai-2012]. Therefore, the packaging sector holds enormous promise for circular economic transformation and accelerated transition. However, actual purchase behavior does not always match stated intentions. This is especially true, when the impact of the environmentally responsible action is not seen immediately, as is the case for reusable packaging.

Although society is increasingly becoming more environmentally aware, e-Commerce is shaped by several other counter trends that block its development. The sector has made same-day delivery the new global standard, fueling a culture of ordering more products than necessary, fast-delivery and subsequent return of those unwanted products upon arrival. Furthermore, the implementation of returnable packaging systems requires customers put in extra effort to either bring the packaging back to a mailbox or a collaborating partner or at least hold on to it until the company arrives to retrieve it.

Research has shown that one of the key factors that determines the environmental benefits of PaaS products is whether customers treat leased products with the same care as products they own and whether they return them on time to the service provider [Tuk-2015]. A critical return rate needs to be at least achieved in every RTI system for it to be economically and environmentally viable. If this is not achieved, part of the environmental potential of RTI systems will not be achieved. In addition, customers sometimes perceive recycled/refurbished products to be of inferior quality to brand new products manufactured from virgin materials [Mob-1995].

According to a recent study, around four in ten consumers reported having difficulties distinguishing between reusable and single-use packaging by just looking at the containers [Bov-2018]. This means that a lot of reusable packaging might not be able to complete one full loop before being discarded, because it cannot be identified as such by the consumers, leading to a chain failure of the circular system.

2.2.3 Drivers to CE in e-Commerce packaging

When devising strategies to introduce CBMs into the economy, the underlying assumption is that overcoming or disabling the barriers explained in the previous subsection will allow faster progress towards CE. Therefore, certain enabling factors or drivers need to be identified and implemented to create better boundary conditions for CE and to deal with individual blockades along the key dimensions exposed in the previous subsection. The following paragraphs introduce possible enabling measures that target the five barrier categories identified within the e-Commerce packaging sector.

Cultural drivers: As mentioned previously, cultural barriers are by far the most pressing and difficult to overcome towards CE implementation. Linear manufacturing chains have been the state-of-technology since the beginning of the First Industrial Revolution, around 250 years ago. As a result, linear thinking is deeply enrooted within society. While the last decade has brought forth significant mentality changes and a growing environmental awareness, some overarching measures can be taken to help accelerate the process.

In order to transition from a linear to a circular business model, companies need to integrate the principles and value creation approaches of circular economy into their vision and strategy. In any strategy project, the long-term vision needs to be broken down into short and medium-term goals as well as a set of KPIs to evaluate progress during the implementation process. Buy-in from top management in businesses and policy makers is a fundamental prerequisite for success, helping to both steer and coordinate efforts as well as implement corrective measures. The main challenge in developing KPIs to track progress resides in defining goals that can be easily measured and quantified. The Ellen Mac-Arthur Foundation suggests a set of strategic KPIs based on the three principles of circular economy:

Table 2-1: KPI set to measure CE progress. Adapted from [Mac-2015]

Principle	Primary KPI	Secondary KPIs
1. Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows.	**Degradation-adjusted net value added**: A metric developed by the UN that is obtained by adjusting the traditional economic accounting measure for ecosystem degradation [Uni-2014].	• Overall remaining finite stocks • Stock annual degradation rate
2. Optimize resource yields by circulating products, components, and materials in use at the highest utility at all times in both technical and biological cycles.	**Profit generated per unit of net virgin finite material input**	• Product utilization rate • Product lifetimes • Material value retention ratio per loop
3. Foster system effectiveness by revealing and designing out negative externalities	**Total cost of externalities and opportunity cost**	• Cost of pollution to air, water and land • Climate change • Cost of effects on human health

In an effort to fill the knowledge and capability void existent at the moment, training programs and workshops on CE skills should be developed and integrated into companies willing to transition to a CBM. To help foster understanding of CE as a holistic approach, clear standardized definitions as well as globally recognized communication organisms need to be put in place. Some organizations, such as the Ellen MacArthur Foundation are already attempting to play this role.

Regulatory drivers: Taxes, incentives, policies, and laws constitute the main instruments at the disposal of policy makers and market regulators in order to overcome regulatory barriers.

Taxes are the most common and extended approach to steering economic production and consumption. As such, they can be used to encourage the development of adequate collection and material treatment facilities, both for life extension and EoL processes. One kind of environmental tax that has been progressively introduced over the last several decades are landfill taxes. Landfill taxes commonly levy a fixed amount per ton of material disposed at landfill sites. Some countries, such as Germany have gone as far as banning landfill altogether for untreated waste. As a result, countries imposing landfill taxes expect that producers will react to them by developing less resource intensive products and redesigning them so they can be reprocessed more easily.

According to Eurostat, labor taxes and social contributions account for more than half of EU total tax revenues [Eur-2014]. Additionally, consumption-based taxes (mainly VAT) account for roughly 22% of tax income in European states, while environmental taxes represent merely 6% of total taxes. This seems to contradict some of Europe’s strategic goals with regard to production and consumption, especially those indicated in the Circular Economy Action Plan. For this reason, some experts have suggested shifting the weight of taxation from labor to resource use, with the expectation that it will both encourage less intensive resource use and reduce unemployment, as labor taxes decrease. Recent studies show that resource taxes account for less than 4% of environmental taxes, with most environmental taxes being levied on energy, leaving much room for regulation within this field. It is yet unclear what the best approach to resource taxation is, with experts having suggested levying taxes on extraction, material input at the first point of industrial use or consumption. Each approach possesses its own implementation challenges and further research is required to determine the best alternative and weigh the advantages.

One more novel approach to stimulate the adoption of circular products consists of introducing tax incentives on products that are circular or use secondary materials, such as VAT reduction for these products.

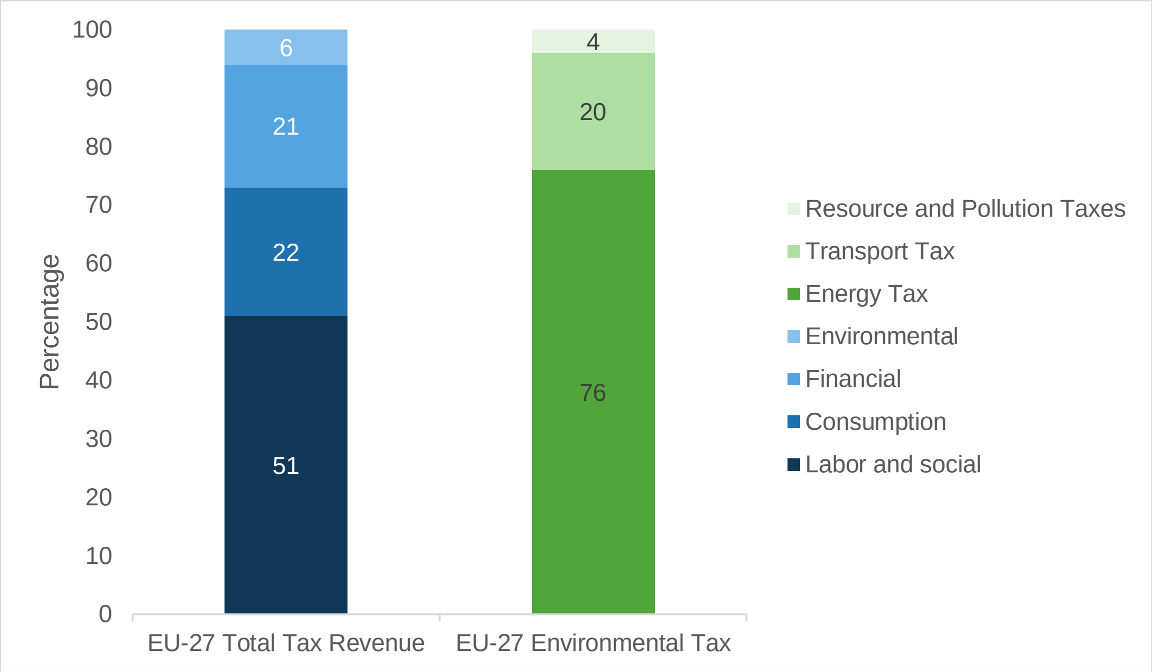


Figure 2-7: EU-27 Total Tax Breakdown. Adapted from [Eur-2014; Eur-2017]

As already explained in Section 2.1.2, the public sector represents the largest consumer in most developed economies. Consequently, Green Public Procurement (GPP) is being promoted within many nations and, especially, within the European Union members, being a part of the European public procurement strategy developed by the European Commission. In order to reduce single-use packaging volume, public entities can form long-term relationships with RTI providers that will handle the delivery and/or logistics of consumables and other goods demanded by the public sector. To ensure the compliance with GPP recommendations and track adoption rate, reusable packaging quotas could be established among public entities.

Additionally, industry experts have advocated for the instauration of Extended Producer Responsibility (EPR) as an instrument to encourage adoption of processes that rank higher in the pyramid hierarchy of waste treatment (see Fig. 2-4) and therefore retain more value. This policy aims to encourage producers to design circular/environmentally friendly products by holding them accountable to manage the cost of their products' EoL treatment processes. In the packaging industry, the underlying concept is to internalize producer externalities by penalizing market introduction of non-circular packaging materials and encouraging circularity by placing penalty schemes on packaging disposal that can be reduced through volume and weight reduction or by ensuring that the packages can be looped as long as possible.

One last regulatory instrument that can help address technological and product barriers related to lack of transparency and product uncertainty are the so-called material or product passports. Such a passport consists of a document that lists and describes the characteristics of all the materials contained in a product with the purpose of facilitating product life extension and resource recovery operations. By introducing material passports, the expectation is that the recovery and reuse rate of products will be increased, as more visibility on required processes is made available. However, material passports are still in an early/conceptual phase of development and further standardization/regulation measures need to be put in place before their implementation. The main concern regarding their viability revolves around the administrative effort required to track and update passports over time. Additionally, since technological innovation is advancing at a fast pace, data could quickly become obsolete, making it impossible to keep up with data gathering.

Market and financial drivers: Market and finance-related drivers aim to ensure and enhance the economic viability of circular initiatives by pooling economic resources, developing secondary markets, and developing valuation measures that quantify the benefits of introducing CE.

Similar to how the environmental impact of a circular product is assessed over its entire life cycle through an LCA, a similar approach can be taken for the economic aspects. Whole Life Costing or Life Cycle Costing (LCC) is an economic valuation approach that assesses the total cost of ownership of a product by incorporating non-economic factors, such as environmental and social externalities. The objective is to provide a holistic evaluation of a product’s life cycle on the economic by including costs and externalities incurred after the use phase has finished, especially EoL processes. LCC places the focus on energy and material resource efficiency as OPEX gains more importance over CAPEX compared to traditional evaluation approaches. Additionally, developing LCC tools provides an objective way to evaluate and compare the expected cash-flows and degradation-adjusted net added value of circular products, mitigating risk and uncertainty of CBMs and decreasing the cost of capital for companies launching new initiatives.

Most circular initiatives have a critical volume that needs to be reached for them to be viable from an environmental and economic standpoint. This critical volume is defined as the number of products and the number of loops per product required such that the LCC and the environmental impacts of reusable alternatives are lower than current linear products. Aggregating circular initiatives or projects and developing platforms to enable collaboration and knowledge exchange between circular economy promoters facilitates the overcoming of barriers and facilitates reaching critical volumes required to scale initiatives.

Technology and product drivers: The digital technologies brought about by the Fourth Industrial Revolution are expected to become the main drivers in shaping future business models and the CBMs are no exception. 4IR technologies have such a disrupting effect on the status quo of circular business operations because they enable the decoupling of economic growth and resource consumption through greater efficiencies and increased intelligence capabilities and insights obtained with the help of data.

IoT devices incorporate multiple embedded technologies and wireless sensors that enable interconnectivity as well as data generation and exchange within a network. IoT technologies can be coupled with data analytics capabilities to allow packaging manufacturers to analyze the performance of the forward and reverse supply chains, track the location and detect lost items through GPS, RFID, QR or NFC technologies, identify consumption patterns and consumer preferences, and give real-time information on status/damage sustained by transported goods. Several initiatives are already attempting to equip reusable packaging with IoT technologies in order to produce superior RTI alternatives. For instance, project ISLT.net, an initiative supported by the German Ministry of Economy and Energy, aims to develop modularized smart containers equipped with IoT technologies that will operate under a Container-as-a-Service business model. These containers will be able to provide real-time information about their flow through wireless networks and improve digital transparency throughout the supply chain. The startup Livingpackets has also developed a shipping box that can be reused up to 1000 times and is equipped with electronic ink displays, temperature, humidity and shock sensors, and a camera to allow a complete real-time monitorization of the package via built-in Internet connection.

When implementing CBMs the arguably most fundamental requirement is the existence of appropriate reverse logistics infrastructure within the supply chain. While most businesses have developed an optimized forward supply chain to deliver products to the end customer, they lack the required equipment and capabilities to collect circular products and carry out repair, refurbishment, or resource recovery operations. The irruption of companies that specialize in providing these capabilities as a service will enable smaller players, which might not able to afford the upfront investments, to enter the market. For instance, so-called producer responsibility organizations are 3PL providers which are paid by manufacturers to handle obligations derived from EPR. Other complementary infrastructures such as secondary marketplaces, storage facilities and re/up/downcycling factories must also be developed in order to drive forth CE implementation.

Finally, package standardization of materials, sizes and weight capacities can be widely regarded as the most impactful driver in the product subcategory. Achieving standardization will enable reuse, cascading and resource recovery of materials across brands and industries. To ensure a meaningful adoption rate, the process of developing standards and rules should be undertaken by a globally recognized organization that also takes care of its dissemination.

Consumption enablers: Barriers to consumption are arguably one of the most difficult types to overcome, since they originate from complex and interrelated social phenomena that encompass interests, psychology, beliefs, and behavior. As a consequence, it becomes difficult to isolate the exact root cause of the barriers and develop measures that individually target them.

The divulgation of the CE concept can be approached in multiple ways. The overarching objective of these endeavors is to raise awareness about the necessity of implementing CE principles to preserve natural resources, stimulate customer engagement and interest, create a sense of urgency, and communicate the benefits of the circular model. Educating the customer is a fundamental goal to be achieved. In a capitalist economy, supply will evolve and adapt to unmet demands. Therefore, if customers start demanding more sustainable products, manufacturers will be forced to conform to the new standard or be left out of the market.

A common approach to increase return rate of RTIs by customers and ensure proper care is taken until the return is started consists of charging a deposit on the shipment of the package that is reimbursed to the customer when it arrives back at the logistics provider’s facilities. Another variant to this scheme consists of giving the possibility to earn certain rewards upon returning the RTI. The rewards can then be used for subsequent purchasing orders and have the potential to help increase customer loyalty and retention rates. Different approaches to designing these deposit/reward schemes, as well as advantages and disadvantages of each of them will be discussed in Section 3.

2.2.4 Benefits of CE in e-Commerce packaging

Aside from the obvious environmental benefits, reusable packaging entails many other advantages for both manufacturers and consumers. Recognizing the untapped potential of RTIs requires looking beyond quick wins in the economic and environmental field. According to the Ellen MacArthur foundation, these benefits have the potential to turn packaging from something that is as inexpensive and as light as possible into a high-value asset that delivers benefits to both users and businesses [Ell-2019]. Some of the most impactful benefits enabled by reusable packaging include:

- Brand loyalty: A corporate culture of sustainability is positively correlated with higher brand values. As a result, companies that implement CBMs are expected to achieve superior brand loyalty and customer retention rates. The setup of deposit and reward schemes upon purchase and return of reusable packaging can further incentivize customer loyalty. Some packaging start-ups, such as Repack, are already implementing these strategies in order to drive up return rates and customer loyalty.
- User experience: Reusable packaging alternatives can deliver an improved user experience in comparison to traditional single-use packaging. Since the initial manufacturing cost can be spread out over many loops, packaging manufacturers can invest more money per product to achieve better functionalities, ergonomics, or a higher-end design.
- Economies of scale: Standardizing RTI dimensions, materials, infrastructure, and processes can enable the development of economies of scale across several supply loop functions such as manufacturing, transport, reverse logistics, maintenance, and EoL operations. Additionally, standardization can enable sharing/cascading of assets across companies and sectors, creating tightly connected networks.
- Packaging volume reduction: e-Commerce purchases sometimes consist of several products that are bundled together into one shipment. This bundling process often results in shipments formed by boxes contained within boxes and large amounts of filler material to cushion impacts. Reusable packaging can be designed in a way that allows compact delivery of different products and allows to eliminate tertiary packaging in most situations. Consequently, packaging costs can be reduced altogether by packaging more compactly and eliminating certain packages.
- Gathering insights: Since RTIs are designed to be reused many times and therefore their fixed costs are spread out over many cycles, they can be equipped with different technologies, such as RFID tags, GPS tracking and IoT sensors. These technologies supply large amounts of data that can be analyzed in order to generate knowledge about the reverse flow streams to improve supply prediction, analyze system performance, provide updates on damage sustained by items, identify consumer patterns and preferences or track lost items.

In conclusion, the circular approaches discussed in this subsection present high potential in relieving the pressure applied to natural resources and the environment by the current linear economic model. Additionally, reusable packaging alternatives offer additional advantages for both consumers and producers that increase their value beyond their environmental benefits. Despite the vast potential held by circular packaging, several barriers need to be overcome prior to their implementation at scale. With this aim, multiple drivers and factors have been identified to enable and accelerate the CE transition in the packaging sector.

Although CBMs are very promising with regard to many potential applications, it is crucial to evaluate each one a case by case basis in order to avoid drawing fallacious conclusions. In order to do this, taking a life cycle approach in order to determine the magnitude of environmental impacts and assess how they are distributed among the different life cycle phases. Indeed, there might be some instances, especially when the majority of impacts take place during the use phase of the product, where replacement is environmentally preferable to looping if the new product has experienced a leapfrog in terms of energy efficiency or an improvement in any of its phases [WRA-2010; Riz-2018; Fin-2013].

2.3 Closed-loop supply chains and reverse logistics

As discussed in the previous section, the implementation of CBMs on a global scale requires the development of additional capabilities and infrastructures to be able to carry out resource recovery and product life extension operations. Traditional linear supply chains need to be further developed into closed loops, cycling back products and materials by integrating reverse logistics into the supply chain.

According to the European Working Group on Reverse Logistics, REVLOG, reverse logistics is defined as the “process of planning, implementing and controlling backward flows of raw materials, in process inventory, packaging and finished goods, from a manufacturing, distribution or use point to a point of recovery or proper disposal” [Rub-2008]. The American Reverse Logistics Executive Council provides a similar definition that includes the management of any information relevant to reverse processes into the domain of RL [Rog-1999]. Especially after the irruption of IoT into SCM, information and data have become an essential source of value creation, hence the importance of including them into the definition. As such, RL processes have their origin at the end users of forward logistics, where products are collected after their use phase has concluded, and then are subjected to life use extension or resource recovery operations. If used goods cannot be reprocessed on a product or material level, they are put into an EoL stream to be discarded. These are the processes that a true CE aims to eliminate. A CLSC is the result of combining forward and reverse supply chains simultaneously to construct a loop, as illustrated in Figure 2-8.

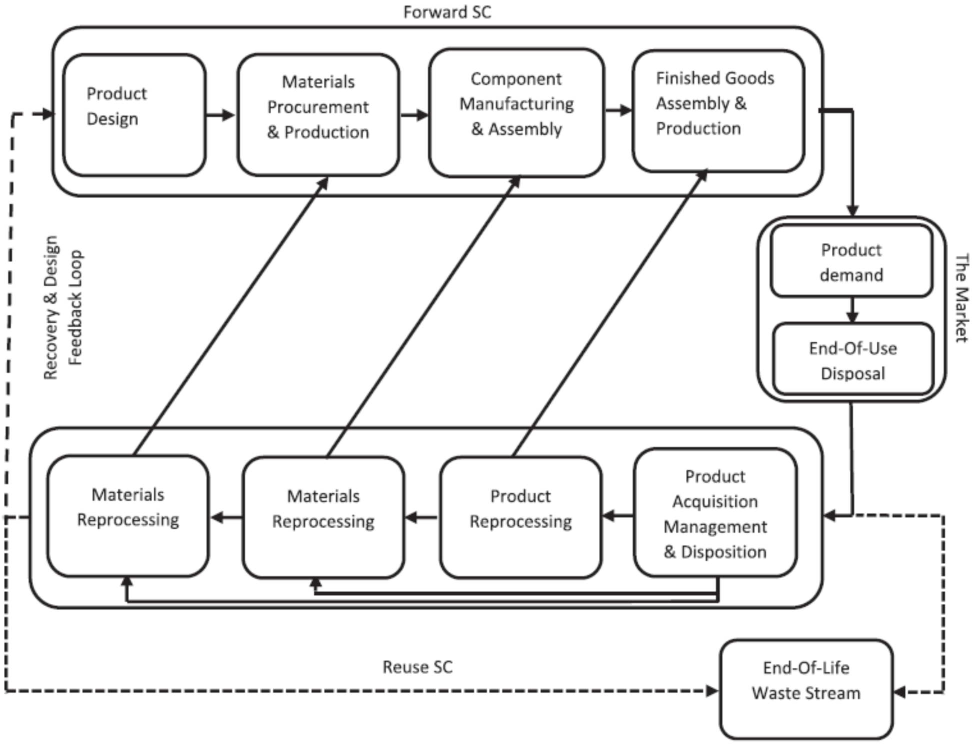


Figure 2-8: Structure and processes of a CLSC [Jam-2017]

Based on this structure, supply chain management can then be defined as the “design, control, and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time” [Gui-2006].

Return flows within a CLSC can be usually assigned to one of five different categories [Fle-2001]:

- EoL return of used products
- Commercial returns, i.e. products returned as they were delivered due to not being wanted anymore, damage, faulty, wrongly delivered, obsolete, etc.
- Warranty returns, i.e. products submitted for repair due to damage/faults during their lifetime
- Production scrap and byproducts
- Reusable packaging material

The destination of a product on the RSC displayed in Figure 2-8 depends on many factors, such as the residual value that can be recovered, ease of disassembly, material composure and the range of reprocessing operations that can be performed on the product. While each one of the categories can be present in an RSC, some will be more relevant than others in a CE concept of the e-Commerce sector.

Aside from reusable packaging material, which ideally should be present in every delivery in the forward and reverse supply chains, commercial returns make up a big portion of the e-Commerce return streams. While the commercial return rate of traditional retail is around 9% of the products sold, for e-Commerce this rate can amount to around 30% depending on the products under study [Don-2015]. As a result, the RSC in the e-Commerce sector requires more capacity in comparison to RSCs for traditional retail.

Additionally, assuming that customers do not keep the reusable packaging until the products reach their EoL, some empty RTIs will be sent through the forward chain to allow EoL and warranty returns. This scenario seems the most likely for products that have a life span exceeding a couple of weeks because leaving RTIs stranded in the customers’ homes results in higher levels of RTI stocks, which in turn decreases the profitability of the system. Production scrap streams should be mostly irrelevant in a CE since they will be designed out of the loop.

2.3.1 CLSC archetypes for e-Commerce

Classifying CLSCs into several archetypes helps simplify the discussion about the most determinant design factors as well as assess feasibility requirements. In terms of economic viability, the residual value of products after their use phase has been completed must be evaluated in comparison to the sum of reverse transport costs and reprocessing expenses. Looping a product back into the system will only be viable if the residual value exceeds the costs of doing so. Assuming that the reprocessing costs will be approximately uniform across the globe once the transition to a CE has been completed, the determinant factor in this analysis are geographical locations, i.e. transport distances between the different stages of the RSC. In terms of geographical distribution, three archetypes of circular or partially circular supply chain setups can be identified in addition to the traditional linear supply chain setup [But-2014]:

Closed geographical loops aim to collect large quantities of products, components and materials after their use phase has concluded and return them from their point of use to their point of manufacture in order to extend their lives or reduce the amount of raw virgin materials consumed to manufacture new products. Closed geographical loops can be further divided into two subcategories.

Closed regional and local groups seem to be the most viable circular approach at the moment due to the ability to leverage proximities between consumption and manufacturing points to reduce transport costs and thus increase the economic viability of the system. Additionally, since they operate on a local/regional scale, international borders can be avoided for the most part. As explained in Section 2.1.2, international borders often pose a strong regulatory/administrative deterrent to circular economy, due to the difficulty of the relabeling of waste streams for reuse, which is required to transport used products across borders.

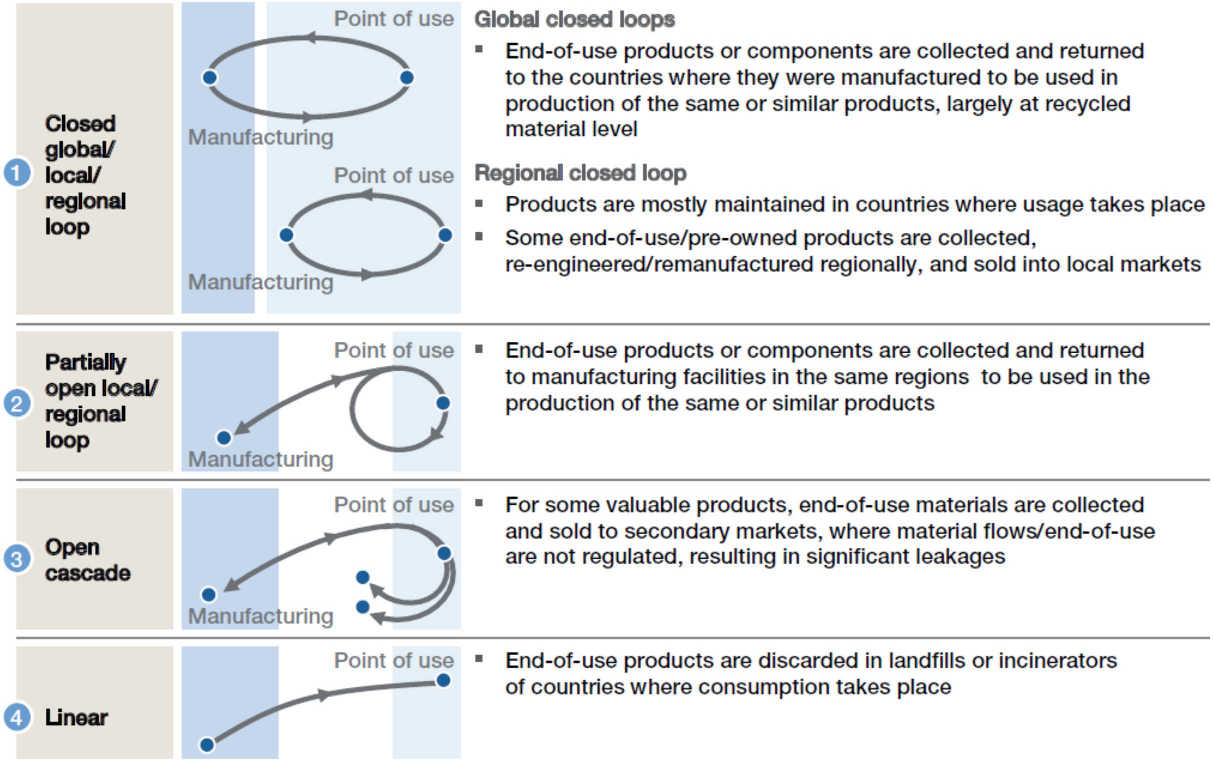
Closed global loops are only implemented on exceptional cases for products that are manufactured in relatively low quantities which retain high residual values after their use phase is concluded, therefore justifying the large transport distances.

Partially open geographical loops consist of a partly linear supply chain (e.g. from virgin material extraction to manufacturing of the finished product) to which loops are added on a regional or local scale to carry out refurbishing/remanufacturing/recycling operations. An example of such a loop would consist of products that are manufactured in a foreign country, such as China, due to the higher availability of required materials, but are then looped on a regional scale to benefit from lower transportations costs.

Geographical open cascades seek to move products, components and materials into different markets or industries after their first use phase has expired. For instance, moving a product into a different geographical location or reselling it to a different market segment would constitute one example of this approach.

Among these options, only closed geographical loops can be implemented in a steady-state CE. The other archetypes however are both viable and very helpful to start implementing circular approaches and drive an accelerated transition. Regional/local closed loops should, in theory, have higher ROIs as a result of lower transport distances, logistics costs and externalities. Nevertheless, closed global geographical loops can be a viable option as economies of scale are achieved in an increasingly globalized market. This is especially the case for expensive products that retain high residual values or for products requiring increasingly scarce resources that go up in price.

Figure 2-9 displays a comparison of the three previously introduced CLSC archetypes and the open linear supply chains that still dominate the current global economy based on a take-make-waste approach. The darker overlays are used to represent predominantly manufacturing countries, such as China, while the lighter overlays represent importing regions such as the EU and the US.



Global closed loops

- End-of-use products or components are collected and returned to the countries where they were manufactured to be used in production of the same or similar products, largely at recycled material level

Regional closed loop

- Products are mostly maintained in countries where usage takes place
- Some end-of-use/pre-owned products are collected, re-engineered/remanufactured regionally, and sold into local markets

- End-of-use products or components are collected and returned to manufacturing facilities in the same regions to be used in the production of the same or similar products

- For some valuable products, end-of-use materials are collected and sold to secondary markets, where material flows/end-of-use are not regulated, resulting in significant leakages

- End-of-use products are discarded in landfills or incinerators of countries where consumption takes place

Figure 2-9: Archetypes of CLSCs and loops [But-2014]

E-Commerce CLSCs can also be categorized according to other parameters, such as whether the RTIs are returned to the original manufacturer or to a third party, who handles the logistics of the system and the ownership of the RTIs. These options are explored in further detail in Chapter 3 of this study.

2.4 Life cycle assessment

According to the International Organization for Standardization (ISO), Life cycle assessment (LCA) is a standardized “methodology for assessing the environmental aspects and potential impacts associated with a product or service” [ISO-14040]. This is achieved by:

- Elaborating an inventory of inputs and outputs of the product system under evaluation.
- Evaluating the environmental impacts associated to every flow in the system, including those which are not directly related to the inputs and outputs of the system.

- Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study. This includes identifying opportunities to improve the environmental aspects of products during different phases of their life cycles.

LCA can follow several approaches depending on which phases of a product's life cycle are included into the scope of the analysis. However, the most common and recommended approach is known as "cradle-to-grave" and encompasses every phase of a product's life cycle, from raw material extraction/acquisition (cradle), through manufacturing, energy and resource consumption, transportation, to use and EoL treatment and disposal, if the product is not part of a circular system. Figure 2-10 shows a schematic example of a product system used for LCA.

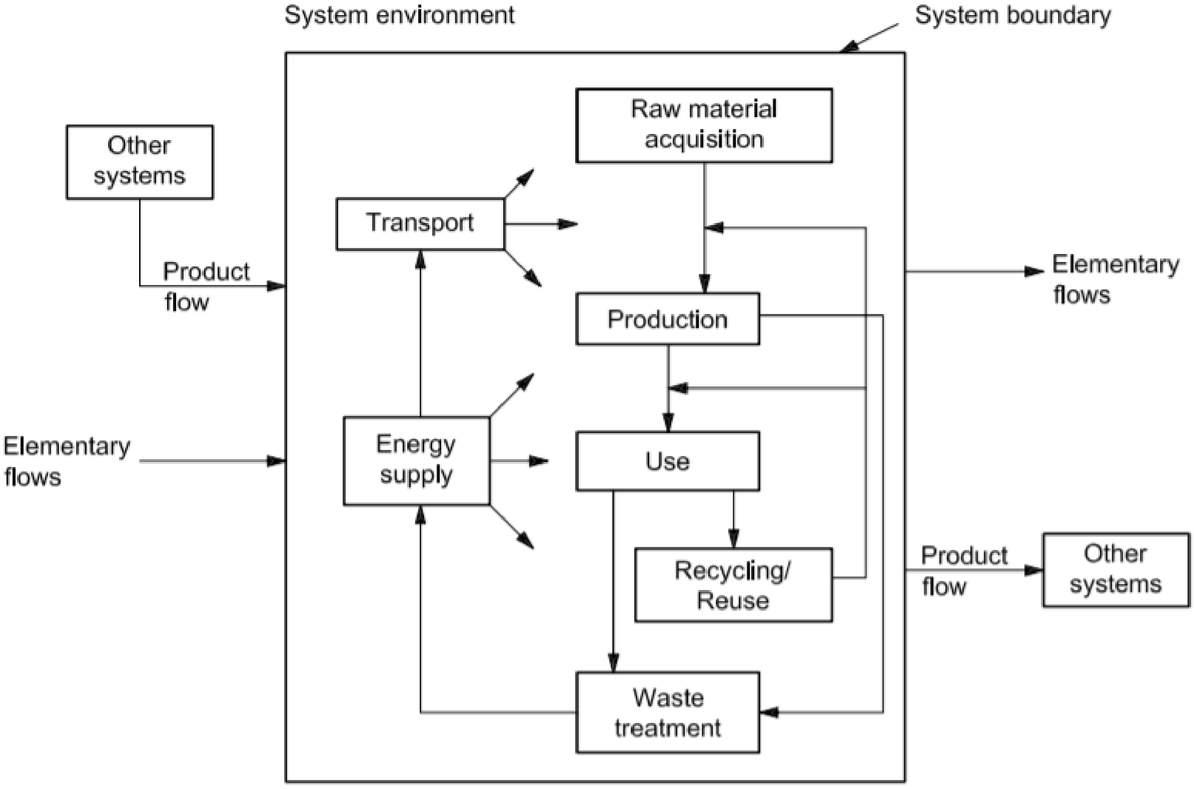


Figure 2-10: *Schematic product system for LCA [ISO-14040]*

Like every methodology, LCA has its limitations and it is essential to be aware of them in order to anticipate possible shortcomings that might be present in the assessment results. Some of the more relevant limitations include:

- Some assessment choices and assumptions are subjective by nature (e.g. system boundaries, impact categories, weighting of impacts, etc.). As such, LCA results could be susceptible to practitioner bias regarding the points they seek to prove.

- The accuracy and reliability of LCA results is limited by the uncertainty, quality, and availability of the data flows relevant to the analyzed system.
- The lack of temporal (and sometimes spatial) dimensions in the Life cycle inventory data introduces uncertainty that varies with the spatial and temporal characteristics of each impact category.
- A one-size-fits-all approach in terms of consistently and accurately associating Life cycle inventory data with the evaluated impact categories does not exist. Some models and impact assessment methods might be better suited than others depending on available data and industries.

2.4.1 Main ISO phases of LCA

According to [ISO-14040], LCA studies comprise four clearly defined phases. The relationship between them is displayed in Figure 2-11. These phases are:

- Goal and scope definition
- Inventory analysis phase
- Impact assessment phase
- Interpretation phase

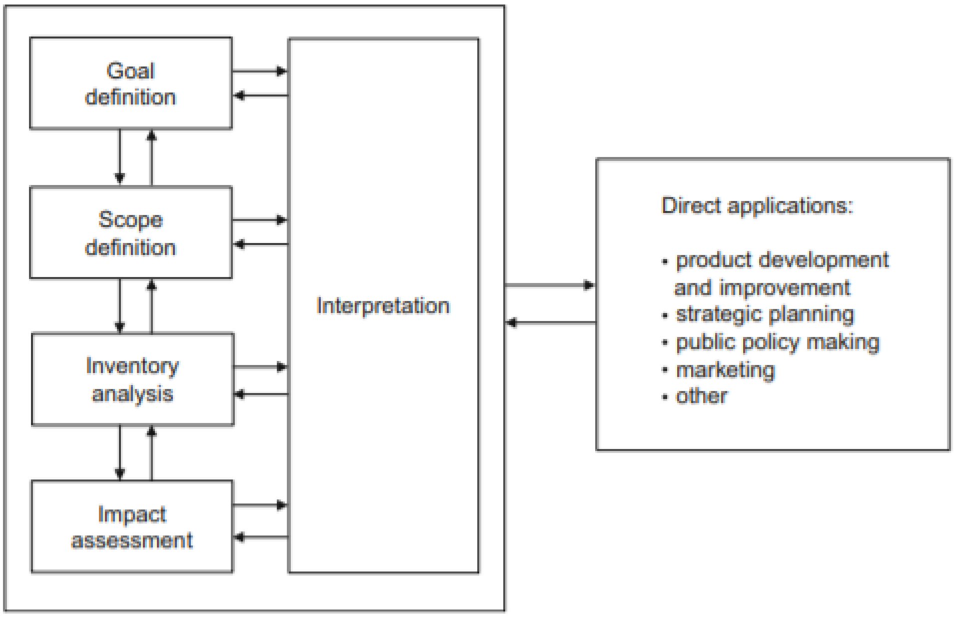


Figure 2-11: Life cycle assessment framework [Hau-2018]

Goal and scope definition:

A goal definition according to [ISO-14040; ISO-14044] needs to contain the following elements:

- Intended application
- Motivation for carrying out the study
- Intended audience

A non-exhaustive list of elements to be considered in the scope definition includes the following items:

- Definition of the product system to be studied
- Functions of the product system
- Functional unit
- System boundary
- Impact categories to be evaluated, methodology of impact assessment to be applied and interpretation to be used
- Assumptions and limitations

The functional unit of the scope definition refers to the common baseline to which inputs and outputs of the system are referenced. The purpose of the functional unit is to ensure comparability of LCA results among different product systems serving one common purpose or different variations of one product system. By defining a functional unit, every flow in the system is expressed relative to the functional unit.

The system boundary delimits which processes are included within the system. Theoretically, every process present in the Life cycle of the product should be included in the system. Additionally, the system should be modelled in such a way that every input and output crossing its boundaries is an elementary flow, i.e. material or energy resources that have not suffered a human transformation prior to entering the system or will not undergo a human-driven transformation after leaving it. However, some flows and processes may be disregarded under proper justification if they do not significantly alter the results of the assessment.

Life cycle inventory analysis (LCI):

The LCI phase is centered around generating a register of every flow existent in the product system. This refers to every input of material, energy, and water resources as well as emissions to the air, water and land. The quantitative data must be expressed in terms of the functional unit defined in the first phase of the LCA. Essentially, the LCI phase comprises all activities related to the gathering, validation and aggregation of data pertaining every unit process contained in the product system. Figure 2-12 illustrates the procedure for carrying out an LCI in form of a flow diagram.

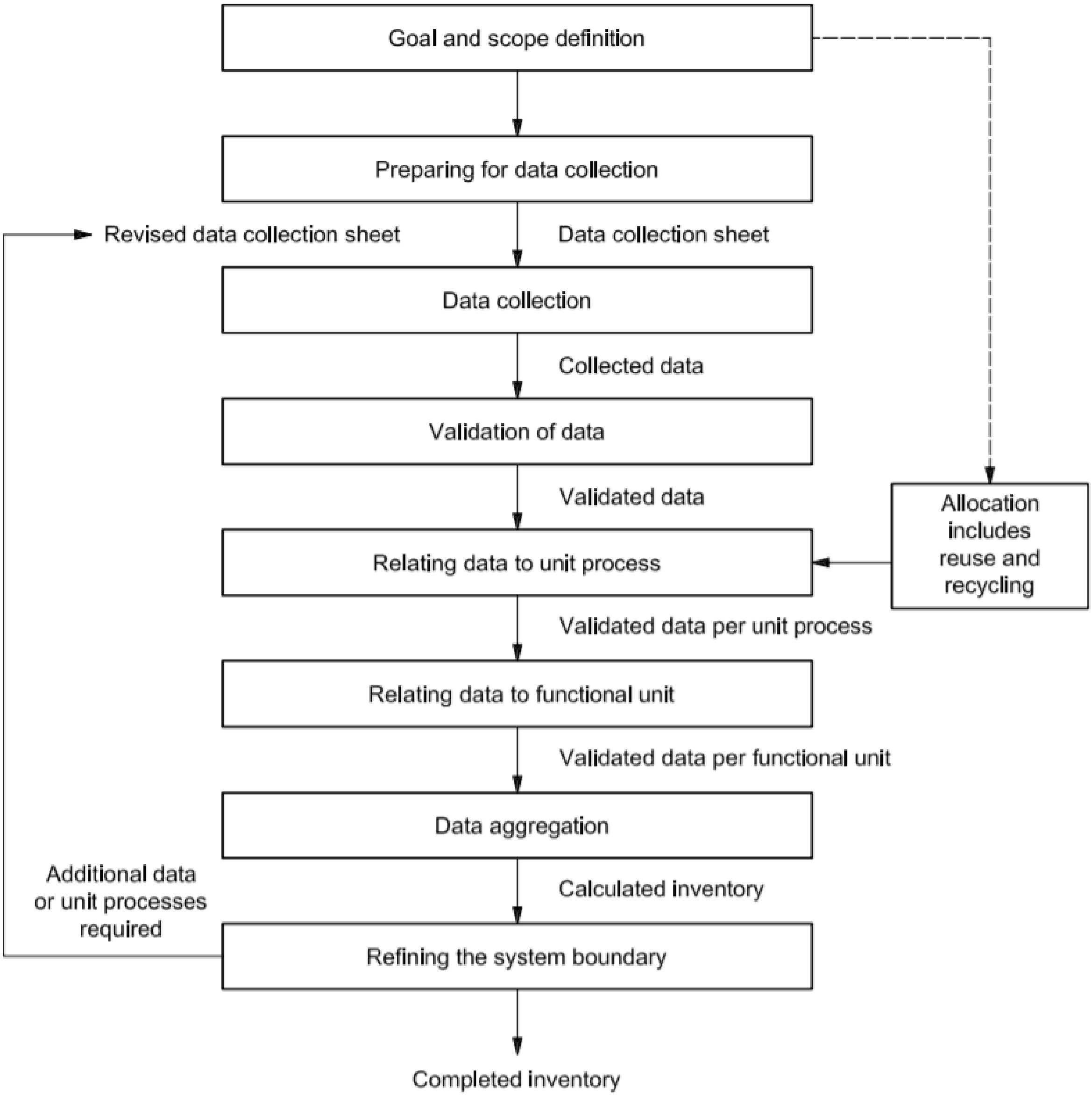


Figure 2-12: Life cycle inventory analysis procedures [ISO-14040; ISO-14044]

Life cycle impact assessment (LCIA):

The impact assessment phase seeks to determine the significance and magnitude of environmental impacts caused by the inventory of flows obtained in the LCI phase. This phase contains mandatory and optional elements. The mandatory elements comprise:

- Selection of impact categories, category indicators and characterization models.

- Classification stage, where LCI results are mapped to the selected categories.
- Characterization stage, where the actual values of category indicators are obtained.

An impact category refers to a general concept that causes environmental concern (e.g. climate change), whereas a category indicator is a quantifiable representation of an impact category (e.g. radiative forcing in $W/_{m^2}$ as a proxy for emission effects on the climate).

Impact category selection is carried out in accordance with the goals defined in the first phase of the LCA and each category requires the identification of:

- Category endpoints
- Category indicators
- LCI results that hold a relationship to the impact category
- Characterization model and characterization factors

The category endpoint refers to the impacts on environment, human health and resource depletion at the end of the cause-effect chain under study (e.g. forests in the case of climate change). Figure 2-13 provides an overview on the concept and attributes of impact categories.

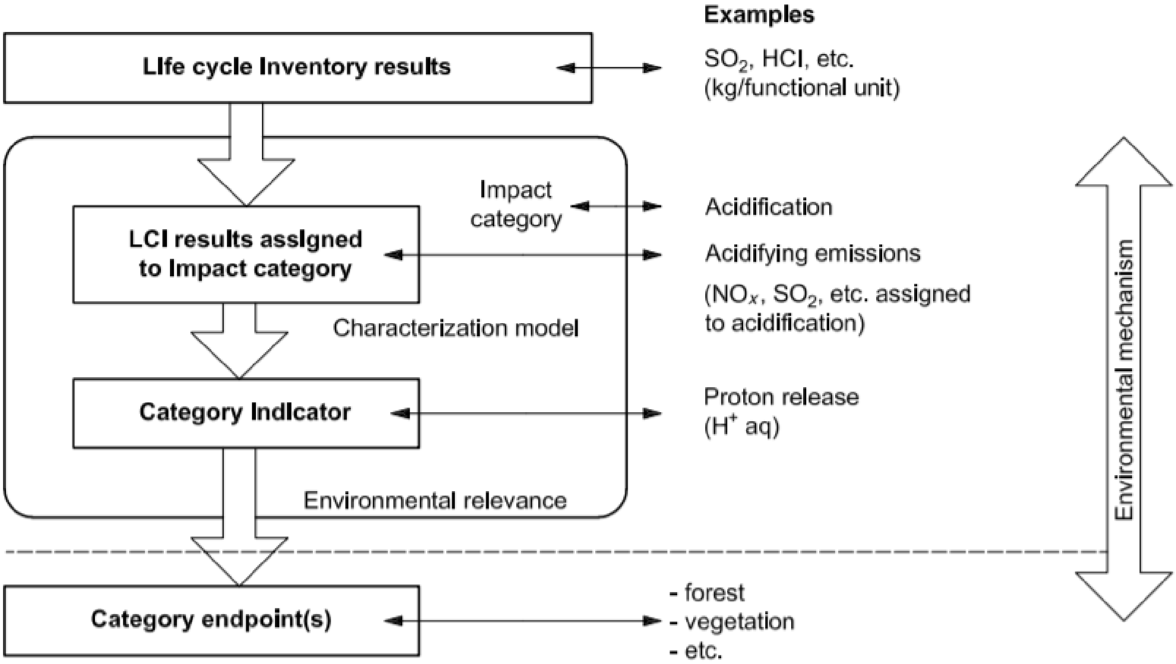


Figure 2-13: Overview of an impact category[ISO-14040; ISO-14044]

After the mandatory steps of LCIA have been carried out, additional optional elements can be included into the analysis. These elements include:

- Normalization: Calculation consisting of dividing the category indicator by a reference value in order to obtain a more easily comparable magnitude.
- Grouping: Sorting and ranking of impact categories into predefined groups or hierarchies.
- Weighting: Converting and/or aggregating indicators of different categories by multiplying them by weighted factors based on value choices.

It is generally not advisable to apply grouping and weighting to LCA studies intended as comparisons to be disclosed to the general public, since they introduce subjectivity into the research.

Finally, it is generally desirable to evaluate the robustness and significance of the LCIA results. In order to achieve this, some of the following techniques are usually applied:

- Gravity analysis: Procedure or representation that identifies the factor that provide the highest overall contribution to the category indicators (e.g. Pareto analysis, Sankey diagram)
- Uncertainty analysis: Procedure used to determine how uncertainties in data and assumptions advance through the LCA phases and impact the end results.
- Sensitivity analysis: Procedure that visualizes how changes in data magnitudes and methodology choices (e.g. impact assessment method) impact the end results.

Life cycle interpretation:

During the interpretation phase of LCA, the results from the inventory and impact assessment phase are regarded holistically in order to produce the results expected from the goal and scope definition. The interpretation phase should contain the following three elements:

- Identification of significant issues based on LCI and LCIA results
- Evaluation or consistency, completeness, and sensitivity of the obtained results
- Conclusions, limitations, and recommendations

Figure 2-14 illustrates the relationship between the interpretation phase and previous phases of the life cycle assessment.

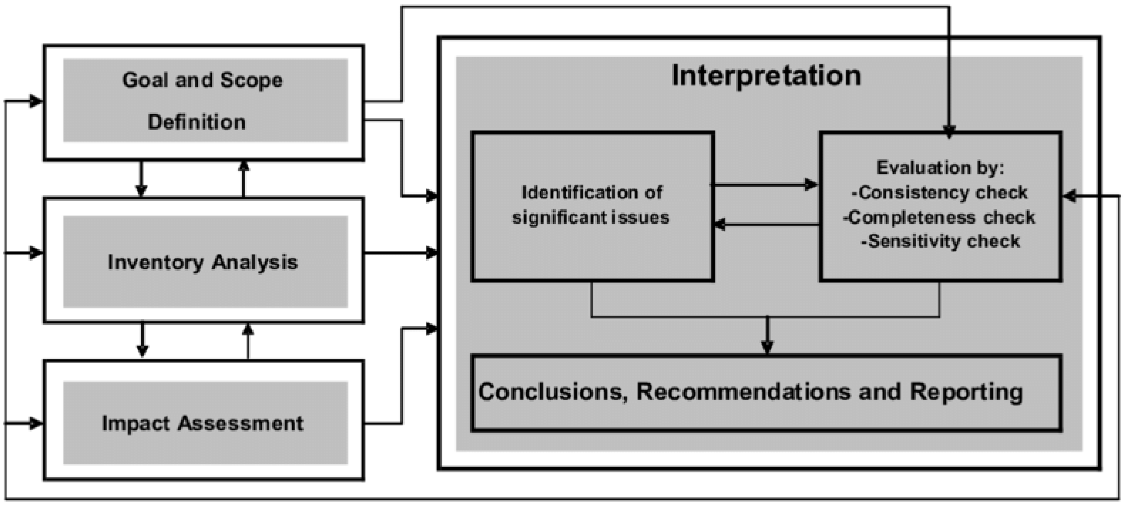


Figure 2-14: Relationship between the interpretation phase and the other phases of LCA [Eng-2015]

2.4.2 LCA software

Calculations of the environmental impacts of a product's life cycle as per [ISO-14044; ISO-14040] can be done by hand. However, it is much more common to make use of specialized LCA software to streamline the process. The function of an LCA software tool is to allocate impact magnitudes (emissions, resource depletion, energy consumption, etc.) to the energy and mass flows of a model in order to then automatically process the calculations required by the inventory and impact assessment phases.

There are many articles and webpages and webpages that analyze the different alternatives and give a detailed comparison on the advantages and disadvantages of the most popular commercial LCA software. According to one such research, among more than twenty alternatives, the three leading programs in terms of both popularity and amount of features offered are SimaPro, GaBi and openLCA [Orm-2014]. Of the three tools, SimaPro and GaBi have been on the market for over 20 years by now and are very widespread programs. They both, however, have closed code and high licensing fees, although they offer academic licenses under certain conditions. On the other hand, openLCA is a more recent alternative, free and open-source, that is being developed by GreenDelta GmbH with the support of PE International (creators of GaBi), PRé consultants (creators of SimaPro) and the UNEP (United Nations Environment Programme). Aside from licensing fees, the other two factors that have been taken into account when selecting a software tool are:

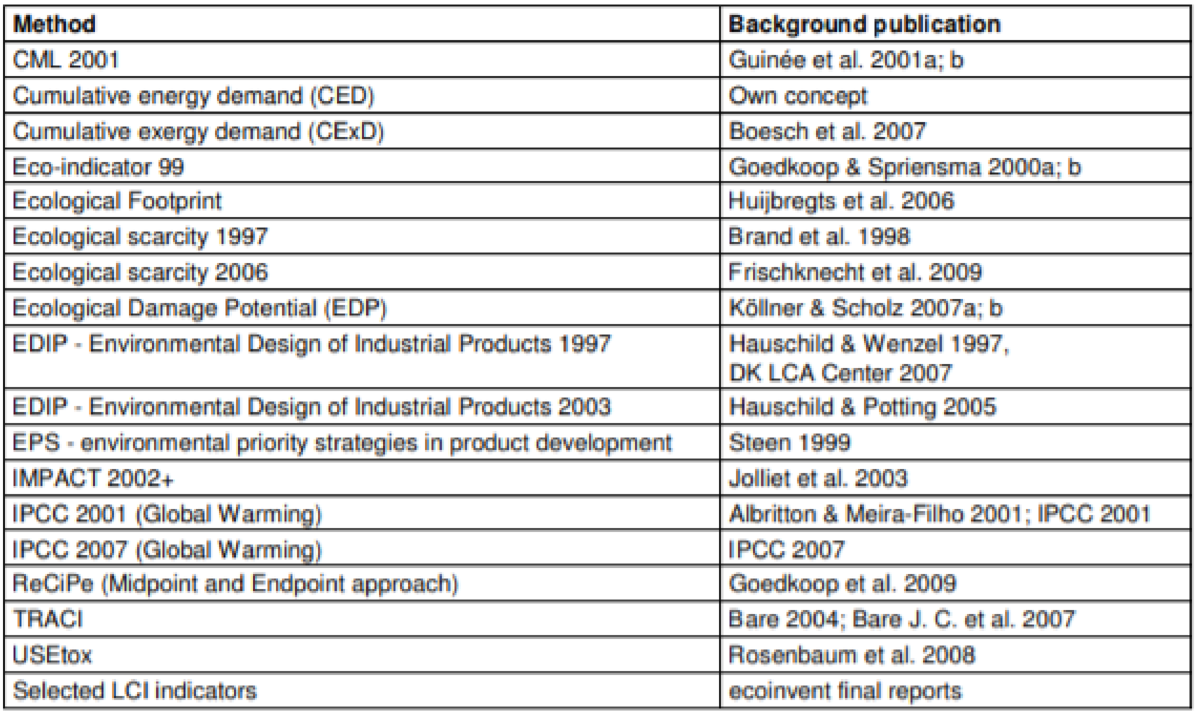
- The quantity and quality of available data in terms of accuracy and relevance to the research field.
- The availability of documentation to support the familiarization process with the software.

Out of the three considered alternatives, openLCA provides the highest number of elementary flows and offers the possibility of working simultaneously with different databases, such as those used by GaBi and others [Cir-2015]. Additionally, these databases have been harmonized to ensure seamless and frictionless usage of several databases in parallel. Taking the abovementioned into consideration, openLCA has been selected as the tool of choice for carrying out the analyses in this study.

2.4.3 Life cycle impact assessment methods

An LCIA method consists of an assortment of impact categories that seeks to provide a broad coverage of possible environmental issues and is typically developed by one research group [Hau-2013]. There exists a plethora of different methods, as there are no generally accepted methodologies in order to consistently and accurately map LCI results with specific potential environmental impacts [ISO-14044]. Table 2-1 shows an overview of some of the most widespread LCIA methods among LCA practitioners as well as the original underlying publication.

Table 2-2: Overview of a selection of LCIA methods [Alt-2010]



Method	**Background publication**
CML 2001	Guinée et al. 2001a; b
Cumulative energy demand (CED)	Own concept
Cumulative exergy demand (CExD)	Boesch et al. 2007
Eco-indicator 99	Goedkoop & Spriensma 2000a; b
Ecological Footprint	Huijbregts et al. 2006
Ecological scarcity 1997	Brand et al. 1998
Ecological scarcity 2006	Frischknecht et al. 2009
Ecological Damage Potential (EDP)	Köllner & Scholz 2007a; b
EDIP - Environmental Design of Industrial Products 1997	Hauschild & Wenzel 1997, DK LCA Center 2007
EDIP - Environmental Design of Industrial Products 2003	Hauschild & Potting 2005
EPS - environmental priority strategies in product development	Steen 1999
IMPACT 2002+	Jolliet et al. 2003
IPCC 2001 (Global Warming)	Albritton & Meira-Filho 2001; IPCC 2001
IPCC 2007 (Global Warming)	IPCC 2007
ReCiPe (Midpoint and Endpoint approach)	Goedkoop et al. 2009
TRACI	Bare 2004; Bare J. C. et al. 2007
USEtox	Rosenbaum et al. 2008
Selected LCI indicators	ecoinvent final reports

In order to assist practitioners in making informed choices on the most appropriate LCIA method to calculate an indicator for an impact category, the International Reference Life Cycle Data System (ILCD) of the European Platform on Life Cycle Assessment (EPLCA) has developed a framework consisting of six criteria to evaluate the appropriateness of a method [Eur-2010]:

- Completeness of scope: To what extent do the indicator and characterization model cover the environmental mechanisms underlying the impact category under evaluation?
- Environmental relevance: How well are the most relevant parts of the impact cause-effect chain included and modelled in accordance with the state-of-science?
- Scientific robustness and certainty: To what degree has the model been validated by peers, does it represent the state of the art, are its outputs certified against validation data and what is the extent of uncertainties reported?
- Documentation, transparency, and reproducibility: How accessible and understandable are the documentation, model, characterization factors
- Applicability: Does the method contain characterization factors for the most relevant flows within the LCI results for the studied impact categories?
- Stakeholders acceptance: Is the model endorsed by relevant authorities in the field and other practitioners and how well can its results be understood by the intended audience within a business and scientific context?

In order to make an informed choice on the most appropriate LCIA method, it is necessary to first introduce and review some relevant terminology and definitions. An overview is given in Table 2-2.

Table 2-3: Essential terminology and definitions. Adapted from [Hau-2018]

Term	Definition	Source
Area of protection	A cluster of category endpoints of recognizable value to society. Examples are human health, natural resources and natural environment.	*[Hau-2015]*
Category endpoint	Attribute or aspect of natural environment, human health or resources, identifying an environmental issue giving cause for concern	*[ISO-14040]*
Category indicator	Quantifiable representation of an impact category	*[ISO-14040]*

Characterization model	Reflect the environmental mechanism by describing the relationship between the LCI results, category indicators and, in some cases, category endpoint(s). The characterization model is used to derive the characterization factors	*[ISO-14040]*
Characterization factor	Factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator	*[ISO-14040]*
Environmental mechanism	System of physical, chemical and biological processes for a given impact category, linking the life cycle inventory analysis results to category indicators and to category endpoint	*[ISO-14040]*
Impact category	Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned	*[ISO-14040]*
Impact pathway	Cause–effect chain of an environmental mechanism	*[Hau-2018]*
LCIA method	Collection of individual characterization models (each addressing their separate impact category)	*[Hau-2013]*
Midpoint indicator	Impact category indicator located somewhere along the impact pathway between emission and category endpoint	*[Hau-2015]*

As already explained in Section 2.3.1, the LCIA phase begins with the selection of adequate impact categories according to the goal and scope as well as category indicators and characterization models for each category. In general terms, the further the indicator is located along the cause-effect chain, the more environmental relevance and meaning it will have. However, statistical uncertainty tends to increase along the chain, while measurability decreases. As a result, it becomes harder to nail down the main source of impact on the areas of protection.

When selecting a set of category indicators, practitioners must thus face a tradeoff between midpoint and endpoint indicators:

- Endpoint indicators (e.g. impacts on human health) are more relevant and easier to interpret but tend to possess higher statistical uncertainty and are harder to measure and verify, since they are more generic by nature.
- Midpoint indicators (e.g. stratospheric ozone depletion) on the other hand offer more detail as to the root cause of the damage to the areas of protection, are more adequate to identify tradeoffs of decisions between impact categories and easier to measure but can prove harder to interpret. For instance, photochemical ozone formation (tropospheric ozone formation) and water quality both have an impact on human health. Nevertheless, the ways of tackling both issues are radically different and independent from each other for the most part.

One decision factor to take into account when deciding which indicators to use should be the target audience defined in the goal and scope phase of the LCA. When presenting LCA results to people who are not familiar with the methodology, it might be more appropriate to use endpoint indicators, as the information might be more accessible to them. Figure 2-15 shows a framework of the ILCD that shows how elementary flows of the LCI phase can be linked to midpoint indicators and subsequently to endpoint categories and areas of protection.

A widespread recommendation when selecting an LCIA method consists of selecting a method that provides the possibility to conduct both midpoint and endpoint level assessment in order to support the results by having to complementary assessments instead of viewing them as two exclusionary alternatives [Hau-2018].

One final model parameter to be selected within LCIA methods revolves around characterization factors. These factors are applied to LCI results in order to convert them into the dimensions of the category indicator. Characterization factors have to take into account situational elements such as:

- Certainty of the modelled consequences and cause-effect relations.
- Existence of impact thresholds, i.e. breaking points where the environmental outlook dramatically worsens.
- Time horizon considered, i.e. when are the consequences going to appear and how long will they last.
- Geographical scale of the consequences.
- Feasibility of controlling, adapting to or cushioning the expected impacts and management styles to be applied in each case.
- Reversibility of the impact.

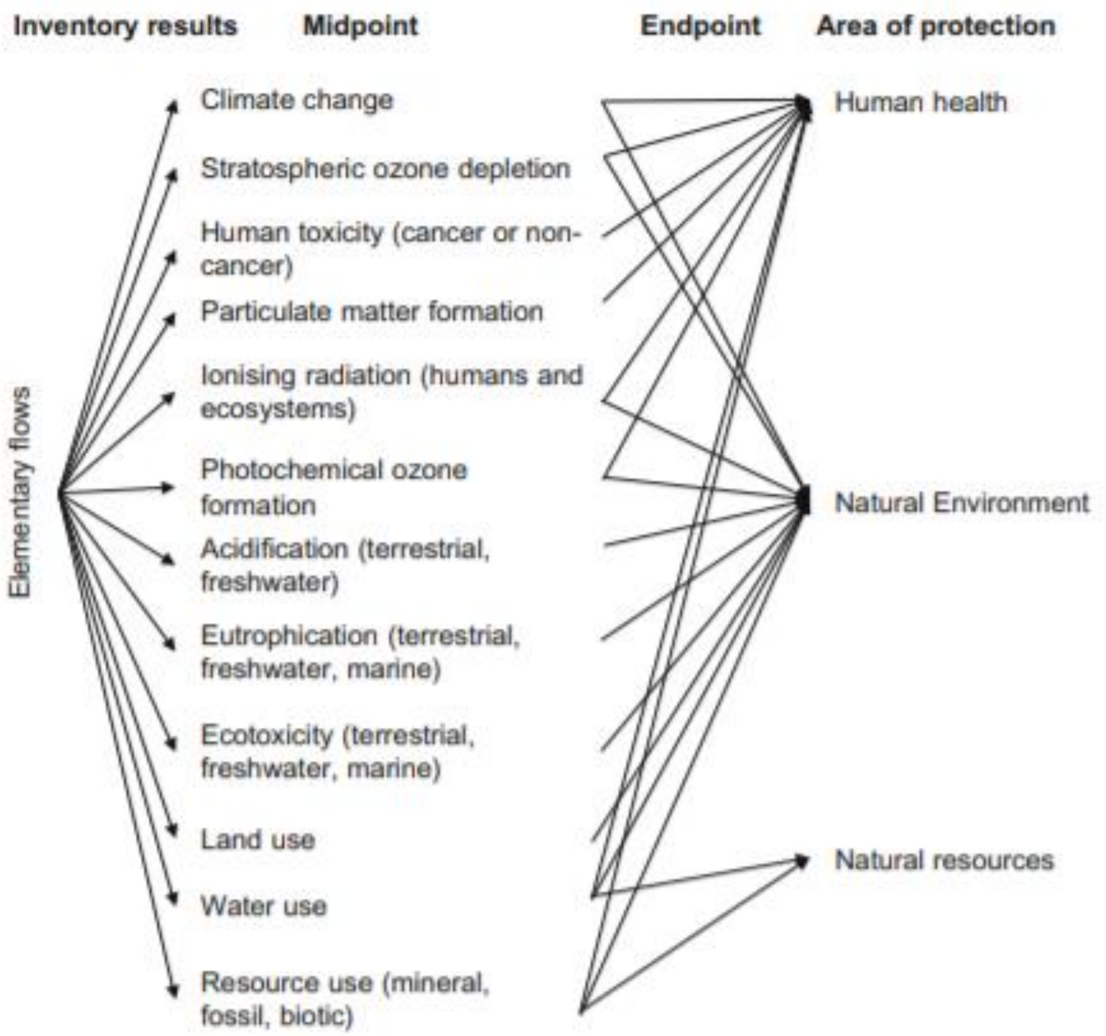


Figure 2-15: Framework of the ILCD that links elementary flows to 15 midpoints and 3 areas of protection [Hau-2018]

One extended approach to modelling these situational components is based on the Cultural Theory of Risk, a conceptual framework developed from a series of empirical studies that aims to cluster societal groups based on how personal values and perspectives influence the value choices people make [Dou-1982; Tho-2018]. Initially, the Cultural Theory of risk approach was introduced as a way to include subjective judgements and cultural bias in LCA models, thus creating a limited set of alternate scenarios based on decision making routes [Jag-1997].

In general, three perspectives are modelled in environmental decision making and included as such in LCIA methods: the Hierarchist (H), Individualist (I) and Egalitarian perspectives (E). Each perspective seeks to model a hypothetical group of practitioners, stakeholders from the audience or decision makers with different personal values, i.e. beliefs, concerns, interests and preferences that explain their attitude towards nature and society. The other two societal archetypes, the Fatalist and the Hermit, are not typically modelled for use in LCA, since these archetypes are not expected to be represented among decision makers. Table 2-3 gives an overview about the defining characteristics of each perspective.

Table 2-4: Overview of the defining characteristics of the hierarchist, individualist and egalitarian perspectives. Adapted from [Hau-2018; Sch-2011]

	Individualist (I)	**Hierarchist (H)**	**Egalitarian (E)**
Time horizon	Short-term perspective	Balanced between short and long term	Long-term perspective
Required level of evidence	Only consider proven effects	Consider likely effects based on consensus	Consider all known effects
Vision of nature	Considers nature robust	Considers nature tolerant	Considers nature vulnerable
Manageability	Adaptive management style	Preventive and comprehensive management style	Controlling management style

There are many state-of-the-art LCIA methods that offer most of the aforementioned (midpoint and/or endpoint assessments, Cultural Theory perspectives, etc.) elements. While no one-size-fits-all approach exists at the moment, some methods are certainly more popular than others among LCA practitioners. According to a survey carried out on the social media platform LinkedIn among LCA experts, ReCiPe, IPCC 2013, ILCD 2011, CML 2012 and Cumulative energy demand were the most commonly used methods, with ReCiPe being the most popular one. Figure 2-16 shows the results of the survey:

Taking everything into consideration, ReCiPe has been selected as the LCIA method of choice for the LCAs that will be carried out in this research study. The ReCiPe 2016 methodology was created by a research group from RIVM, CML, PRé Consultants, Radboud Universiteit Nijmegen and CE Delft. The authors include developers of the Ecoindicator 99 and CML 2001 methodologies, two very popular LCIA methods at the beginning of the century.

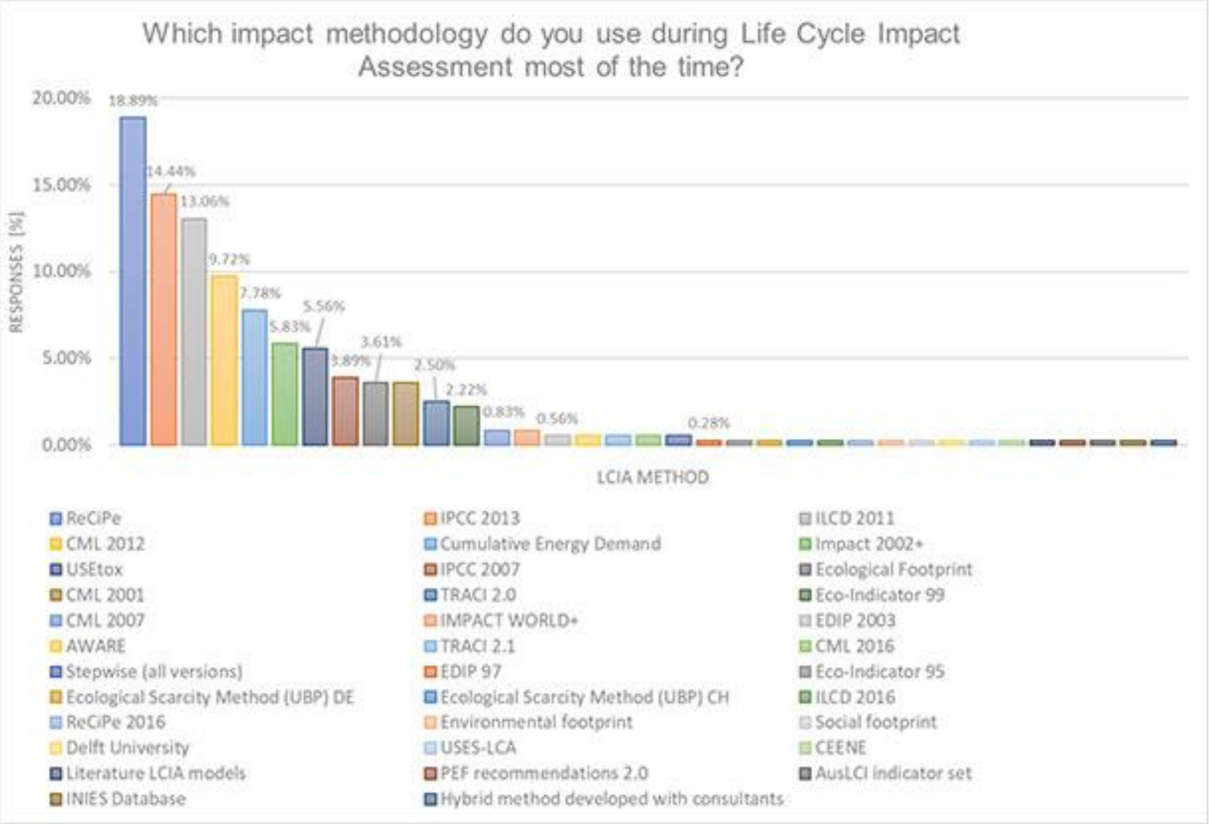


Figure 2-16: Survey: LCIA methodologies by popularity [iPo-2018]

ReCiPe offers the possibility to determine category indicators on both levels: midpoint and endpoint indicators. ReCiPe gives instructions on how to calculate:

- 18 midpoint indicators that focus on single environmental problems (e.g. global warming). (Based on CML methodology).
- 3 endpoint indicators that show the environmental impact on three equivalent areas of protection: Damage to human health, damage to ecosystem quality and damage to resource availability. (Based on Ecoindicator methodology).

As mentioned previously, endpoint indicators are easier to interpret, but statistical uncertainty increases with each aggregation step. Figure 2-17 gives an overview of ReCiPe's structure.

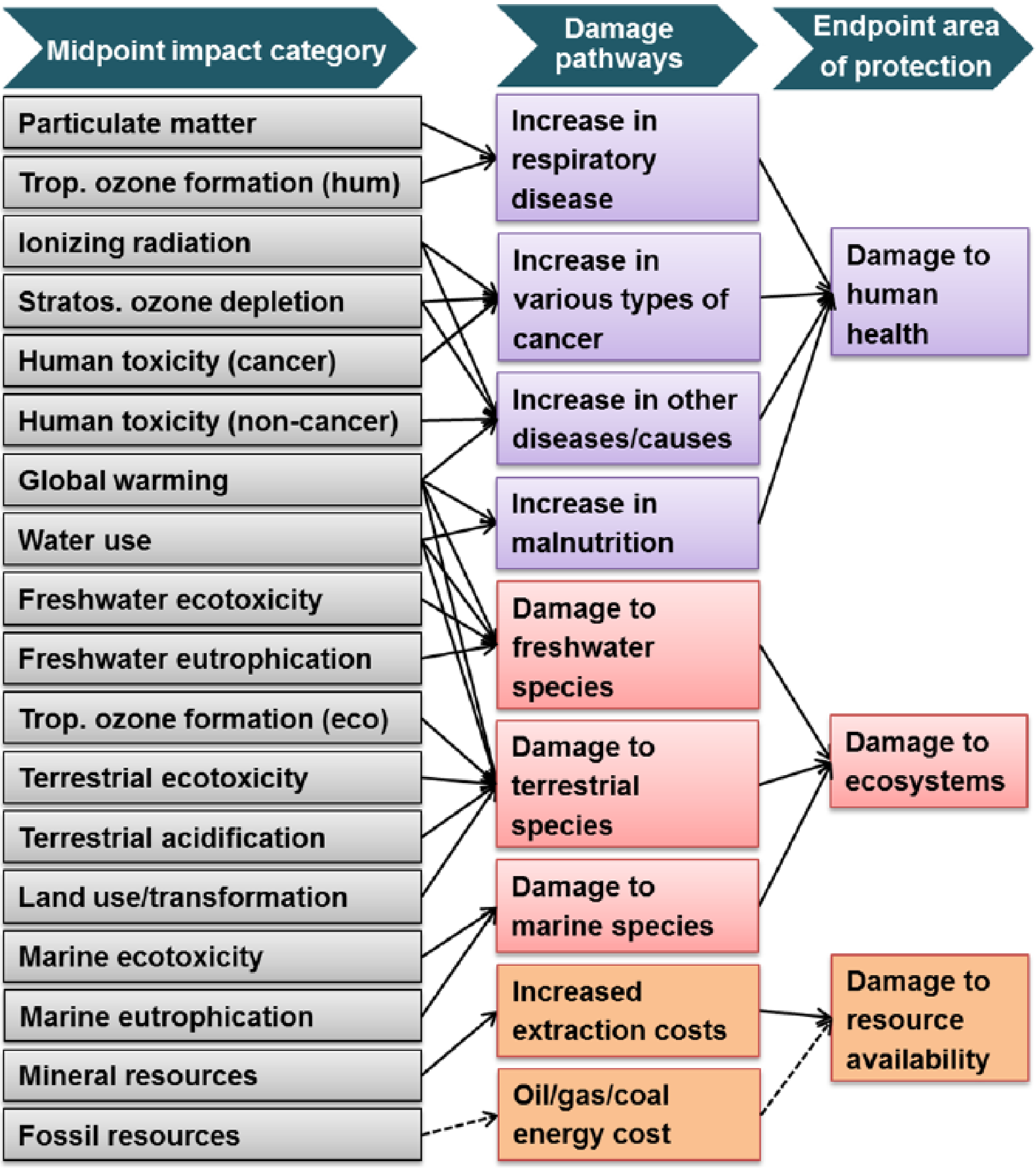


Figure 2-17: Overview of structure in ReCiPe 2016 [Hui-2017]

Finally, the method also incorporates the archetypical approach of the Culture Theory to group similar decisions and assumptions into three clusters: Individualist, hierarchist and egalitarian.

2.5 Life cycle costing

This subsection intends to provide an overview of a methodology for assessing the total costs associated with a product and its economic viability known as Life Cycle Costing (LCC).

The life cycle cost is defined as the total cost of ownership over the life cycle of an asset. Every product or service is always purchased at a certain price. However, the market value of an asset only represents a part of the cost of manufacturing, delivering/purchasing, owning/using, and disposing of a product throughout its lifetime. When performing LCC, every cost incurred during the asset’s lifetime must be considered, including:

- Manufacturing and all associated costs (raw materials, machinery depreciation, etc.)
- Delivery/Transportation costs (fuel, energy, etc.)
- Operating costs (expendables, water, maintenance, repairs, etc.)
- EoL costs (such as recycling, decommissioning, or other disposal approaches) as well as residual value (i.e. revenue obtained from reselling the product)

Furthermore, the considered costs are not limited to financial measures, but can also include any externalities placed upon the environment or society (such as greenhouse emissions), which are more difficult to quantify under numerical values.

According to the European Commission, LCC “is being applied by an increasing number of public authorities across the EU and in a range of sectors” and is regulated by a series of directives that aim to ensure the transparency and fairness of these methods [Eur-2020b]. As such, LCC plays an important role in GPP policies, forcing authorities to take into account not only the purchase price, but also other costs that are not reflected in this value, such as resource use (energy, water and fuel), maintenance/replacement costs and EoL processes as well as other externalities.

Additionally, because of the parallel characteristics between LCA and LCC, the two analyses can be carried out simultaneously, (provided that enough accurate/reliable data is available) offering combined insights about the economic-environmental cost-benefit comparison of the life cycles of different alternatives. In fact, several published papers already make use of this methodology to evaluate the economic viability of reusable plastic containers [Acc-2014; Mol-2005].

Although the analysis can be carried out in absolute terms, the most common approach in literature and previous studies seems to be a relative/differential one. By comparing relative costs between the systems under examination, only those costs that vary between them are taken into consideration. This not only helps simplify the analysis and reduce the amount of data to be gathered, but also offers deeper insights by revealing how the differences between the systems ultimately result in cost (dis)advantages.

In particular, the life cycle cost for both packaging alternatives under study can be subdivided into the following categories [Mol-2005; Acc-2014]:

- Container costs: Unit cost of purchasing a packaging unit from an OEM. The costs between both systems vary because of different manufacturing processes, the fixed costs of RTIs being spread over many delivery cycles, etc.
- Transportation costs: Usually defined as proportional to the required delivery distance, frequency of transportation as well as the number of packaging units that can be transported per vehicle. Again, transportation costs between both systems differ due to variances in the amount of km. to be covered in each system (due to different supplier locations, availability, EoL facilities, etc.). Moreover, empty RTIs need to be returned and additional costs for drop-offs might be incurred if multiple stop shipments are used.
- Labor costs: These costs are driven by the amount of time required by handling activities of the packaging alternatives and include the times needed to fill the containers with products, load them on the transportation vehicles, recover RTIs to return them to the owners and store them for their next use.
- Management costs: Although these costs are present in both systems, they are more relevant in the RTI-based system. Since RTIs are expensive to purchase, asset traceability is an essential component of RTI system designs. Their management requires dealing with large amounts of data to track them, anticipate the need to purchase new units, damage, and loss of assets, etc. Monitoring the flows and stocks of units entails the payment of fixed administrative costs.
- Disposal costs: These costs are usually modelled as being proportional to the volume/mass of material to be disposed.

In addition to the abovementioned costs, a potential revenue derived from recycling or any other sort of residual value is included in most models, offsetting the disposal costs. Similar to these costs, recycling revenue is also usually assumed to be proportional to the amount of material recycled or up/downcycled.

Different cost analysis approaches for comparing alternative packaging approaches can be found in literature for both specific and more generic applications [Kat-2017; Mol-2005]. Ideally, however, the models should be individually tailored to every application to ensure that every relevant cost is considered in the final calculation. For instance, the required maintenance procedures might vary considerably depending on the type of goods being transported by the containers, and the management operations depend heavily on the logistics network and RTI designs, i.e. the tracking technologies used in the system.

Additionally, a comprehensive LCC analysis should encompass the cost of every externality incurred by the systems under evaluation. This is especially important in this document's field of study, as avoiding environmental externalities is one of the main drivers of the transition towards a circular economy. Currently, no complete LCC analysis of returnable packaging that includes externalities is known to exist in literature or other sources.

Although a detailed LCC analysis falls out of the scope of this master's thesis, a comprehensive economic viability analysis of the systems under examination is one of the most beneficial paths of future research towards assessing the complete potential of reusable packaging alternatives in e-Commerce.

3 RTI SYSTEM DESIGN

Chapter 3 focuses on the main design parameters as well as the approaches that can be used in order to solve the operations management-related issues of an RTI CLSC. In doing so, the study takes a top-bottom approach by decomposing issues hierarchically according to the planning horizon they target. As such, the study delves sequentially into the strategic, tactical and operational design decisions that determine the whole design process of an RTI system. Examples of some already existing RTI closed loops are presented simultaneously to illustrate how circular systems are already being implemented as well as to try to explore any potential room for improvement.

The conception process of an RTI system consists of a myriad of individual design decisions that determine the system on the strategic, tactical, and operational level. In addition to these decisions, two other complementary subsystems have to be considered during the conception and implementation process of an RTI system:

- RTI support systems: Management of information and communications technology systems, especially tracing and information sharing across the system on an operational level, and governance of decision support systems.

- Stakeholder collaboration and contract management systems: Management of collaborations with every stakeholder as well as organization of subcontracts/outsourcing, procurement agreements, etc.

Although an extensive review of every how every design parameter can be optimized for an RTI system in e-Commerce requires a separate research work that falls out of the scope of this thesis, this study goes in depth into the most impactful/relevant aspects for such a system. An overview of the central design elements is provided in Figure 3-1:

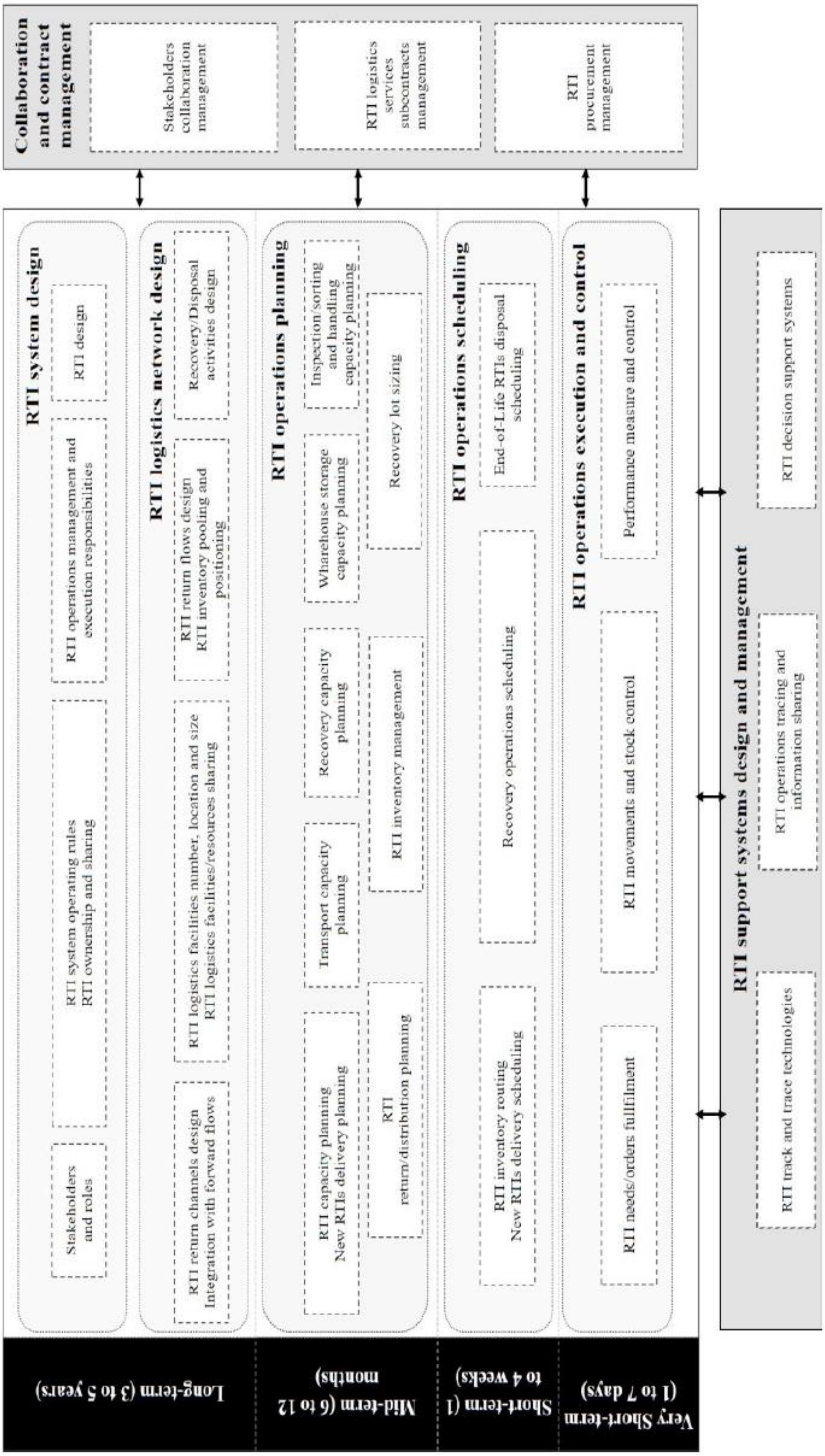


Figure 3-1: RTI system design framework [Lak-2019]

3.1 Strategic parameters

The planning horizon for strategic decisions tends to range from three years upwards. However, given the uncertainty surrounding the development of circular economy at this current stage, any planning attempt that exceeds a scope of five years is probably unrealistic in most scenarios. Decisions on the strategic level deal with network design, definition of responsibilities and ownership of assets, selection of recovery strategies, and capacity definition, among others.

3.1.1 Stakeholders and RTI system design

The first step to designing an RTI system consists of identifying the involved stakeholders as well as allocating the responsibilities and roles each of them is going to carry out with regard to the system management activities. In an RTI system for e-Commerce, the following stakeholders can be identified:

- RTI manufacturers: Original equipment manufacturers (OEMs) that supply RTIs to the system.
- Suppliers: Product sellers that make use of the RTI system to deliver goods to the customers.
- Customers: Consumers that purchase goods through an online marketplace.
- 3PL providers: Companies that handle the storage, management, cleaning, sorting, repair, disposal, and any other logistics operational activities necessary for the proper functioning of the system. Some 3PL providers might also handle the delivery service of packages.
- Transportation agencies: Carriers that deliver RTIs from storage site to the suppliers' manufacturing plants and/or deliver the packaged goods from the supplier to the customer. Additionally, they carry out the inverse process within the RSC.
- Online marketplace providers: e-Commerce site where consumer transactions are processed by the operator and then delivered/fulfilled by the participating companies. The online marketplaces can be operated by a specific supplier of goods (e.g. Adidas) or handled by a third party that aggregates many suppliers (e.g. Amazon).

It should be noted that in some cases, several of the previous stakeholder roles might be held by one single entity. For instance, some suppliers operate their own marketplaces, where they exclusively sell their own products. Some 3PL providers might offer transportation services where they handle the delivery and retrieval of empty packages between their own storage facilities and the clients. Additionally, some

RTI manufacturers have set up their own logistics systems handled by the company instead of outsourcing these responsibilities to third parties, although this is mostly the case within small loops with a limited range of available products.

Defining responsibilities and roles within an RTI system raises the question of RTI ownership and operating business model. Although the RTIs are manufactured by the OEMs, these can then be sold to a third party, such as a pooler that then manages the system, leased in exchange for a regular subscription or operated under a pay-per-use scheme. In general, three RTI system design archetypes can be distinguished [Kro-1995]:

Switch-pool systems: In a switch-pool system, every stakeholder owns a portion of the RTIs that circulate in the system. The participants are then responsible for cleaning, sorting, managing, storing, and maintaining their own share of RTIs. A switch-pool system can be designed as a sender-recipient or as a sender-carrier-recipient system. The difference between both alternatives resides in the management of return flows. In the former case, the sender is in charge of managing the reverse flows, while in the latter layout an ownership exchange takes place between participants when RTIs are swapped and the logistics are handled by the carrier, which owns their own share of RTIs.

While a switch-pool system might be appropriate for some stages within an e-Commerce supply chain, such as the deliveries between suppliers of goods and a storage facility where orders are aggregated, it is unreasonable to place the burden of owning RTIs on the final consumer. As explained previously, convenience is one of the main drivers of e-Commerce and it cannot be expected that customers will pay, own and manage and allotment of RTIs to use them for every delivery.

Systems with return logistics: In this system, the RTIs are owned by a pooling agency that can be the OEMs themselves or a separate company that has purchased them. The agency is responsible for managing the returns after the customer has emptied the packages. In order for such a system to be viable from an economic standpoint, there has to be a large enough amount of customers within a geographical region such that the transportation costs of empty RTIs pay off, or the customers have to store them until they receive their next purchase. In a system with return logistics, it is usually necessary to establish return incentives in form of penalties or rewards in order to encourage fast returns and prevent shrinkage of stock levels. Systems with return logistics can be subdivided into the following:

1. Transfer systems: The pooling agency is only responsible for the return of the containers, while senders take care of cleaning, maintenance, storage, and tracking of RTIs.
2. Depot systems: The pooling agency stores idle capacity in depots and takes care of cleaning and maintenance in addition to the functions it already carries out in the transfer systems. Two different designs for depot systems exist depending on how the allotment is controlled and the incentive systems that are put in place:
    a) Book systems: The control is carried out by creating an account with the central agency for every sender. When RTIs are delivered to the sender, the corresponding amount is debited in the account. When the sender sends RTIs to the customer, they notify it to the agency so that the amount is credited in the sender’s account and debited to the recipient. Through this process, the agency can track and manage the RTI flow.
    b) Deposit systems: These systems are based around the sender paying a deposit to the agency for every RTI in use. Theoretically, the deposit paid should cover, at least, the RTI’s manufacturing costs and allow to cover damages/thefts sustained. Analogously, the customer is debited by the sender for the same amount. When the RTIs are returned, the deposits are refunded to the respective debtor. Additionally, a delay clause can be placed to encourage fast return of the RTIs. If the time limit is not met, part of the deposit will be kept as fees.

Systems without return logistics: In systems without return logistics, the RTIs are also owned by a third-party agency. The suppliers can rent the packaging for individual uses and returns them to the agency when they do not need them anymore. In these systems, however, the supplier is responsible for managing the RTIs while renting them, including return logistics, cleaning, maintenance, sorting, and storage. The advantage to this system is that it offers the suppliers the possibility to reduce fixed costs by adjusting the amount of RTIs to seasonal demands. Similar to the systems with return logistics, incentive-based approaches can also be implemented in systems without return logistics to increment circulation rate.

Since most customers make online purchases through marketplaces, systems with return logistics appear to be the superior option in terms of logistics simplicity. Most marketplaces aggregate different suppliers/sellers into one platform, where customers can buy several items from different brands at the same type and receive their orders in a bundle. A centralized agency that can handle product and RTI returns independently of the supplier is therefore more convenient from a logistics point of view. Within the systems with return logistics, the most popular approach at the moment is the depot deposit system. For instance, Ökokiste, a German retailer of fruits and vegetables places a one-time 15€ fee that covers all subsequent deliveries while the RTIs are returned without damage. MemoBox, another German online retailer does not place a deposit, but will charge a packaging size-dependent amount if the RTIs are not returned within 14 days after the delivery. Finnish RTI manufacturer RePack uses a slightly different reward-based approach, where a reward is issued to the client upon arrival of the returned RTI. This reward is provided even if the RTI has been damaged and can be used in subsequent deliveries.

3.1.2 RTI logistics network design

RTI logistics network design revolves around characterizing the defining variables of flows and logistics facilities that determine the performance of the RTI system in the long term. Starting or halting production in a facility is both an expensive and a time-consuming decision, since resuming production requires fixed ramp-up periods where the equipment cannot achieve full productivity.

The first question to be tackled when designing an RSC consists of defining the global return logistics structure with special attention to the collection approaches as well as the return channels that are going to be used as well as their integration with the forward supply chain.

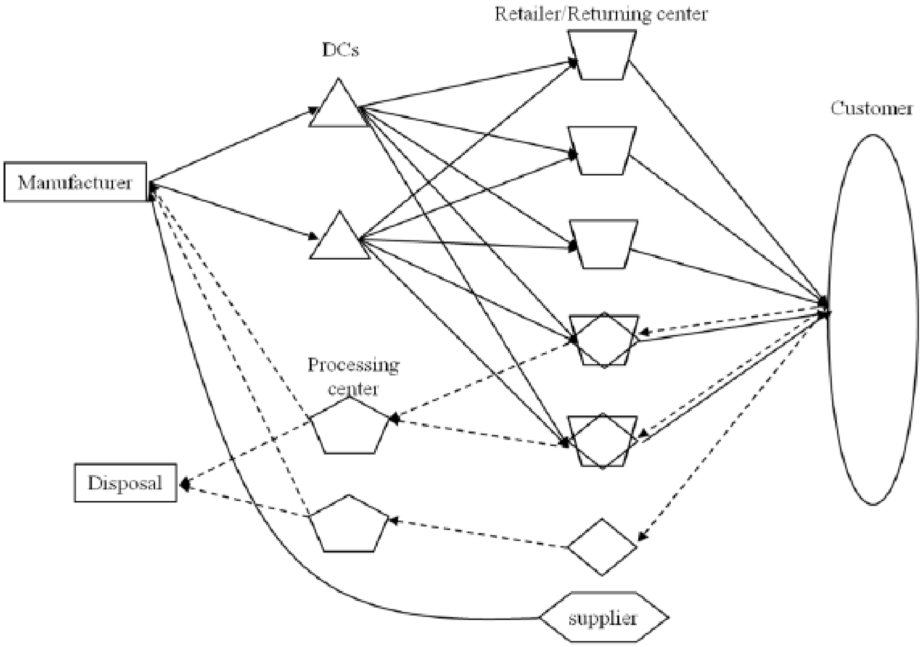


Figure 3-2: Integrated forward and reverse RTI logistics network model [Lee-2012]

Reverse logistics activities can be broken down into three phases: collection, sorting and testing, and processing. Different collection strategies exist depending on the volume of the reverse streams, the geographical density of customers and the size/weight of the RTIs, including:

- Traditional postal mail: Emptied RTIs are placed into traditional mailing boxes, where they are subsequently returned by the owner. RTIs will usually include a preprinted label when delivered so that they can be conveniently returned with little or no additional effort for the customer. This approach is especially advantageous for small-sized shippers or packages that can be collapsed to reduce their size when emptied.
- Collection point: Empty packages are dropped by the customers at centralized stations where they are aggregated and collected by the owners or a third-party carrier. Collection points are beneficial from an environmental point of view, since they reduce the amount of transportation required and contribute to reducing urban traffic/congestions. However, they are less convenient for the customer, are only viable in cities with high population densities, and require the availability of appropriate locations.
- Milk-run: The carrier periodically visits the customers to pick up any empty RTIs or returned goods. This approach requires that customer stores the emptied packages until the transportation company returns to pick them up. This variant requires little effort from the customer and is the most convenient alternative in subscription-based deliveries or regular purchases. In these cases, new deliveries and empty RTIs can be exchanged simultaneously with economic and environmental benefits.

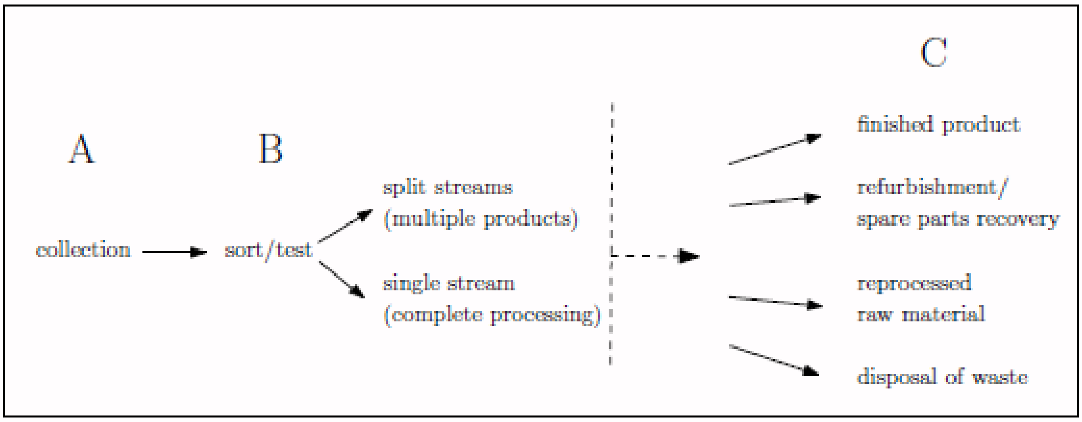


Figure 3-3: Phases of reverse logistics (strategic and tactical decision phases) [Bar-2008]

The return channels determine how the reverse flows are collected from the consumer and transported back to the manufacturers where they are subsequently sorted. Common return channels include:

- Direct return: the RTIs and possible returned goods are collected and brought straight to the original manufacturing facility, where they are subjected to maintenance/repairs or disposed.
- Indirect return: the RTIs and possible returned goods are recovered from the customers and brought to several collection centers where they are temporarily stored until enough volume has been gathered, sorted and separated into recovery and disposal streams. Collection centers can often be installed at the same location as distribution centers to achieve a higher integration between forward and reverse supply chains (see Fig. 3-2).
- Cross-docking: the recovered RTIs and possible returned goods are collected from the customers and then aggregated and sorted at a cross-docking station with little or no storage in between.

The final step consists of determining the optimal number, location and capacities of collection, recovery and disposal facilities, buffer sizes as well as the flows exchanged between the different echelons of the RSC. Ideally, forward and reverse logistics network design should be approached jointly to maximize synergies and integration. Since it is impossible to make location changes in the short term, an adequate logistics network design is therefore crucial in terms of system performance.

RTI logistics network design problems tend to be approached through mixed integer linear/non-linear programming models, where the objective function is set to minimize the fixed costs of facilities, transportation, and processing, usually with the additional secondary goal of maximizing the network's responsiveness, i.e. the RTI circulation rate.

3.1.3 RTI design

E-Commerce RTI design approaches are very diverse and depend mainly on the type of goods they must carry. While most packaging within e-Commerce must be designed to carry any type of product over long distances, some are specifically developed to carry fruits and vegetables, supermarket purchases, or office supplies. Over the last years, many start-ups have launched pilot projects aimed at implementing circular supply chains within different e-Commerce sectors. Most of these initiatives however are still in early development, proof of concept trials, first customer acquisition phases or operating within restricted geographical locations. Therefore, full-fledged CLSCs that over extensive geographical ranges have not yet been put in place which implies that most RTI prototypes have not been tested over extended cycles/distances.

Packaging design involves defining the RTI’s physical characteristics and technological features, such as:

- Shape
- Dimensions/capacity
- Materials
- IoT sensors
- Tracking technologies

Additionally, some RTIs have the ability to be collapsed after being emptied, which considerably reduces their space requirements, decreasing the transportation costs and increasing convenience in case customers need to store them temporarily. For instance, *the Box by LivingPackets* can be collapsed to reduce its volume from 25 liters to just 1 liter.

Another feature that some RTI prototypes are starting to incorporate are integrated holding mechanisms that make disposable components, such as filling materials and bubble wrap unnecessary, contributing to the environmental benefits of the RTI system. Specialized locking systems are also included in most prototypes, some of them even offering the possibility to record every failed opening attempt that the RTI has sustained. Finally, a minority of prototypes is experimenting with the option to feature electronic ink displays that would make paper labels obsolete, allow instant update of delivery addresses and increase return convenience.

These variables determine other processes, imposing constraints on transportation, cleaning and storage operations, the amount of cycles in a product’s life, recovery processes and end-of-life alternatives. Each of these processes needs to be considered and evaluated in conjunction with the characteristics and features during the design phase.

Once proofs of concept have been conducted successfully and first full-scale RTI system implementations are in progress, the industry should aim to standardize the designs as much as possible. The goal of standardization is to achieve a compromise between the amount of different RTI models/sizes, which result in higher operating costs and reduced synergies, while minimizing unused space by adapting dimensions to delivery requirements. Additionally, standardization enables the development of economies of scale on a global level and allows RTIs to be shared between different participants or cascaded across industries. While full standardization might be unrealistic, as it would mean manufacturers would have to give up on branding/customization opportunities, homogenizing dimensions into specific ranges or materials would simplify EoL management and reprocessing operations across industries, still allowing for some degree of differentiation.

Most e-Commerce deliveries will fall within a reduced range of size/weight requirements. Manufacturers currently offer an assortment of 1-3 sizes depending on the amount/dimensions/weight of the delivery. The majority of RTIs fall between a lower bound of 1-4 liters (Livingpackets and S-sized Repack) and an upper bound of 45-50 liters (memoBox and L-sized Repack).

Figure 3-4: Examples of RTI designs. Sources: Livingpackets, Repack, Loop, memoBox

As for the materials, most RTIs are mainly composed of polymer-based materials, although some might incorporate other components, such as steel, aluminum or class for specific features, such as temperature insulation or displays.

3.2 Tactical parameters

The planning horizon for tactical decisions usually ranges between six months to one year. Tactical decisions encompass every planning activity needed to successfully operate an RTI system. Concretely, the volume/capacity of every system stage needs to be determined such that the mid-term demand can be satisfied. This implies planning:

- RTI acquisition volumes and delivery dates
- Sorting, inspection, and cleaning capacities
- Recovery and refurbishment activities
- Storage surfaces
- Handling equipment
- Size of transportation fleet
- Stock levels

These plans are elaborated on the basis of RTI demand forecasts as well as delivery time estimates that take into account the facility locations defined on the strategic level. Tactical plans are then broken down at the operational level to adapt them to everyday activities and account for demand variations that cannot be predicted in advance.

3.2.1 Inventory management

Within an RTI system, inventory management activities can be divided into two interrelated subtasks:

- Forecasting of RTI returns
- Purchasing policies of new RTIs

It should be noted that the results of the forecasting procedures are used as inputs for the purchasing policies. Requests for the acquisition of new RTIs will be issued depending on whether enough RTIs will be returned compared to the expected demand and on whether the returns will arrive on time.

Forecasting of RTI returns: Returns forecasting aims to formulate a model to predict the quantity of reverse RTI flows and the timing of their arrival. The biggest hurdle to an accurate forecast of RTI returns revolves around the uncertainties of reverse logistics processes and its stakeholders. Some RTIs are returned immediately after they have been emptied, others are returned long after their arrival at the customers' properties, and others never return at all. Accurate information on return volumes facilitates scheduling of downstream shipments while minimizing stockout risks as well as purchases of new RTIs. The uncertainties surrounding RTI returns originate from different sources, such as:

- Customer behavior and their willingness to take adequate care of the packages as well as return them on time.
- Stochastic variables of the transportation process, idle time spent in collection centers, and non-predictable events like losses.
- Quality of returned RTIs due to damaged sustained within the RSC. Additionally, old RTIs or items that experience damage during their delivery or while being handled by the end-customer often have a smaller chance of being returned.
- Age of the RTI compared to its average lifespan.

One approach to determining the return distribution of RTIs consists of trying to correlate RTI returns to a set of parameters that have an influence on them. For instance, one of the first studies that aimed to forecast net RTI demand (demand of deliveries minus forecasted flow of returned empty RTIs) during a given lead time developed a discrete linear transfer function model based on the following characteristic life cycle parameters [Goh-1986]:

- Trippage, i.e. total number of trips made by an RTI in its life cycle.
- Average trip duration
- Average length of an RTI’s life cycle
- Container loss rate

The most common application of forecasting methods has traditionally been the development of models to obtain an estimate of future demands. Demand forecasting approaches aim to fit the underlying structure of past sales data to a model, project the development of past data to the future while accounting for any changes in the boundary conditions/environmental variables and then provide a forecast for the short and medium-term. Forecasting RTI returns has many similarities to forecasting future demand, hence the same approaches can be applied to both activities.

Univariate time-series forecasting methods, i.e. forecasts that model time series changes of a single variable over time, constitute one possible approach to forecasting RTI returns. Univariate time-series models offer a wide span of sophistication possibilities, ranging from deterministic moving average-based approach, such as the Holt-Winters model, to stochastic autoregressive approaches, such as the SARIMA (Seasonal Autoregressive Integrated Moving Average) models. Figure 3-3 represents the structure of these methods.

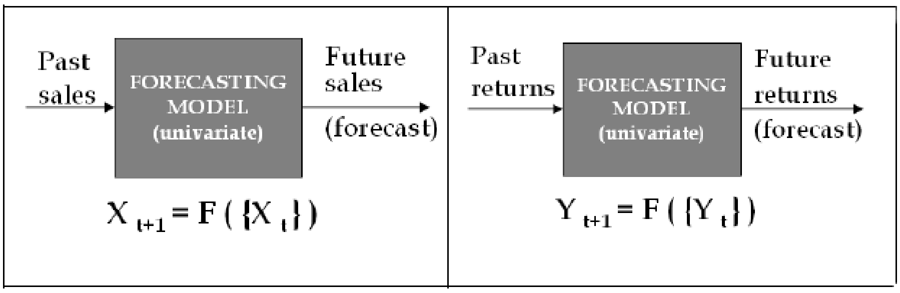


Figure 3-5: Traditional univariate sales forecasting approach and univariate RTI returns forecasting model [Car-2009]

Univariate approaches are the most appropriate models, when the only available information are past returns data series. A study on forecasting of reusable containers' returns suggests that these models might work best for organizations that manage linear reverse logistics systems, such as sectorial recycling networks. However, they fail to take into account one essential aspect of CLSCs, namely, the correlation between past sales and future returns according to a stochastic return delay, which will be infinite in the case that an issued RTI never returns [Car-2009]. As a result, most state-of-the-art returns forecasting approaches currently use dynamic regression models that predict future returns on the basis of past and current sales.

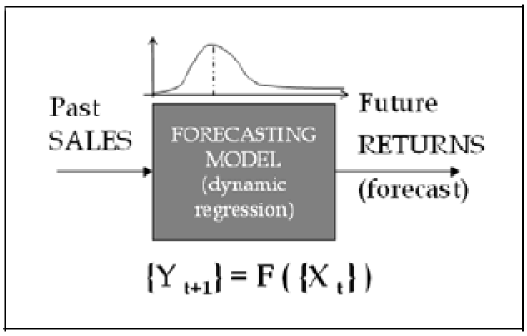


Figure 3-6: Returns forecasting based on past demand [Car-2009]

Purchasing policies of new RTIs: When the RTI system experiences a positive net demand, it becomes necessary to manufacture or purchase new RTIs to ensure that scheduled deliveries can be carried out and future demand is met. System imbalances can emerge due to an increase in demand or in the event that RTIs are damaged, lost during transportation or never returned by the customer. Decisions related to purchasing policies revolve around the following questions:

- How many RTIs should be ordered?
- When to order new RTIs?
- Where should the RTIs be received and stored?
- How much is the company willing to pay?

The process of determining how many RTIs should be purchased is usually tied to the optimization of a certain target function. One common approach to defining a purchasing policy consists of aiming to minimize the sum of purchasing cost and expected inventory holding costs over finite time periods, while ensuring a predetermined high level of customer demand satisfaction [Kel-1989]. Most policies are designed to cope with some degree of randomness in the distribution of returns and customer demand.

Some approaches can simultaneously tackle two of the abovementioned questions to determine both the optimal purchasing policy and an inventory management strategy. For instance, one of the first research papers in the field develops an inventory management model based on a periodic review inventory approach, where the objective is to minimize the total expected cost within a finite period. The model assumes that the return rate is a random constant of two state-variables, the inventory of RTIs and the number of units in the field, and independent of the RTI’s age, i.e. the time since the container was issued [Buc-1998].

While the previously introduced article designs a model based on a periodic review inventory approach, other methodologies can be applied, such as continuous review approaches. In general, RTI inventory is managed analogously to any other stock. As such, is becomes necessary to define/calculate the typical characteristic variables of inventory management, including:

- Reorder point
- Safety stock
- Stock level target
- Lead time
- Maximum stock level
- Service level

RTIs can be received at a central storage point and then distributed to the individual distribution centers or directly delivered to each distribution point. The decision usually depends on a tradeoff of savings due to economies of scale at the storage point and the additional transportation costs incurred to then deliver the RTIs from the central storage to the distribution centers.

3.3 Operational parameters

Operational decisions are generally defined to have a planning horizon under one month. Most of them, however, are executed on a weekly or daily basis. Operational plans are derived from tactical decisions, by breaking down medium-term goals into actionable activities that are carried out in the long term, measuring their impact and readjusting. RTI system operations management activities are mainly concerned with the scheduling of operations as well as their execution and subsequent monitoring. As a result, operational decisions are centered around defining and managing the following activities:

- Delivery routing and scheduling to maximize operational profit, taking into account capacity and stock constraints. Also, scheduling the reception of incoming RTIs, both newly purchased and recovered through the reverse logistics network.
- Scheduling of recovery and EoL operations.
- Order fulfillment and management of the surrounding logistics. In order to support these activities, auxiliary systems and technologies are installed throughout the supply chain. These systems aim to increase visibility and predictability along the CLSC by gathering operational data. A prominent example is track and trace technologies that give discrete/continuous real-time information about the RTI's status.
- RTI system performance measurement. The performance of an RTI logistics system is usually measured against a double/triple bottom line that is broadly constructed to not only measure operational/economic optimality, but also environmental and social benefits/efficiency.

The following subsections give an overview about the importance of stock control in operational management activities and the different alternatives to implement these systems, as well as methodologies to evaluate the performance of an RTI system.

3.3.1 RTI tracking and stock control

As explained in the previous sections, reusable packaging approaches offer many benefits, including reduced operational costs by spreading them across many cycles, decreased environmental impacts and many, increasing consumer loyalty or growing the brand's value. However, without an appropriate asset management system, RTIs can quickly turn into an expensive variant of single-use packaging.

Despite their relatively high manufacturing costs, RTIs are prone to loss and damage, resulting in excessive shrinkage rates of RTI fleets. According to several surveys, many pooling agents report that 15-20% of RTIs in circulation are disappear every year due to customers/third parties misplacing them or removing them for own use [Bre-2006]. Aside from losses, it is estimated that on average 9% of the RTIs suffer breakage on an annual basis and thus need to undergo repairments [GS1-2007].

As mentioned in previous sections, many studies point to a lack of RTI visibility as the major source of ineffective asset management [Joh-2007; Twe-2003]. The uncertainty about their location and status induces supply chain participants to take worse care of them and feel less responsible of them. Apart from container loss/attrition, lack of visibility/RTI tracking capabilities throughout the system can result in a wide range of other management-related issues, including [Mal-2011a]:

- Lack of supplier liability: The absence of abilities to track RTI creates liability loopholes for making any SC participant liable for the damage or loss of containers. As a result, the owner is unable to know at which point the containers got lost/damaged and must incur the economic expense of replacing them by purchasing/manufacturing new assets.
- Deficient communication between SC participants: Since most SC players have incomplete information about the timing and quantity of RTI flows in the system, coordinating shipments, purchases and other movements becomes very hard. Giving visibility to participants by providing point-of-sale (POS) data or implementing centralized management points through vendor managed inventory (VMI) or collaborative planning, forecasting and replenishment (CPFR) approaches can help solve these problems.
- Inadequate containers in the system: In systems where more than one RTI design type is present, several kinds can inadvertently be switched together by the carriers/3PL providers such that the poolers receive the wrong RTIs. Wrongly returned RTIs are rarely ever seen again, resulting in more costs.
- Difficulties locating/identifying RTIs.
- Imprecise RTI count: Since RTIs are continuously lost/damaged and replaced by new ones, most poolers do not have an accurate count of the total number of containers they own if they do not implement a tracking system.

In many cases, supplier liability is implemented through the inclusion of liability contracts between the RTI owner and each of the SC participants. However, these clauses need ways to prove which RTI was damaged and who is to be held responsible in order to be enforced. As a result, it becomes essential to equip RTIs with a system that allows for individual identification and tracking.

There exist several different AutoID technologies that can be used to manage RTIs. No one-size-fits-all approach can be found when deciding which technologies to implement in an RTI tracking system. Each alternative provides different advantages from a technological/economic standpoint. As a result, each implementation case must be analyzed individually in order to determine the optimal alternative for that scenario. The following paragraphs provide a brief overview of the available technologies as well as their unique advantages and characteristics.

Barcode/QR code: Barcodes/QR codes are the most mature and widely established tracking technologies worldwide. Consequently, most companies in the e-Commerce sector already have the required infrastructure/equipment to implement an RTI tracking system to increase asset visibility. Transitioning into a code-based tracking system usually has a relatively small impact for most companies in terms of economic costs and employee effort. Code-based tags can store most information needed to successfully track/locate RTIs, such as asset ID numbers, locations, owner, purchasing information, maintenance data and other user-defined data.

Code tags are the most economical alternative among AutoID technologies. Additionally, the required scanners are also affordable and work wirelessly, enabling flexible and convenient scanning procedures for SC participants. Most readers offer visual/audio-based cues that indicate whether a code has been scanned correctly. Accordingly, code-based systems tend to have accurate identification rates and low ratios of misread assets [Mal-2011b].

Among the most commonly cited disadvantages of code-based tracking systems are the need the scan every code individually and usually manually. As such, the process can quickly become repetitive and tedious for employees, causing the misread rate to increase over time. Another disadvantage is that the codes need to be visible to the scanner in order to be read. If the RTIs are facing the wrong way, they will need to be individually handled before scanning. These technologies are also very susceptible to damage, dirt or attrition that might cause them to become unreadable. Finally, codes do not offer real-time locating/tracking capabilities and the SC participants need to wait until the assets arrive to a new destination to receive updates on their status.

All in all, code-based tracking technologies constitute a cost-effective approach that is commonly implemented in lower-value assets, where more expensive alternatives might exceed the value of the underlying asset itself. Some RTI prototypes have circumvented the issues of traditional code tags by implementing electronic ink displays that get updated with new information when required.

Figure 3-7: e-Commerce RTI prototypes with barcode sticker (left) and electronic ink barcode (right). Source: RePack, Livingpackets

Passive RFID tags: Passive RFID tags have progressively attracted attention over the past decades as the next state-of-the-art AutoID technology. Using code-based tags might not be viable in some applications due to the manual nature of their scanning procedures, especially when RTIs are stacked on top of each other in large piles.

Passive RFID systems usually comprise the tag itself, a reader and a computer. The defining characteristic of these technologies is that they do not require an internal power source to emit signals. Instead, they receive power from the reader through an antenna incorporated in the tag and then use the obtained energy to generate a response containing the stored information. Although more expensive than barcodes, passive RFID tags are relatively inexpensive with costs typically amounting to .2€/tag. According to recent publications, the impact of RFID from a financial perspective can amount to cost savings of roughly 22% for each round-trip and 5-6% in investment costs [Ili-2009].

In contrast to code-based technologies, RFID tags offer:

- Automatic identification of tags without needing a direct line of sight, thus reducing manual effort, required time and costs.
- Possibility of reading large quantities of tags simultaneously, considerably increasing speed in comparison to code-based approaches.
- Automatic data acquisition eliminates errors caused by manual data entry. Movement data can be recorded with more detail, allowing improved visibility and a higher-quality dataset for inventory management purposes.

Many scientific papers have analyzed the benefits of implementing an RFID-based RTI tracking system, arriving at the conclusion that these approaches tend to increase container return rates and reduce the procurement frequency of new batches [Tho-2009].

Most limitations of passive RFID technology revolve around its lack of own power supply. Passive RFID tags require strong signals to function, resulting in the necessity for more scanners to be placed and reducing their read range. Additionally, the maximum speed at which the scanners can detect a tag is reduced when many RTIs must be detected simultaneously.

Another issue relates to the lack of global standardization, particularly in terms of frequency choice. Ultra-high frequency might be the most appropriate choice for supply chain applications, since it provides the highest range in terms of readability. However, especially in Europe, the use of ultra-high frequency devices is heavily restricted by legislation, limiting the range of RFID scanning capabilities [Sta-2004].

Lastly, although integrating RFID technology inside fully operational facilities tends to have limited impact on a layout/routing level, transitioning from a non-RFID to an RFID-based system can be cost-intensive and time consuming until the existing RTI fleet is completely equipped with tags.

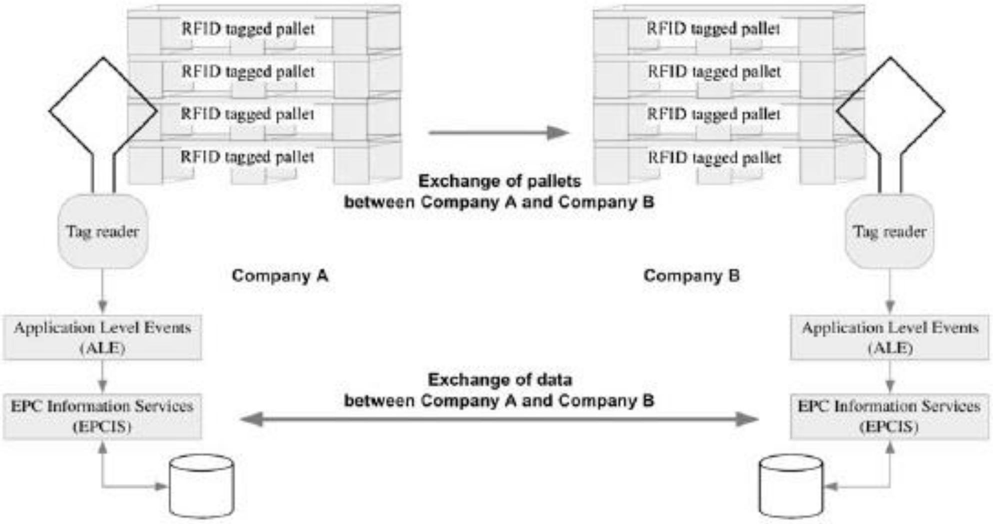


Figure 3-8: RFID-based RTI tracking system: Components and processes [Ili-2009]

Active RFID tags: Active RFID technology operates under a similar principle to passive RFID technology with the exception that active tags incorporate an embedded power source that allows them to send stronger signals, effectively increasing their read range and the amount of tags that can be detected simultaneously. Active RFID technology allows real-time identification, location, and tracking of RTIs within a range of around 100 meters of the readers. In exchange, these tags are considerably more expensive than their passive counterparts.

Since RTIs in e-Commerce need to be tracked throughout the whole supply chain, the range of real-time location capabilities offered by active RFID technology are insufficient in most cases, such that the increased investment costs are not worth it in most cases. Therefore, active RFID technology is currently only used in some niche RTI applications.

Wi-Fi real-time locating system (RTLS): Wi-Fi RTLS consist of a “combination of active tags, access points and location applications that together provide a periodically updated estimate of the location of the client devices within a known environment” [Mal-2011a]. These tags can be read continuously as long as their battery is active and a Wi-Fi signal is available, making their effective range considerably larger than that of active RFID tags. Additionally, up to thousands of tags can be tracked simultaneously.

However, the costs of Wi-Fi RTLS tags are usually similar or higher than those of active RFID technology (up to 50€/tag), especially when large amounts of assets need to be tracked simultaneously, as is the case for e-Commerce RTIs. This makes the tags hardly justifiable from an economic standpoint except for high-end and expensive RTIs whose life can be extended almost indefinitely with adequate maintenance procedures.

Global Positioning System (GPS): GPS is one of the most widely extended RTLS technologies. In comparison with the aforementioned RTLS approaches, GPS sensors are cheaper and do not require any kind of special readers to operate, just some kind of communication system to exchange real-time data between the RTIs and the monitoring stations. GPS systems have high positioning accuracy outdoors and can be used to track items in bulk, which makes them very appropriate for e-Commerce supply chains.

The main downside of these systems is that they cannot operate indoors since an unobstructed line of sight to four or more satellites is required for the system to function appropriately. While GPS technology cannot be used indoors, it is very convenient to track RTI deliveries in the forward/reverse supply chain as it enables SC participants to determine whether a package got lost and where it happened as well as gives more visibility to estimate the remaining time until arrival at destination.

3.3.2 Performance measurement of RTI systems

Once an RTI system has been designed, set up and is fully integrated with the existing CLSC, appropriate management measures and KPIs need to be implemented in order to ensure adequate steady-state operations and achieve the objectives established during the strategic design phase.

A set of quantifiable performance indicators is essential to help determine how effective the system's operations are and how well the available resources are being managed. Generally, KPIs seek to capture the status and progress towards underlying management objectives while remaining simple enough to be intuitively understood by top management, even if they are not familiar with day-to-day operations.

While KPIs are usually tailored to the specific objectives and characteristics of the considered system, some indicators have been commonly established management standards in many supply chains and/or within their individual echelons. Among the most frequent ones are the required initial investments and return on investment (ROI) as economic measures and inventory turnover, product/order fill rate, ready rate (availability of stock) and cycle service level (expected probability of not hitting a stock-out during the next replenishment cycle).

For the RTI sector in particular, many research studies have suggested different sets of KPIs depending on the overall target function that wants to be optimized. For instance, [Goh-1986] developed a set of four indicators with the objective of minimizing the management/purchasing costs derived from lost containers by trying to predict the fraction of delivered RTIs that would be able to be used in the next cycle. The suggested indicators consist of:

- Trippage
- Average trip duration
- Container life
- Container loss rate

A recent study suggests another set of four interrelated measures which are especially tailored to RTI management, under the assumption that they have long shelf lives and negligible loss rates [Che-2002]:

- Inventory turnover: Indicates how quickly product units are taken out of the shelves.
- Out-duration: Represents the duration of the periods where the RTI is not available at a storage location. These periods include transportation, time spent by the end-customer, as well as inspections, cleaning and maintenance. The smaller this value, the leaner the system, such that the assets can be made available faster for further deliveries.
- Average utilization rate: Helps determine whether RTIs are utilized in an effective manner by indicating the average proportion of the fleet that is being used at a point in time.

- Standard deviation of the utilization rate: Is correlated with the amount of safety stock required to handle fluctuations in the daily RTI demand in order to guarantee a certain service level.

In addition to traditional operational and economic indicators, most companies nowadays are also interested in measuring the environmental performance of their supply chains/systems. As a result, specific indicators have been included into many performance reports to evaluate performance from a sustainability and environmental standpoint.

The most intuitive and widely used environmental indicator used across systems and industries is the conventional recycling rate index, defined as the recycling streams within the system divided by the sum of recycling and waste streams.

$$r = \frac{R}{R+W}$$

However, studies have shown that, although extensively by the EPA and the European Commission to impose environmental performance targets, this indicator alone is not enough to reflect the environmental performance of an RTI CLSC, since reusing assets should be always prioritized over recycling in these systems and the recycling index fails to capture these activities [Tsi-2005]. The reuse Instead, the author suggests extending this index into a combined reuse/recycle rate index, where RU represents the annually reused packaging streams:

$$\rho = \frac{R + RU}{R + RU + W}$$

By maximizing this index, three sub-criteria can be optimized, namely, minimizing the amount of waste streams that need management, limiting virgin material extraction and natural resource depletion, and minimizing environmental impacts derived from manufacturing new products. Additionally, the effect of intuitive RTI life cycle parameters on the combined index can be easily modeled through equations/balances to support decisions and management. These parameters include the annual reuse frequency, lifetime, maximum number of reuse trips, number of years in reuse as well as consumer behavior (fraction of returned RTIs).

Finally, it should be mentioned that these KPIs are intended to provide fast and intuitive measures of a system's environmental performance. The most effective way to obtain a comprehensive ecological assessment of an RTI system consists of carrying out an LCA, albeit requiring more intensive calculations and time.

4 SIMULATION MODELS

Chapter 4 is centered around modelling and analyzing several e-Commerce delivery chain alternatives with respect to their environmental impacts. The aim of this section is to establish a comparison between traditional open-loop delivery chains that use disposable single-use packaging and closed-loop supply chains that make use of RTIs to deliver the goods to the customer and then reclaim the packaging to use it in subsequent deliveries. Two different CLSCs are modelled based on the currently most common RTI design and logistics network design approaches and examined with respect to the operational requisites needed to outperform single-use packaging systems.

4.1 Supply chain characterization

The system under study aims to represent a generic e-Commerce supply chain, which presently relies predominantly on single-use packaging and has not experienced a meaningful penetration of reusable packaging alternatives, contrary to other sectors, such as groceries. Modelling a generic e-Commerce supply chain can prove to be quite difficult, since their characteristic parameters (e.g. transportation distances, flow quantities, logistics network design decisions) tend to vary considerably from one supply chain to another. As a result, assigning values to these variables is not a trivial decision, since network design does influence the overall impacts of the system. The final values that are used in the analysis have been derived from literature, case studies and a series of hypotheses that will be explained in the following paragraphs.

The e-Commerce supply chain is characterized by low sales volumes per customer in relationship to the value of the whole supply chain, as well as a large number of product manufacturers. The touch points between customer base and producers are manifold and can be owned by either the producers themselves or managed by a third party that is responsible for aggregating deliveries from different producers and bundling them by destination, as well as packing, storage and distribution activities along the SC. As a result, the e-Commerce sector emerges as a complex multi-agent supply system, with a myriad of coexisting marketplaces and SCs and where the profile of customer demand often requires less than unit pics/loads in the deliveries.

Supply chain configuration: The two supply chains under evaluation are illustrated in Figure 4-1. System A depicts a traditional linear supply chain, where single-use packaging is produced and sent to both product manufacturers and distribution centers (DCs), depending on the SC configuration and management. The DC then receives products to be delivered from the different suppliers and is responsible for the storage, picking, loading, bundling/aggregation and shipping processes of deliveries by customers/destinations. Carriers handle transportation activities along the network. The CLSC alternative illustrated by system B makes use of RTIs to deliver products and requires the inclusion of a new SC participant, the pooler, which owns the RTIs. Additionally, the pooler is responsible for managing, washing, storing, and maintaining the system's RTI fleet. As such, the pooler supplies the required amount of empty RTIs to manufacturers and DCs in order to match the forward supply chain demand and also receives returned RTIs to perform EoL/maintenance operations to then store them until their next loop. Although, in some CLSCs, the product manufacturers might own and manage a proprietary RTI fleet, the pooler is considered to be a separate entity from product manufacturers and DC/logistics providers in this study.

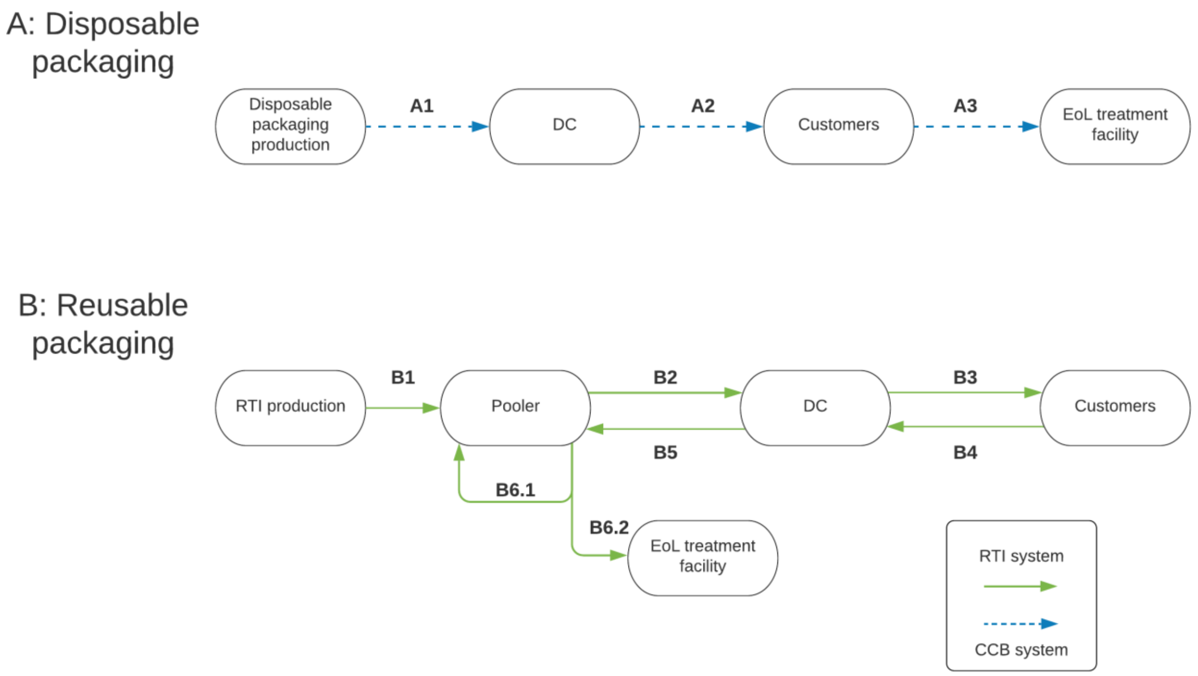


Figure 4-1: Disposable and reusable packaging supply chain networks for e-Commerce distribution

The values of the networks' characteristic parameters in terms of transportation routes, distances and means of transport are summarized in Table 1.

Table 4-1: Disposable and reusable SC network routes

Route	Description	Distance (km.)	Package condition	Truck type
A1	Supply of disposable packaging from manufacturer to DC	100	Empty	Heavy
A2	Transport of products on one-way packages to customers	115	Filled	Light
A3	Transport of disposable packaging to EoL treatment facility	200	Empty	Light
B1	Supply of new RTIs from manufacturer (once per life cycle)	500	Empty	Heavy
B2	Transport of empty RTIs from pooler to DC	100	Empty	Heavy
B3	Transport of products on RTIs to customers	110	Filled	Light
B4	Retrieval of empty RTIs through DC	110	Empty	Light
B5	Transport of recovered RTIs to pooler for management	100	Empty	Heavy
B6.1	Washing and maintenance of reusable RTIs	0	Empty	-
B6.2	Transport of RTIs to EoL treatment facility	250	Empty	Light

The values for the average transportation distances have been derived from several literature studies [Kos-2014; Acc-2014]. Additionally, the estimation for the average distance between distribution center and customer has been refined by locating the closest DCs to the city of Munich of some of the biggest e-Commerce distribution agents and carriers and adding the average distance covered to deliver the amount of packages contained in a light delivery truck.

Packaging and transportation specification: The most common packaging alternatives for e-Commerce deliveries are corrugated cardboard boxes (CCBs) due to their simple manufacturing process, wide range of available sizes and cheap production costs. Additionally, recycling facilities for CCBs tend to be quite common, as the recycling process and technologies are already mature. The suggested CLSC approaches use RTIs made of PP to guarantee close to complete recyclability in their EoL treatments, simulating the potential of fully circular systems.

Within the reusable packaging approach, two different alternatives have been considered. These packaging variants differ in their design, and hence in their manufacturing process, as well as in the logistics system design under which they usually operate.

The first alternative consists of a reusable plastic container manufactured through injection molding of PP. Since this RTI is rigid and usually bulkier, the reverse logistics process is usually carried out by individually recovering the RTIs from the customers' homes. Conversely, the product's rigidity confers it the ability to better withstand impacts and wear/tear, allowing it to successfully complete more loops during its life cycle. The second RTI considered in this study is a foldable mailer manufactured out of woven PP, similar to reusable grocery bags. After having extracted the delivered goods, these RTIs can be usually folded in order to take up less space and returned to the pooler via postal correspondence or a designated 3PL provider. Foldable mailers have the advantage of weighing less, requiring less raw materials to be manufactured and less trips to transport them between manufacturers, pooler and DCs. On the flip side, they might be more susceptible to wear/tear as well as loss, since customers might not take them back to a mailbox, which could reduce their lifespan. The three delivery packaging options considered in this study are illustrated in Figure 4-2 and a summary of their characteristics can be found in Table 4.2.

Figure 4-2: Analized packaging alternatives: a) Corrugated cardboard box (left), b) Reusable plastic container (middle), c) Reusable mailer (right). Sources: Prattplus.com, Ikea.com, Navygrey.co

Table 4-2: Packaging characteristics

	Corrugated cardboard box	*Reusable plastic container*	*Reusable mailer*
Weight (kg.)	0.35	1.7	0.116
Dimensions (mm.)	400 x 300 x 220	400 x 300 x 220	400 x 300 x 220
Packaging per pallet (filled)	72	72	72
Packaging per pallet (folded)	-	-	432

Although corrugated cardboard boxes have an obvious advantage over reusable packaging in terms of the range of available sizes, which enables them to better adapt to different deliveries and minimize filler material, the packaging dimensions/capacities have been standardized in order to ensure intercomparability of the three alternatives. Additionally, the analysis makes a distinction between folded and filled reusable mailers due to the difference in volume taken up by the two packaging states, enabling more mailers to be transported per pallet when folded.

As illustrated in Table 4.1, two types of vehicles have been taken into account: The light lorry has a maximum payload capacity of 3.3t and 15 pallets and is mainly used for urban deliveries, back and forth between DCs, customers and EoL treatment facilities. On the other hand, the heavy articulated lorry has a maximum payload capacity of 27t and 30 pallets and is used to transport packaging between manufacturers, poolers and DCs. Heavy lorries have both lower impacts and economic costs per delivery unit and are the preferable alternative when their lower maneuverability and speed allows their use.

4.2 Assessment of environmental impact

As the debate around packaging and its environmental impacts across many industrial sectors and supply chains has been gaining attention over recent years, many comparison studies of packaging systems have been carried out to assess the potential of reusable packaging approaches. Typically, most studies have focused on one specific sector, such as fresh fruits and vegetables [Sin-2006], food catering [Acc-2014], or the automotive parts sector [Kat-2017]. While in most cases reusable alternatives have proven to be the superior choice in terms on environmental impacts, this is not necessarily true in every case and recyclable single-use packaging might be the environmentally preferable alternative under certain circumstances [Kos-2014]. Thus, the system under evaluation should be individually modelled and analyzed in order to extract meaningful conclusions with regards to the environmental performance of the system.

The following analysis has been carried out following the LCA methodology introduced in Section 2.3 which is internationally standardized by the ISO 14040 series. LCA is a method that seeks to provide a holistic approach to evaluate the environmental performance of a product. A full LCA follows all processes and flows in the system from cradle to grave, considering all potential impacts derived from every stage of its life cycle. As prescribed by the ISO 14040 series, the assessment has been subdivided into the following four phases, which are subsequently introduced in the following subsections:

- Goal and scope definition
- Life cycle inventory and analysis
- Life cycle impact assessment
- Life cycle interpretation

4.2.1 Goal and scope definition

Objective: This study aimed to:

- Identify the environmental impacts generated by single-use packaging throughout a generic e-Commerce delivery chain as well as its individual processes (i.e. manufacturing, transport and EoL treatments).
- Model and assess the environmental impacts that would be derived from implementing a circular packaging model for two different RTI approaches.
- Compare both systems under different parameter combinations to determine which conditions optimize their environmental performance.
- Identify the critical system parameters that have the biggest impact on the overall performance to provide insight into which design decisions and strategies should be followed to maximize sustainability.

Functional unit: The functional unit of an LCA serves as the benchmark for the system's performance. Each measurement and evaluation must be carried out relatively to this parameter. In this study, the functional unit has been defined as delivering one fully loaded light truck worth of goods to the end-customers. As a result, the functional flow consists of the amount of packages (single-use or RTIs) necessary for the deliveries.

System boundaries: In LCA methodology, the system's boundaries determine the set of processes belonging to the product's life cycle that will be taken into account in the study. In this assessment, the phases illustrated in Figure 4-1 have been taken into consideration. Concretely, the following phases have been included in the linear system that operates with single use corrugated cardboard boxes:

- Industrial production of corrugated base papers from primary (Kraftliner paper and semichemical fluting) and recycled (Testliner paper and Wellenstoff) fibers.
- Industrial production of corrugated board sheets and boxes.
- Transport of boxes between the different supply chain echelons: From manufacturers, to DCs, end-customers and EoL treatment facilities.
- EoL treatment: Recycling of corrugated cardboard in a paper mill. The disposed boxes are used to produce Testliner paper and thus avoid the generated impacts of manufacturing paper from virgin materials.

Similarly, the phases considered for the circular system using both reusable plastic containers and reusable mailers are as follows:

- Industrial production of virgin polypropylene granulate (from raw materials extraction).
- Manufacturing of reusable plastic containers through injection molding or manufacturing of reusable mailers from woven propylene through wire drawing, fabric weaving and bag sewing.
- Transport of the RTIs between manufacturers, poolers (sorting and washing facilities), to DCs, end-customers and EoL treatment facilities in both the forward and reverse supply chains.
- Sorting and washing processes of the RTIs.
- EoL treatment: Sorting and recycling of disposed RTIs in a recycling plant, where PP can be recovered in form of pellets.

Processes that do not differ significantly between the two systems under evaluation, where not sufficient data is available or where the generated impact is negligible in comparison with the rest of the system. In particular, the neglected processes include:

- Manufacturing of the products delivered in the e-Commerce SC. In this analysis, the transported products have been modelled as generic 1 kg. goods for transportation purposes, where the weight of the packages plays a role on the environmental impacts.
- Transport of products from manufacturers to the DCs.
- Product packing.
- Handling activities (e.g. truck loading/unloading, pallet consolidation, storage and picking activities).

Environmental impacts studied: The selection of an LCIA method is one of the most impactful decisions in an LCA. Not only does it determine the results in terms of magnitudes and impact categories, but also allows their comparison with other papers, studies and benchmarks that have used the same LCIA method. As already explained in Section 2.3.3, LCA practitioners and researchers do neither agree on a single optimal assessment method (single vs. multi-impact), nor on whether to use midpoint or endpoint indicators.

This study uses ReCiPe 2016 as its LCIA of choice, since its current popularity and widespread use among LCA practitioners will increase the comparability of this assessment with other studies carried out in the field. This work focuses on midpoint indicators due to their lower statistical uncertainty and because they are easier to measure and evaluate than their more abstract endpoint counterparts. Additionally, midpoint indicators provide more insight into the root causes of environmental damages and help elucidate the tradeoffs of strategic decisions aimed at tackling different impact categories. Finally, the Hierarchist (H) perspective has been selected as the Cultural Theory perspective of choice as a midpoint between the short-term Individualist (I) and the very long-term Egalitarian (E) perspectives. The Hierarchist perspective considers likely effects based on scientific consensus and is thus the most pragmatic approach from an engineering standpoint.

Table 4.3 gives an overview about the most relevant impact categories considered in this study:

Table 4-3: Impact categories considered in the analyzed systems

Impact category	Units
Fine particulate matter formation	kg. PM2.5 eq.
Fossil resource scarcity	kg. oil eq.
Freshwater ecotoxicity	kg. 1.4-DCB
Global warming	kg. CO2 eq.
Human carcinogenic toxicity	kg. 1.4-DCB
Human non-carcinogenic toxicity	kg. 1.4-DCB
Marine ecotoxicity	kg. 1.4-DCB
Ozone formation, Human health	kg. NOx eq.
Ozone formation, Terrestrial ecosystems	kg. NOx eq.
Terrestrial acidification	kg. SO2 eq.
Terrestrial ecotoxicity	kg. 1.4-DCB

In this study, most relevant impact categories for these systems have been analyzed. These categories aim to provide a holistic overview of damages to the three main areas of environmental protection: Environment, human health, and resource scarcity. Among these categories, some environmental impacts might be more relevant than others due to the magnitude of the impacts or the socio-environmental circumstances of the world. For instance, the issue of Global Warming has increasingly attracted attention over the last decades, resulting in the elaboration of global agreements, such as the Paris Agreement, with the aim of reducing greenhouse-gas emissions and mitigating global warming, restraining the rise in global temperature to less than 2ºC above pre-industrial levels. As a result, the analysis will put special focus on the results of this impact category.

Data sources and quality: This study draws data from a variety of sources, such as previous literature studies (i.e. recycling rates, transport distances), existing products/prototypes (packaging weights and dimensions) and specialized reports from manufacturers and industrial associations (i.e. production processes, recycling operations, energy consumption, washing process). Some parameters, such as transport distances, have then been further refined through average distances of distribution centers to cities and determination of optimal distribution routes. In the case of unavailable/unreliable data (i.e. average number of trips per life cycle, average return rates) hypotheses have been made and the robustness and impact of these parameters on the overall performance has been studied through a sensitivity analysis and different scenarios.

Several LCA databases have been imported into openLCA to take advantage of already modelled processes while ensuring maximal data quality. In particular, the Ecoinvent version 3, Agribalyse (provided by the French Agency for Ecological Transition) and ELCD (European reference Life Cycle Database of the Joint Research Center) databases have been merged in openLCA to perform this analysis.

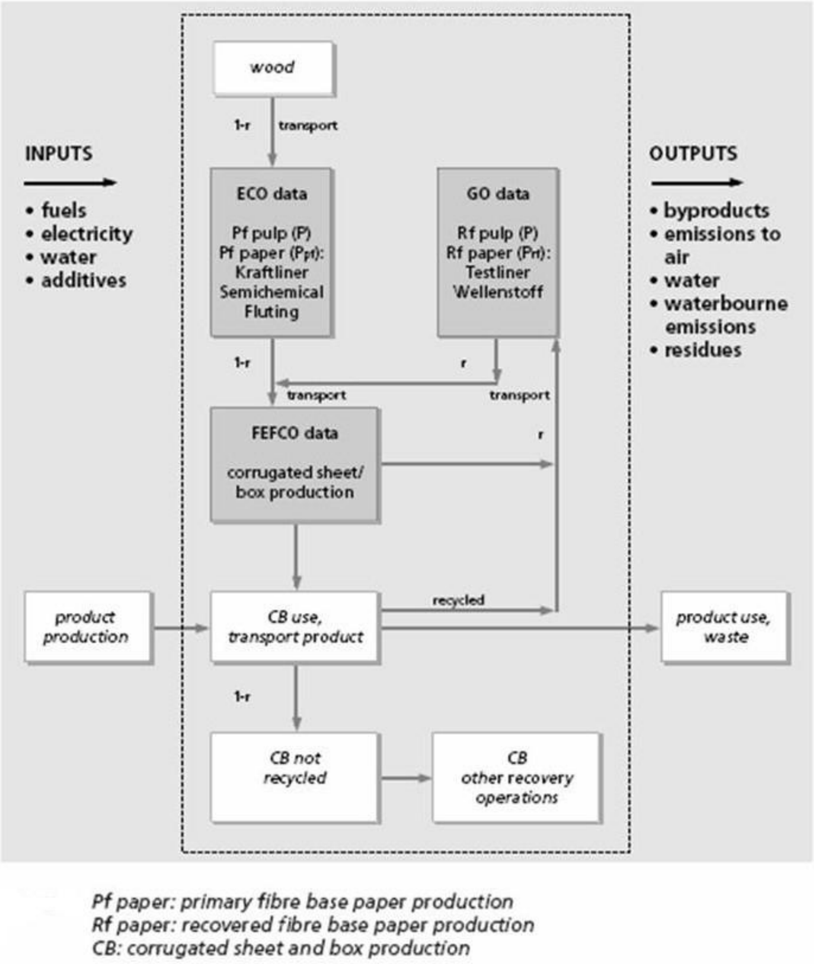
4.2.2 Life cycle inventory and analysis

In the following, the life-cycle phases taken into consideration are listed, describing the processes and information sources used to model them. For each packaging system, a specific analysis of the manufacturing process, transport and maintenance/EoL phases has been conducted, as illustrated below:

Manufacturing:

a) Corrugated cardboard boxes: The CCB production process has been extracted from the ELCD database and models an average CCB production and technology mix in the EU and Switzerland, with 16.6% primary fibers (Kraftliner and semichemical fluting) and 83.4% recycled fibers (Testliner and Wellenstoff). The data for the production of corrugated base papers have been gathered from the European Containerboard Organisation and Groupement Ondulé, while the production process for the CCBs is provided by the European Federation of Corrugated Board Manufacturers (FEFCO), according to the process illustrated in Figure 4-3.
b) Reusable plastic containers: The pre-production phase of RPCs consist of the industrial production of virgin polypropylene granulate, which is subsequently turned into RPCs through injection molding [Lev-2011]. Both processes have been extracted from the ecoinvent version 3 database and include the auxiliaries and energy demand required in the processes.
c) Reusable mailers: Since detailed data on the manufacturing process of reusable mailers cannot be found in literature on through online manufacturers, the assessment assumes that these RTIs undergo a manufacturing process similar to

that of reusable woven PP bags. The manufacturing process and its environmental impacts are described in detail in a recent LCA published by the Danish Environmental Protection Agency and the Ministry of Environment and Food of Denmark [Bis-2018].



Pf paper: primary fibre base paper production
Rf paper: recovered fibre base paper production
CB: corrugated sheet and box production

Figure 4-3: CCB manufacturing process as modelled by the ELCD database. Source: openLCA

Transportation: As mentioned in Section 4.2.1, two different means of transportation have been modelled in each SC depending on the stages connected by the route: Articulated heavy lorries and light lorries. It should be noted that although both systems are assessed for the same functional unit, the different weight of the packaging types results in different impacts even for the CLSC, where the covered distances are the same. Transportation flows are modelled in kg·km of carried goods and the processes for both means of transport have been extracted from the ELCD database.

End-of-Loop treatment: This phase is exclusively modeled for both RTI systems and represents the washing/maintenance processes carried out at the end of each loop by the pooler before the RTIs are returned to storage and made available for future deliveries. The washing process is modeled in accordance with existing industry publications [Lev-2011]. Additionally, it should be noted that the number of packages washed at each use constitutes another additional uncertain parameter for which scenarios need to be built in order to determine its impact on the overall system. Washing procedures might not be mandatory in every case and depend on the quality-of-service as well as the goods delivered.

EoL treatment:

a) **Corrugated cardboard boxes:** The disposed CCBs are brought to a paper mill, where the cardboard is treated to produce testliner paper by consuming electricity, water and natural gas [Lev-2011]. Since the system under assessment produces testliner paper as a result of the recycling process, the impact that would be generated for the production of testliner paper in a standalone system has been considered as an avoided impact (also known as using a system expansion approach) for the linear supply chain, as recommended by ISO 14044, clause 4.3.4.2. The system expansion approach is illustrated in Figure 4-4. The manufacturing process of testliner paper has been modeled in accordance with the European Database for Corrugated Board Life Cycle Studies, an LCA report elaborated by FEFCO and Cepi ContainerBoard experts [Cep-2018].

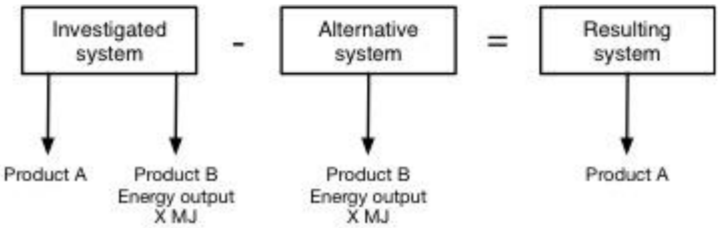


Figure 4-4: System expansion approach (avoided impacts) in systems with more than one product [Wei-2014]

b) **Reusable plastic containers and reusable mailers**: Similar to CCBs, both RTI alternatives are brought to a specialized plastics recycling plant, where materials are sorted and then recovered. In this assessment RTIs are treated to obtain polypropylene granulate, which can then be used to manufacture further RTIs. The obtained recycled PP has also been modeled through the system expansion approach. Data for the PP sorting and recycling processes has also been obtained from a specialized report published by The Association of Plastic Recyclers on life cycle impacts for recycled materials [Fra-2018].

4.2.3 Life cycle impact assessment

This section illustrates the results of the LCIA phase and covers the following topics:

- Initially, the section introduces the LCIA results for a set of industry-averaged system parameters obtained from providers and compares the results of the systems under evaluation.
- Then, taking *global warming* as the most important impact category, both in terms of absolute impact magnitudes as well as from a political (environmental agreements to reduce greenhouse gas emissions) and social awareness standpoint, the total impact is broken down into the individual life cycle phases to evaluate the relative importance of each one, determine courses of action to improve environmental performance and compare the contributions of every phase among the different systems.
- Finally, a sensitivity analysis is carried out for the most significant system parameters to determine the critical factors that should be targeted in order to further improve the systems.

For this study, a series of parameters have been considered in each of the evaluated systems to mitigate the uncertainty of unknown characteristics and behaviors. These parameters include:

- Transport distances for the linear and closed-loop supply chains.
- Recycling rates for both corrugated cardboard boxes and PP-based RTIs
- Number of loops per life cycle for each RTI.
- RTI return rate, i.e. how many of the delivered reusable packages actually make it back through the reverse supply chain and are received by the pooler to be used in subsequent deliveries.
- RTI washing rate.

Both the transport distances and the recycling rates have been modeled in accordance with expert reports, previous studies, and other data as explained in the previous paragraphs. Therefore, the three latter parameters need to be considered as variables in the following assessment:

Number of loops: Due to the different nature of both RTI assets under study, the average number of uses in a life cycle is expected to differ considerably among them. While RPCs are more robust and built to withstand impacts and scratches, reusable mailers can be torn and clawed more easily due to their thinner structures. According to manufacturer data, every reusable mailer is built to be reused at least 20 times, with some having completed over 50 cycles. On the other hand, RPCs can complete over 100 cycles with ease and up to several hundreds more.

The number of loops per life cycle can be expected to display an asymptotic effect on the overall impacts. As the number of successful loops increases, the contribution of fixed manufacturing impacts becomes more diluted, while the contribution of fixed transport/use phases gains importance. After a certain amount of loops, the impact of completing one more cycle will be hardly noticeable.

Return rate: Similar to the number of loops, RPCs and reusable mailers are also expected to exhibit different return rates due to the nature of the logistics systems under which they are operated. For reusable mailers, which have to be manually returned by the customer through a mailbox or a third party, the average return rate is expected to be lower, since some might choose to not put the effort. On the other hand, RPCs are usually collected from the customers by the pooler or a third-party, achieving much higher return rates, albeit at a higher cost. According to manufacturer data, the direct return rate for reusable mailers is around 75%, while RPCs can achieve rates upwards of 95%.

Washing rate: No universal washing rate can be derived from literature. Hence, a variation between 0% and 100% has been considered. The standard percentage of washing considered in this study is assumed to be 100% as a way to set a worst-case scenario on the benefits of reusing assets. The washing rate can be expected to have a linear impact on overall system performance. Moreover, since the resource and energy consumption of the washing phase is low, the overall contribution of the washing phase is expected to be reduced in comparison with other phases.

Table 4-4 displays a summary of the standard parameters considered for each system:

Table 4-4: Standard parameters for each CLSC

	Trips per life	*Return rate*	*Washing rate*
RPC	100	0.95	1.0
Reusable mailer	20	0.75	1.0

The following figures illustrate the results of performing the LCIA phase according to the processes and parameters described in previous sections.

Table 4-5: Environmental impacts of the analyzed systems

Indicator	***CCB***	***RPC***	***RM***	***Unit***
Fine particulate matter formation	1.190e+0	1.030e+0	1.152e+0	kg PM2.5 eq
Fossil resource scarcity	1.352e+2	3.697e+2	2.549e+2	kg oil eq
Freshwater ecotoxicity	1.383e+1	8.558e+0	2.162e+1	kg 1,4-DCB
Global warming	1.237e+3	9.393e+2	7.765e+2	kg CO2 eq
Human carcinogenic toxicity	2.341e+1	1.883e+1	3.522e+1	kg 1,4-DCB
Human non-carcinogenic toxicity	3.225e+2	2.040e+2	4.754e+2	kg 1,4-DCB
Marine ecotoxicity	1.833e+1	1.207e+1	2.897e+1	kg 1,4-DCB
Ozone formation, Human health	6.379e-1	1.304e+0	1.399e+0	kg NOx eq
Ozone formation, Terrestrial ecosystems	6.878e-1	1.416e+0	1.440e+0	kg NOx eq
Terrestrial acidification	3.770e+0	3.020e+0	3.329e+0	kg SO2 eq
Terrestrial ecotoxicity	2.1670e+2	4.467e+2	6.030e+2	kg 1,4-DCB

In order to provide a better overview of the relative performance of the three systems, Figure 4-5 represents the impact indicators as a percentage of the maximum impact of each category.

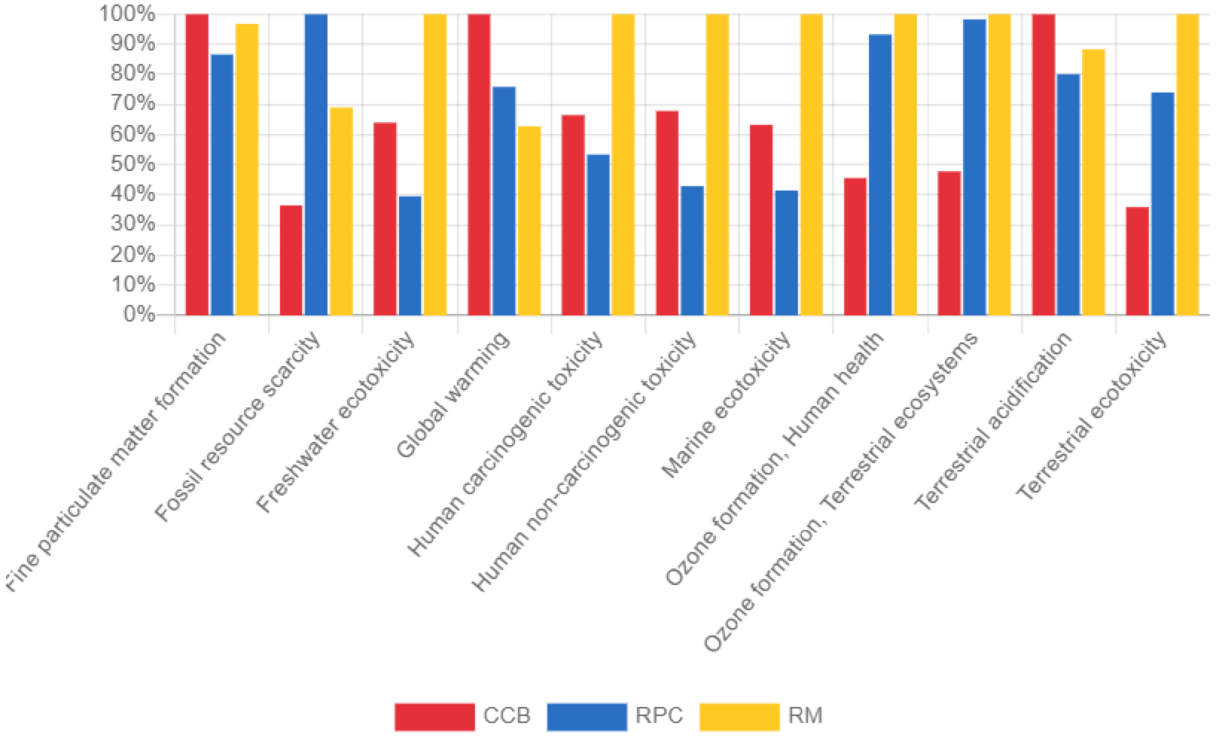


Figure 4-5: Relative impact indicators as a percentage of the maximum impact per category

The following observations can be extracted from the obtained results:

- In terms of absolute impacts, *global warming* is the most relevant impact category for each of the three systems, i.e. CO_2 eq. is the most emitted source of environmental damage. This supports the growing global focus on reducing greenhouse gas emissions as well as other sources of global warming. Aside from global warming, the most impactful categories are *fossil resource scarcity, human non-carcinogenic toxicity* and *terrestrial ecotoxicity*.
- Aside from *terrestrial ecotoxicity*, every other "toxicity"-related impact category displays the same approximate relative performance, with the RPC system exhibiting superior performance, followed by the single-use CCB system and finally, the mailer-based approach. Similar to the toxicities, both impact categories for photochemical ozone formation display almost identical results, with the CCB system being superior to the RTI-based alternatives. Figure 4-6 shows a cropped version of Figure 4-5, where only one impact category per toxicity/ozone group plus the remaining impact categories are displayed.

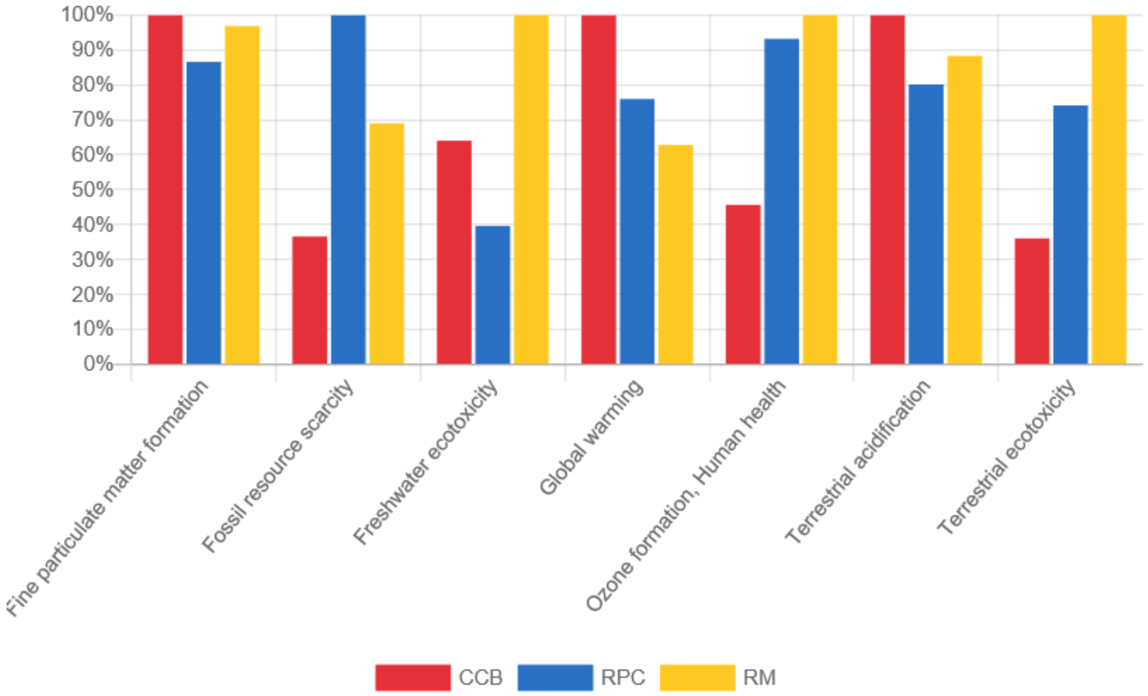


Figure 4-6: Relative impact indicators as a percentage of the maximum impact per category (cropped version)

- With regard to *global warming*, the both RTI-based approaches exhibit superior performance compared to the single-use packaging system, with the reusable mailer approach achieving the lowest impact. However, Figure 4-6 also shows the lack of correlation between *global warming* and the remaining impact categories. In fact, *global warming* is the only impact category where reusable mailers have the best performance. Additionally RPCs have lower impacts in almost everything else baring *fossil resource scarcity*, where a higher impact is to be expected due to the higher amount of fossil-based materials that need to be consumed to produce an RPC compared to a reusable mailer because of their much higher weight per unit. Consequently, it should be noted that all relevant impact categories need to be analyzed individually and results of one analysis cannot be generalized to the remaining categories. In this case, an appropriate weighting/normalization set might also aid in the holistic evaluation process.

- Although reusable mailers exhibit the highest impacts for many of the categories listed in Figure 4-5, it should not be concluded that their manufacturing/EoL processes are inferior to those of RPCs/CCBs in terms of those impact categories. In fact, most deviations are directly attributable to the differences in system parameters, rather than the processes themselves. Table 4-6 and Figure 4-7 illustrate the LCIA results for the three systems, if both CLSCs were to operate under the same return rate conditions (i.e. return rate = 0.95 for both RTI-based systems). It can be observed that the reusable mailer system would now have the best overall performance in every category baring *terrestrial ecotoxicity*, with the RPCs only coming close for *freshwater ecotoxicity*. This result is to be expected, since reusable mailers have much lower average weights per unit, which in turn result in lower overall impacts for the virgin material, transport and EoL phases, which are equal for both systems. Consequently, reusable mailer approaches seem to have the highest potential in terms of environmental impact if their system parameters are improved, by obtaining higher return rates through higher customer engagement (i.e. overcoming customer barriers as described in Section 2.1.2) and/or improving the logistics design to achieve higher collection rates.

Table 4-6: Environmental impacts of the analyzed systems (Return rate = 0.95)

Indicator	***CCB***	***RPC***	***RM***	***Unit***
Fine particulate matter formation	1.190e+0	1.030e+0	4.598e-1	kg PM2.5 eq
Fossil resource scarcity	1.352e+2	3.697e+2	8.156e+1	kg oil eq
Freshwater ecotoxicity	1.383e+1	8.558e+0	8.226e+0	kg 1,4-DCB
Global warming	1.237e+3	9.393e+2	3.058e+2	kg CO2 eq
Human carcinogenic toxicity	2.341e+1	1.883e+1	1.308e+1	kg 1,4-DCB
Human non-carcinogenic toxicity	3.225e+2	2.040e+2	1.813e+2	kg 1,4-DCB
Marine ecotoxicity	1.832e+1	1.202e+1	1.104e+1	kg 1,4-DCB
Ozone formation, Human health	6.379e-1	1.304e+0	4.934e-1	kg NOx eq
Ozone formation, Terrestrial ecosystems	6.878e-1	1.416e+0	5.072e-1	kg NOx eq
Terrestrial acidification	3.770e+0	3.020e+0	1.328e+0	kg SO2 eq
Terrestrial ecotoxicity	2.170e+2	4.467e+2	2.258e+2	kg 1,4-DCB

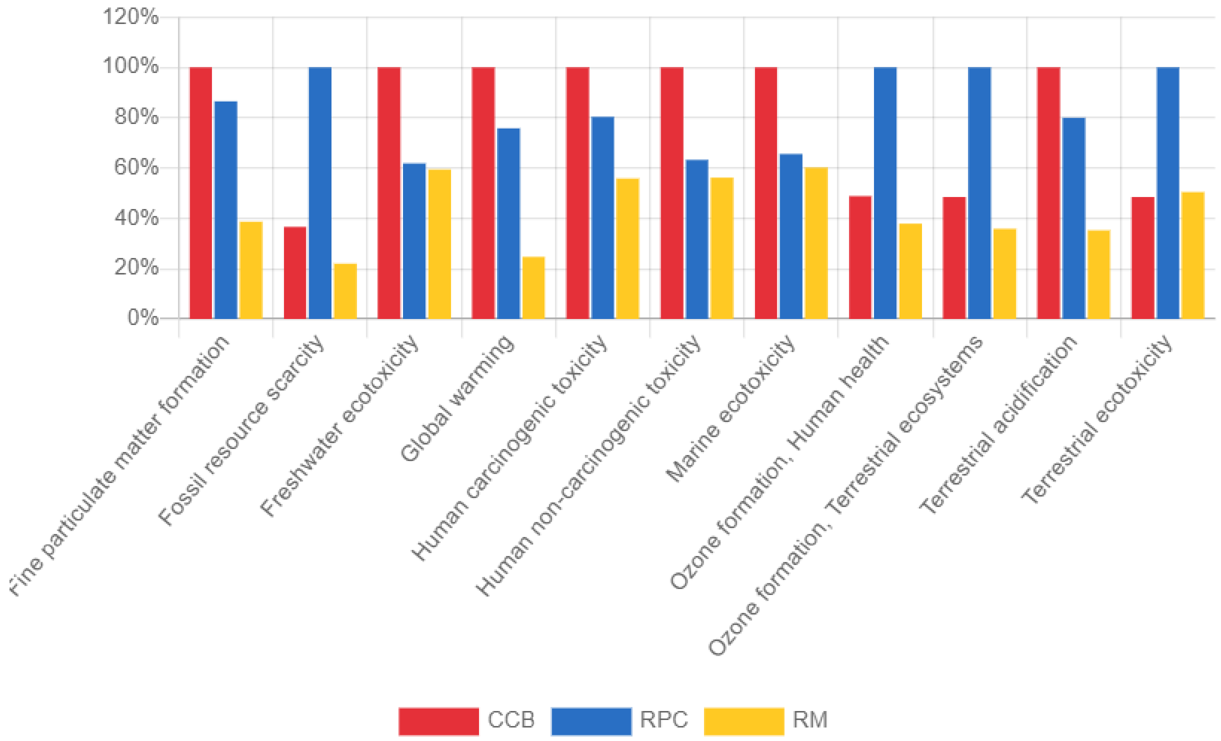


Figure 4-7: Relative impact indicators as a percentage of the maximum impact per category (Return rate = 0.95)

The following paragraph breaks down the *global warming* impact indicator into the contributions of different life-cycle phases, in order to illustrate and analyze their significance as well as identify potential for improvement.

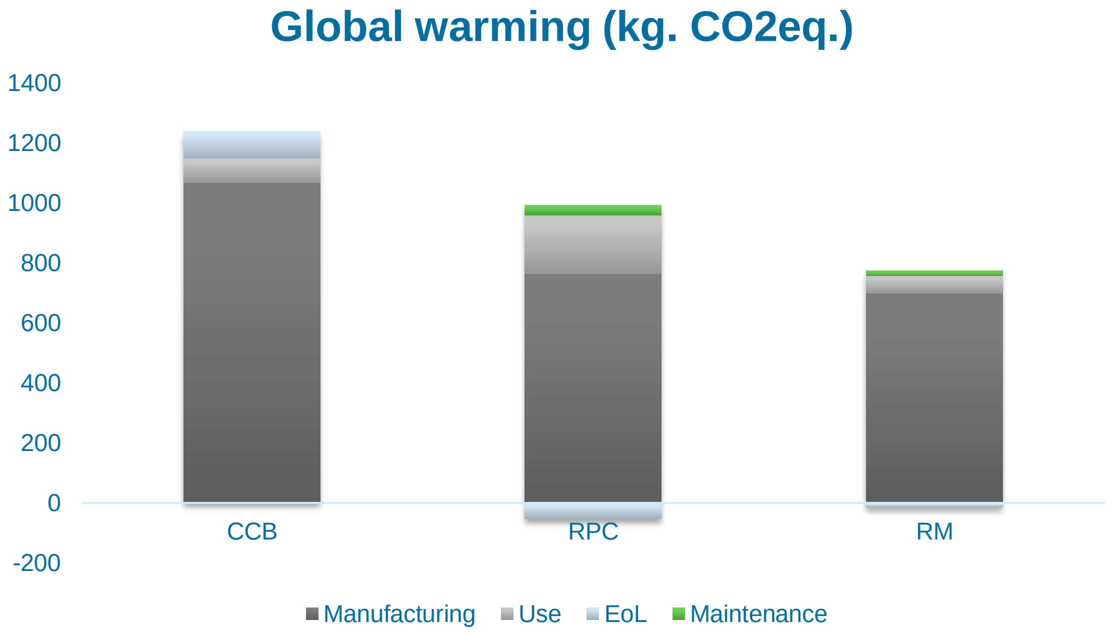


Figure 4-8: Global warming according to different life cycle stages of the 3 analyzed systems

Figure 4-8 shows the global warming breakdown by life cycle phases, from which the following observations can be extracted:

- The single-use approach has the biggest impact in the manufacturing phase, although processing plastic-based materials results in higher emissions per kg. than cardboard/paper-based materials. This happens as a consequence of reusing the same RTI over a high number of loops, where the manufacturing impacts are spread over many cycles.
- Corrugated-cardboard packaging has a smaller impact during its use phase compared to RPCs, which is mainly attributable to the shorter distances that have to be covered in the linear supply chain in comparison to the CLSC.
- However, reusable mailers have the least significant impact across every category, although some of its system parameters, such as the return rate, place a burden on its overall performance. The lower impacts during the use phase might seem especially counterintuitive at first glance. Nevertheless, this difference can be explained due to the lower overall weight per unit of reusable mailers compared to RPCs/CCBs, which also results in lower impacts, especially during the transport phase, where impacts are a function of mass·distance.
- The maintenance phase of RTIs, consisting of washing/sorting has a relatively small influence compared to the remaining life-cycle stages, since not many resources are consumed.
- EoL treatment for CCBs results in positive overall global warming, i.e. the resources, energy, and additional transport necessary outweigh the avoided impacts obtained from testliner production. This does not mean that the recycling phase has an overall negative impact for the system. Firstly, its effect on the remaining impact categories would need to be analyzed individually, but most importantly, if the recycling phase was not carried out, it would have to be substituted by another EoL process, such as incineration with energy recovery or landfilling, which results in considerably higher impacts.

The last portion of this subsection aims to evaluate the influence of the three uncertain system parameters on the *global warming* impact of both CLSC approaches in order to fulfil the remaining goal defined in the LCA’s goal and scope phase. Consequently, the effect on global warming of RTI return rate, number of trips per life cycle and RTI washing rate will be subsequently quantified and compared to the single-use packaging case to determine how efforts could be focused to obtain the maximum cost-adjusted improvement as well as the breakeven points.

To begin with, a Monte Carlo simulation has been carried out for every parameter to determine the type of existing correlation between variations of the independent parameter on the dependent variable. Table 4-7 shows the type of distribution as well as the distribution parameters chosen for the Monte Carlo simulation for each one of the three evaluated parameters. Figures 4-9 to 4-11 illustrate the results.

Table 4-7: Distribution types and distribution parameters for Monte Carlo simulation

Parameter	***Distribution type***	***# of simulations***	***Lower bound***	***Upper bound***
RTI return rate	Uniform	5000	0.7	1.0
Number of trips per life	Uniform	5000	10	150
RTI washing rate	Uniform	5000	0.0	1.0

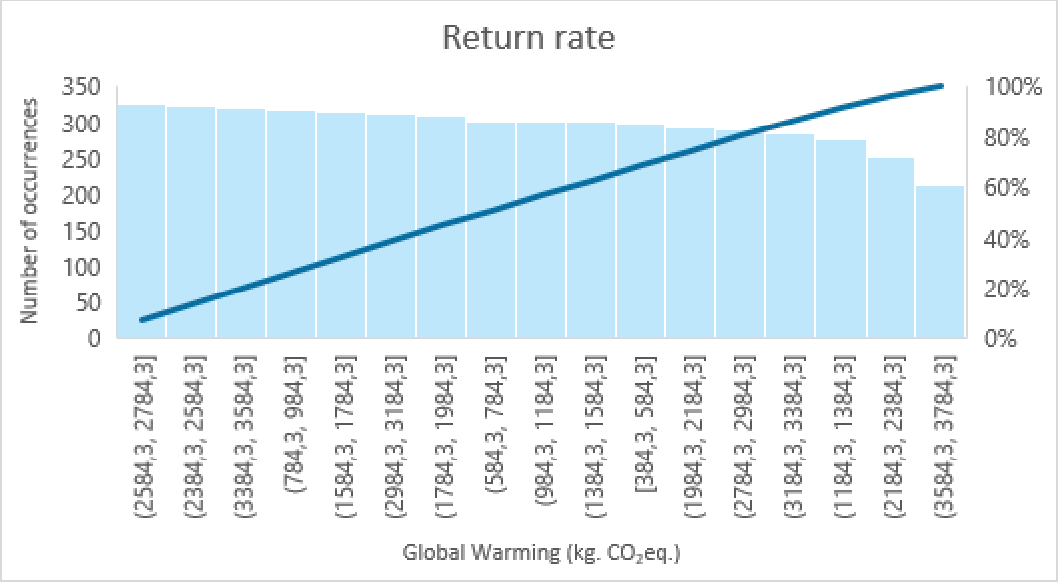


Figure 4-9: Monte Carlo simulation results for the return rate displayed in a Pareto chart

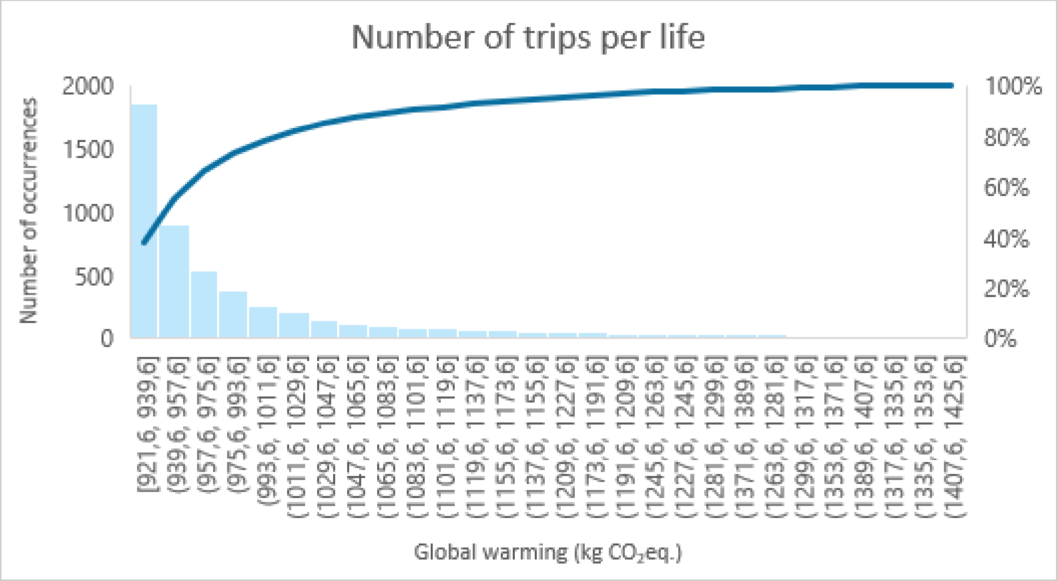


Figure 4-10: Monte Carlo simulation results for number of trips per life displayed in a Pareto chart

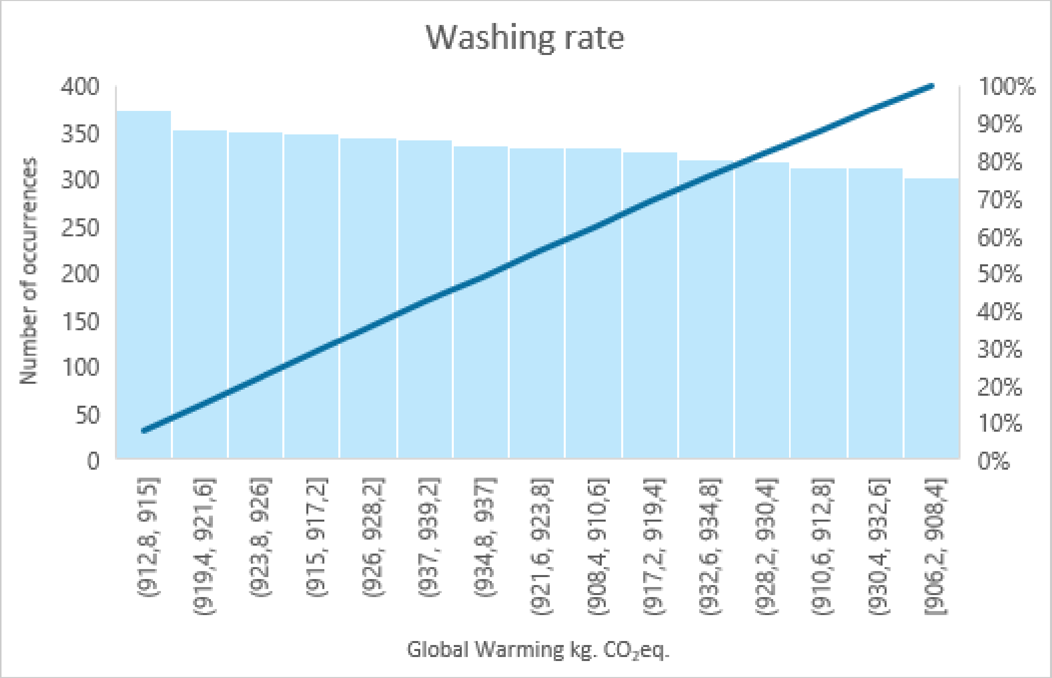


Figure 4-11: Monte Carlo simulation results for washing rate displayed in a Pareto chart

The simulations illustrated in Figures 4-9 to 4-11 have been carried out on the RPC CLSC model. Performing the same simulations on the reusable mailer model yields completely analogous results, differing only in the magnitude of the indicator's values. For the sake of brevity, these simulations are not illustrated in this study.

The results obtained in the Monte Carlo simulations confirm the initial hypotheses regarding the parameters' influence on global warming):

- RTI return rate has a linear correlation with global warming (and the rest of the impact categories), since a uniform uncertainty distribution of the parameter results in a uniform distribution of the dependent variable. This means that a 1pp. increase in return rates is always equally valuable in terms of environmental performance. As a result, the cost-adjusted effectiveness of different policies and strategic measures can be easily evaluated to then decide on the necessity of implementing them based on a cost-benefit analysis.
- The number of trips per life shows an asymptotic impact on global warming. Varying the number of trips per life between 10 and 150 for the RPC system results in a denser amount of results between 921 and 1020 kg. CO_2eq. and the remainder above this latter threshold in an 80:20 split. This implies that once a critical number of trips per life has been reached, successive trips have an increasingly lower impact on the overall system performance. Consequently, the cost-benefit ratio of policies/decisions aiming to improve the number of trips per life will depend on the upside potential of the current situation.

- RTI washing rate also displays a linear correlation similar to that of RTI return rate. The simulation also shows a much smaller result spread, which confirms the low overall impact of the maintenance/washing phase on global warming, as shown in previous paragraphs of this section.

Finally, the remaining portion of this subsection illustrates the effect of deterministic parameter values on the global warming impact category for the three systems under evaluation. The effect of each parameter is examined under a ceteris paribus approach, i.e. the remaining parameters remain constant at the values established for the standard case.

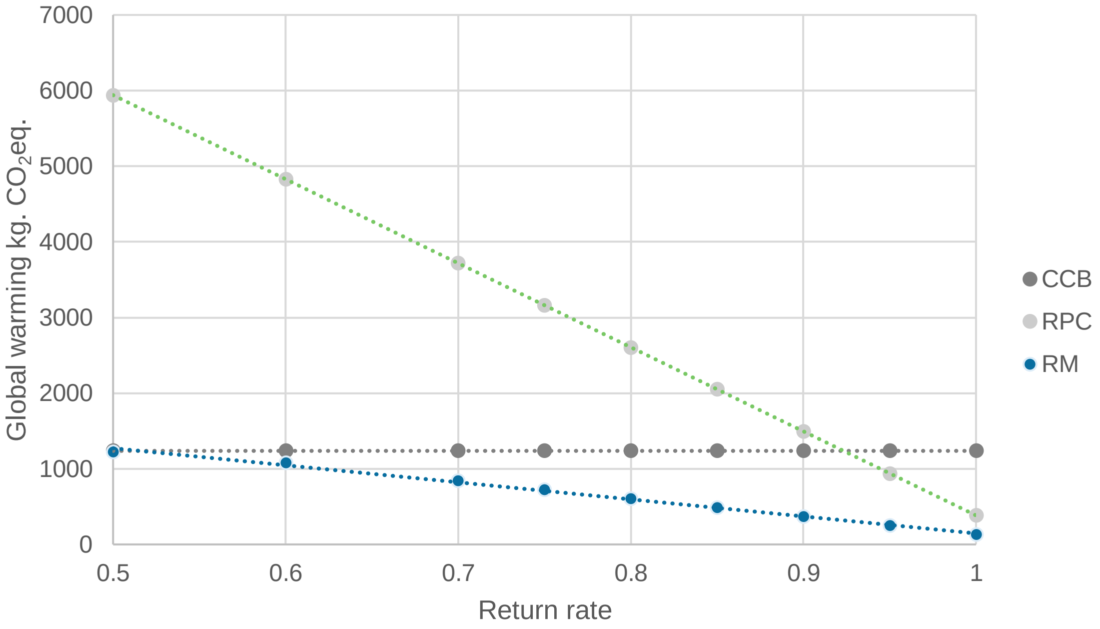


Figure 4-12: Sensitivity analysis for the return rate

As determined from the Monte Carlo simulations, the global warming impact indicator shows a monotonous linear decrease with increasing return rate. The reusable mailer approach reaches the breakeven point with single-use packaging at much lower return rates than the RPC approach (0.5 vs 0.925). However, the absolute difference becomes increasingly smaller with growing return rates. Another aspect to be noted is that RPC approaches in e-Commerce tend to achieve higher return rates, albeit usually at higher logistics costs, since they are directly recovered from the customers instead of being sent back.

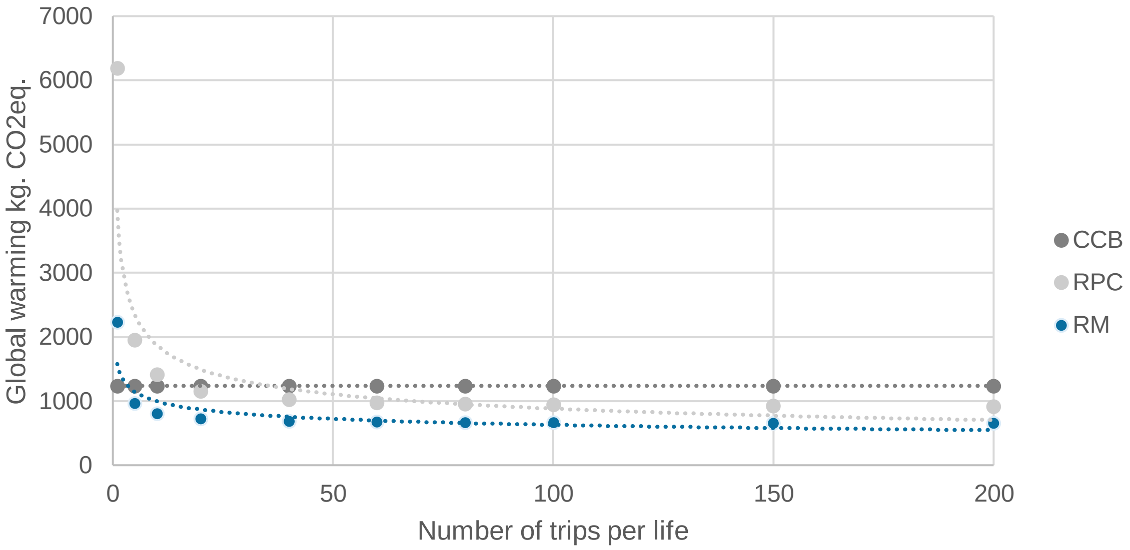


Figure 4-13: Sensitivity analysis for the number of trips per life

The sensitivity analysis for the number of trips per life illustrates the asymptotic effect determined during the Monte Carlo simulation. Once again, the reusable mailer approach reaches the breakeven point with corrugated cardboard boxes for a very small amount of trips (~4), while the RPCs require around 20 to achieve the same goal. After approximately 20 trips for the reusable mailers and 60 for the RPCs, no significant reduction in the total impact per life cycle can be appreciated anymore. Further increases in the number of trips per life do not result in significant environmental benefits. However, they could be significant from an economic standpoint, which is why a case by case analysis needs to be performed to determine the cost/benefit convenience of putting in effort to increase the total number of trips

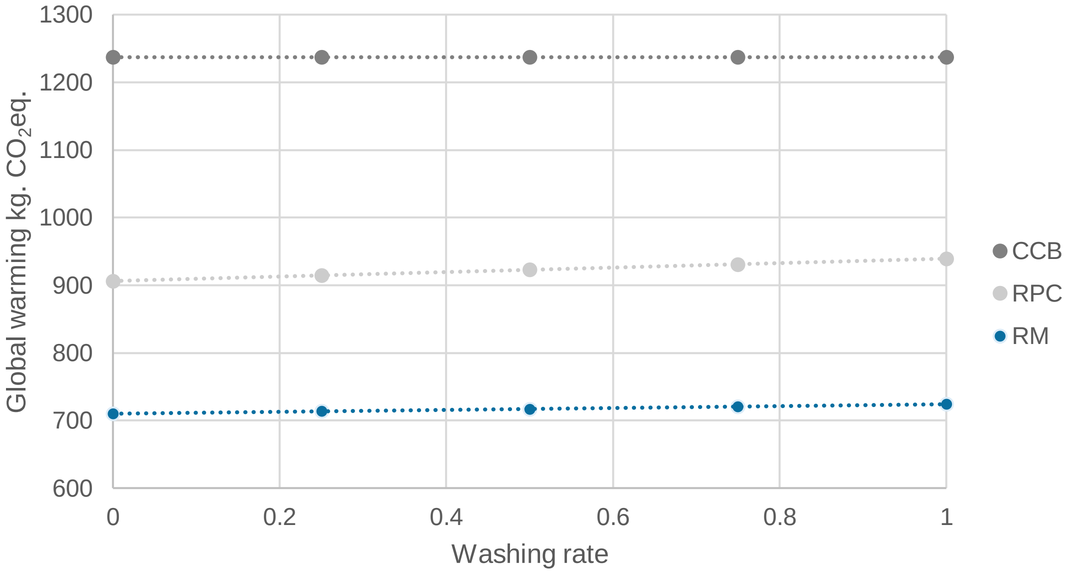


Figure 4-14: Sensitivity analysis for the washing rate

Finally, the washing rate displays a similar effect to that of the return rates, with the overall impact being much lower for both RTI approaches. The total difference between 0 and 100% washing rate amounts to approximately 4% of the total impact for the whole system. For this reason, decisions about washing rate should be centered around economic and quality of service-related parameters rather than environmental performance.

4.2.4 Life cycle interpretation

In this LCA comparison study, two different delivery systems have been examined for the e-Commerce supply chain. In the first model, the products are delivered in disposable, single use corrugated cardboard boxes, while in the second one the products were delivered in two different reusable packaging alternatives: reusable plastic containers and reusable mailers.

The LCA compares the performance of the three approaches for a generic delivery supply chain for which the characteristic parameters have been defined to represent an average of the expected values. The assessment concludes that both reusable packaging approaches are preferable to single-use packaging in terms of environmental impacts under the defined circumstances.

Additionally, the LCA illustrates that the environmental impact associated to both systems is mainly generated during the manufacturing phases. Nevertheless, transportations can also play a significant role, especially in the RPC model, due to the higher weights and larger transportation distances to be covered. The environmental impact associated with the EoL phases is dependent on both the material to be recovered and the volume of the stream itself.

The uncertainty/impossibility of determining average values for critical parameters that can profoundly affect the assessment’s outcomes leads to the necessity of performing several uncertainty analyses that determine the circumstances under which each approach might be able to achieve superior performance in comparison with the two remaining ones.

Nevertheless, it should be noted that the performed assessment suffers from a number of limitations that can play a role on the outcome and conclusions of the evaluation. These limitations include:

- The manufacturing processes for both RTI packaging approaches have been modeled through specialized reports/previous studies and might not perfectly represent those of current RTI providers. Especially for reusable mailers, hypotheses need to be made in analogy to the manufacturing process of woven PP bags since no data can be found in literature/reports due to the recentness of these products.

- Several parameters, such as transportation distances within both network designs and recycling rates/procedures have been modeled based on a combination of hypotheses and previous studies. In general, it is quite difficult to model a “generic” e-Commerce delivery supply chain due to the diversity and heterogeneity of these systems, as explained in Sections 2.1 and 2.2.
- The LCA assumes that every RTI is originally manufactured from virgin PP granulate, although the EoL treatment considers the recycling of these materials to produce recycled PP. Many RTI packaging manufacturers claim to use recycled materials/variants of PP to produce their packaging, which could considerably reduce the impacts of their manufacturing life cycle stage. As shown in Section 4.2.3, this phase has the biggest impact on the total life cycle and improvements to this stage could result in considerable impact reductions.
- The impact breakdown per life cycle stage and sensitivity analyses have only been carried out for the global warming impact category under the assumption that this category is the most relevant one. However, the remaining categories could also be examined individually or jointly by applying some sort of weighting method.

5 CONCLUSIONS AND FUTURE RESEARCH

The final chapter summarizes the main aspects covered in this document as well as the key conclusions and findings that have been reached as a result of the project (see Section 5.1). Finally, the document provides an outlook into further research that would improve, validate, or complement the sustainability and viability assessments of the different RTI approaches for e-Commerce packaging (see Section 5.2).

5.1 Summary and final conclusions

In the first chapter, three research questions were formulated as the main focus points that this study should aim to answer:

- Firstly, the drivers and barriers towards the implementation of a circular approach in e-Commerce packaging should be examined.
- Secondly, the study should elucidate the main design parameters and decisions that need to be taken into account when conceiving and implementing such an approach.
- Finally, the project should ellaborate on the sustainability and viability of RTI approaches in e-Commerce when compared to single-use packaging alternatives.

Initially, the document starts by briefly reviewing the state-of-the-art fundamentals and definitions of CE, including its three main principles, which can in turn be decomposed into four strategic sources of circular value creation, resulting in five different scalable circular business models. The study then particularizes this knowledge by examining which business models are currently being used or have the potential to be used in reusable e-Commerce packaging and provides examples of such initiatives. Subsequently, a comprehensive framework is introduced with the aim of classifying barriers into archetypes which can then be overcome by making use of their corresponding driver counterparts. The overall benefit potentials of implementing a circular system are then enumerated and explained. Finally, RL & CLSC fundamentals archetypes are briefly summarized in order to gain insight into the most promising approaches for this specific application.

The following subsections explain the main steps and rules that need to be obeyed in order to carry out an environmental impact assessment according to the LCA methodology as prescribed by the ISO 14040 series. Furthermore, a framework is introduced to provide an outlook on the economic viability assessment of RTI approaches in e-Commerce through application of the Life Cycle Costing methodology. If accurate and reliable cost data are available for the different life cycle phases of a product, this framework will provide an accurate comparison of the economic costs of reusable and single-use packaging in a parallel approach to that of LCA for environmental assessments.

In order to provide an answer to the second research question, yet another framework is introduced, which decomposes system design decisions hierarchically according to the planning horizon that they should be considered in. The study presents a series of selected deep dives into the most important aspects to be considered on the strategic (stakeholders & system design, logistics network design, and product deisgn), tactical (inventory management), and operational (tracking technologies & stock control and performance measurement) levels. Additionally, some concrete examples of existing approaches are introduced to illustrate their potential and explore potential improvements.

Finally, in order to reach a conclusion about the third and last research question as well as about the environmental viability of RTI packaging approaches as a whole, a detailed assessment of environmental impacts is carried out according to the LCA methodology. The model aims to simulate two generic e-Commerce supply chains: a traditional linear SC and a CLSC. The assessment has been carried out for corrugated cardboard boxes and two different reusable packaging alternatives: reusable plastic containers and reusable mailers.

The initial assessment uses industry-averaged system parameters and points towards global warming as the most impactful category for this specific system, thus corroborating the growing concerns about the impact of e-Commerce packaging on climate change. The analysis also displays promising results for both RTI alternatives in most impact categories, where they achieve lower impact indicators compared to the single-use packaging alternative. Due to their lower weight per package and capacity to be collapsed into smaller volumes, reusable mailers show the highest potential in terms of environmental impact reduction, although the realization of these benefits is subject to achieving an improvement of its current system parameters. In terms of the influence of life cycle phases on global warming, the manufacturing phase is the most impactful by far, indicating that any improvements to the production processes will entail considerable improvements to the overall system performance.

Lastly, the research study examines the influence on system performance of three system parameters: Number of trips per life, RTI return rate and RTI washing rate. Through a series of Monte Carlo simulations, the correlation between global warming and these parameters is elucidated, which in turn can be used to determine the convenience of developing strategic plans to improve each of these parameters. To conclude, a sensitivity analysis is carried out for each of the parameters under a ceteris paribus approach, which provides detailed insights into the most benefitial approach for a certain combination of system parameters and which can also be used for cost-benefit analyses in strategic decision making.

5.2 Future research

There are two main lines of work through which the research carried out in this project could be further improved, validated, and/or complemented:

On the one hand, the assessment of environmental impacts presented in Section 4.2 can be enhanced in several ways. The limitations and hypotheses of this model have already been thoroughly discussed in Section 4.2.4. More accurate and reliable data, especially on manufacturing processes and manufacturing materials of RTIs would significantly increase the value of the insights provided by the analysis. As shown in previous sections, the manufacturing life cycle phase is the most impactful and is therefore impacted the most by data uncertainty. Collaboration/association with RTI OEMs and other service providers can provide the data required to improve this analysis. Additionally, the results of the LCA have determined that there is no apparent correlation between one impact category and the rest. Achieving superior performance in one domain does not guarantee similar results in others. This issue can be tackled by either determining and standardizing a set of relevant impact categories for the sector or, even better, by developing weighting/normalization sets for the used LCIA methods. Finally, as justified in previous sections of this document, supply chains and application cases should be analyzed on a case by case basis. For this reason, it would be helpful to particularize this analysis to a specific application (i.e. specific geographic locations, providers, products, marketplaces, delivery hubs, etc.) and examine how much the results vary between the specific case (for concrete transportation distances, recycling rates, RTI sizes, etc.) and the generic approach described in this study.

On the other hand, the economic viability of these approaches should be analyzed to complement the environmental assessment introduced in this study. Both economic viability and environmental sustainability are necessary requirements for the successful introduction of a circular system. Although many different approaches can be followed to determine the economic viability of such a project, Section 2.5 provides an outlook into the LCC methodology, which lends itself very well to this task, due to the prominent parallelisms between LCA and LCC. By gathering either industry-averaged or data from a specific system, a full comparison can be established between single-use packaging and reusable packaging approaches to deliver a complete cost-benefit analysis.

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Anhang A OpenLCA models

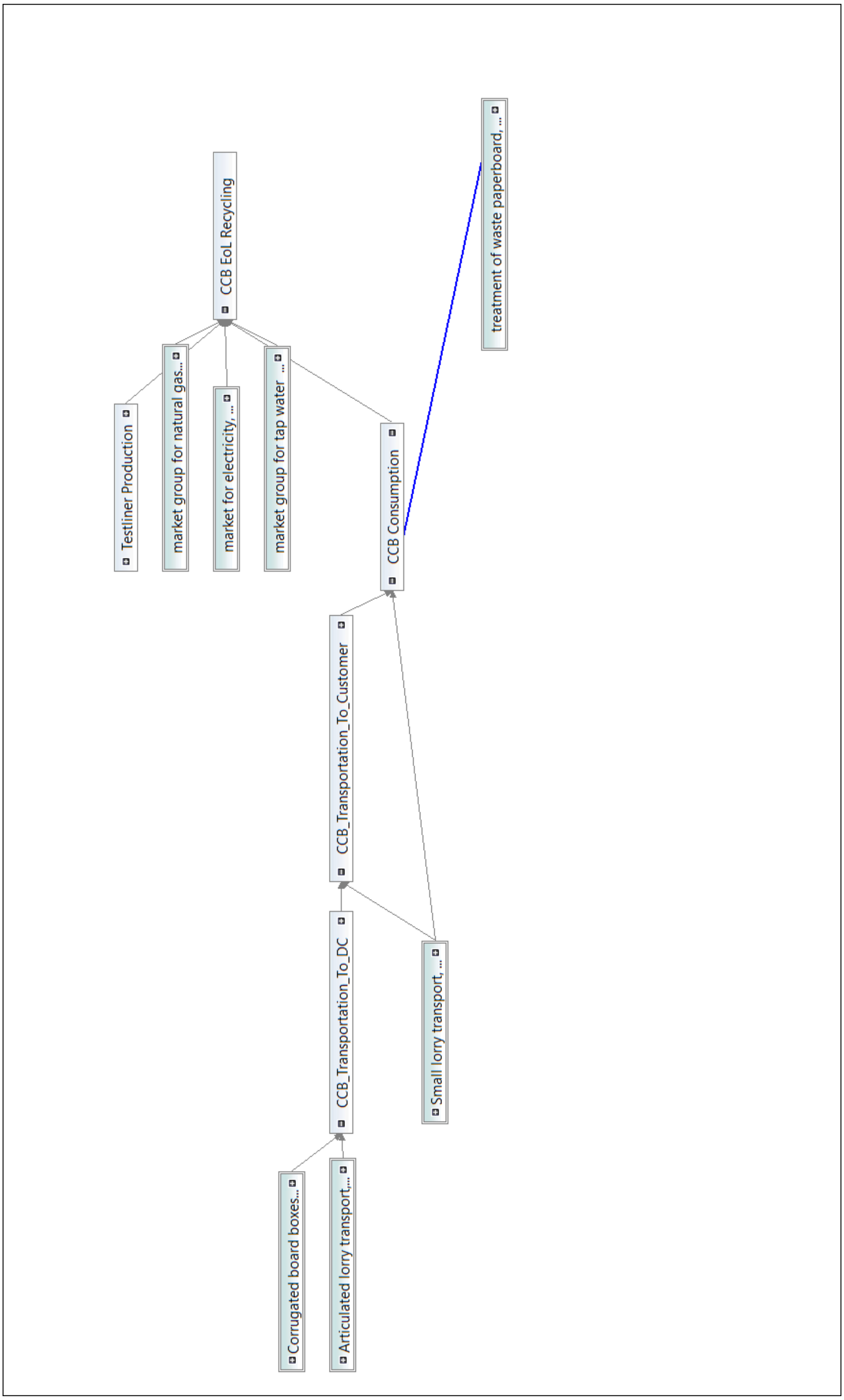

Figure A-1: OpenLCA model for single-use (CCB) packaging in a linear supply chain

Figure A-2: OpenLCA model for reusable (RPC) packaging in a CLSC

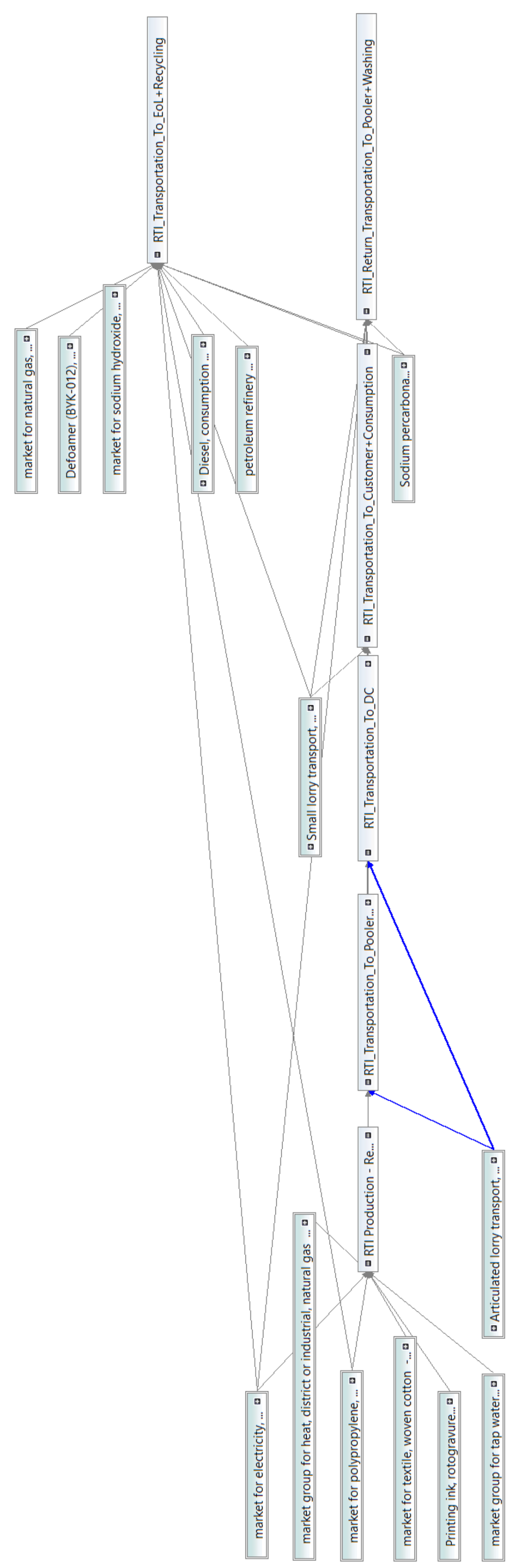

Figure A-3: OpenLCA model for reusable (RM) packaging in a CLSC

Anhang B Impact pathways

Appendix B briefly illustrates the main impact pathways and affected areas of protection for the impact categories under assessment in Section 4.2.3.

Global warming: The global warming cause-and-effect chain begins with the emission of a greenhouse gas (GHG) which results in an increased atmospheric concentration of greenhouse pollutants. This will subsequently increase the radiative forcing capacity of the Earth's atmosphere, defined as the difference between sunlight insolation and the energy reflected back to space. A net gain of radiative forcing results in an increase of the Earth's mean temperature. An increase in average temperature ultimately causes damage to human health and ecosystems.

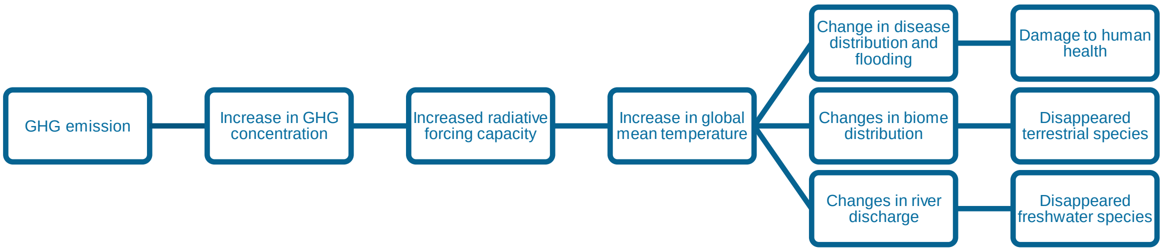

Figure B-4: Global warming cause-and-effect chain and damages to areas of protection

Fine Particulate Matter Formation: The emission of air pollutants results in the formation of primary and secondary aerosols (a suspension of fine solid particles or liquid droplets contained in a gas) in the atmosphere. These aerosols can have a significant negative impact on human health with different degrees of severity ranging from respiratory deficiencies to death. Especially dangerous for human health are particles known as PM2.5, (fine particulate matter with a diameter of lees than 2.5 µm.) which can cause health issues if they reach the lungs through inhalation.

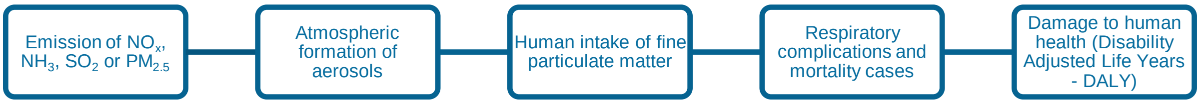

Figure B-5: Fine particulate matter formation cause-and-effect chain and damages to areas of protection

Fossil Resource Scarcity: In order to model fossil resource scarcity, ReCiPe places an assumption at its endpoint on the fact that fossil fuels with the lowest costs are prioritized in their extraction. As a result, the marginal cost of fossil fuel extraction increases monotonously due to a change to more expensive extraction technologies or by having to source from a more expensive location. This leads to a surplus cost potential of future fossil resource extraction (endpoint indicator for the impact category). The fossil fuel potential (loss of heating value, i.e. ration between the energy content of fossil resource x and the energy content of crude oil) is considered as the midpoint indicator for the category.

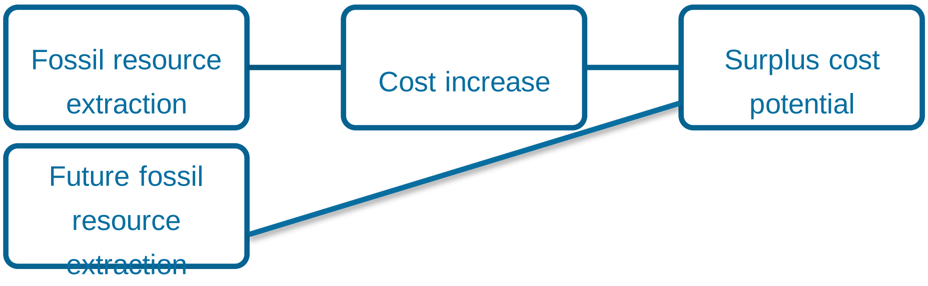

Figure B-6: Photochemical ozone formation cause-and-effect chain and damages to areas of protection

Photochemical Ozone Formation: Ozone is not directly emitted into the atmosphere but rather formed as a result of complex photochemical reactions between NO_x and Volatile Organic Compounds (VOCs). Ozone poses a health threat to humans, causing issues ranging from lung damage and respiratory inflammations to increased heart frequency. Additionally, it can worsen the severity of already present respiratory diseases, such as asthma and Chronic Obstructive Pulmonary Diseases (COPD). Aside from human health, ozone can have a negative impact on terrestrial ecosystems, especially on vegetation including a reduction of growth and seed production and increased fragility towards stress. Ozone formation is a complex non-linear process that depends on meteorological conditions and present concentrations of NO_x and VOCs.

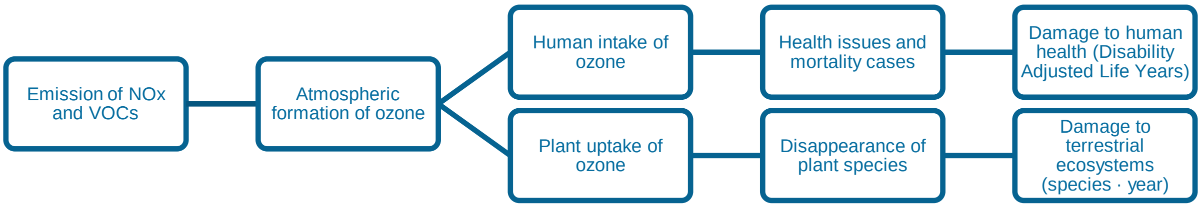

Figure B-7: Photochemical ozone formation cause-and-effect chain and damages to areas of protection

Toxicity: The toxicity impact pathway encompasses many of the impact pathways included in the LCA carried out in this study: Human carcinogenic and non-carcinogenic toxicity and freshwater, marine and terrestrial ecotoxicity. The emission of a toxic chemical results in an increase of the chemical's concentration in the environment. This has an effect on human health as well as animals and plants, ultimately causing diverse issues to humans and ecosystems.

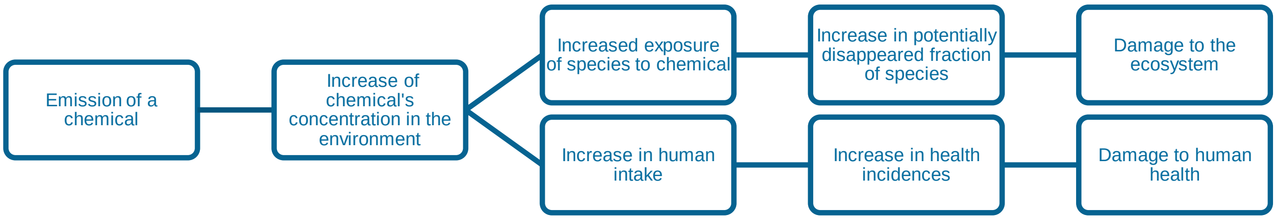

Figure B-8: Terrestrial acidification cause-and-effect chain and damages to areas of protection

Terrestrial Acidification: Deposition of atmospheric inorganic substances in the soil, such as sulphates, nitrates, and phosphates, can lead to an increase in its acidification due to the chemical formation of their corresponding acids (sulfuric, nitric, and phosphoric acids). Since almost all plant species have an acidity range of the soil in which they can survive, a significant alteration of the soil's pH level can lead to a shift in species occurrence as excessive acidification is detrimental for their survival. The most impactful acidifying emissions are NO_x, NH_3, and SO_2.

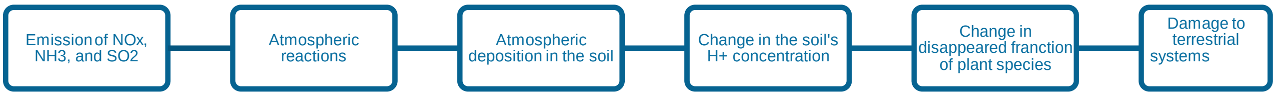

Figure B-9: Terrestrial acidification cause-and-effect chain and damages to areas of protection

Erklärung

Ich versichere hiermit, dass ich die von mir eingereichte Abschlussarbeit selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

München, 31.08.2020

Ort, Datum, Unterschrift

Alberto Huerta Plaza

Digitally signed by Alberto Huerta Plaza
Date: 2020.08.31 22:57:28 +02'00'