THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

How can consumables be made more resource efficient?

Environmental and resource assessment of measures

SIRI WILLSKYTT

Division of Environmental Systems Analysis
Department of Technology Management and Economics

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2018

How can consumables be made more resource efficient?
SIRI WILLSKYTT

Licentiate thesis report no L2018:100

Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 772 100

How can consumables be made more resource efficient?
Environmental and resource assessment of measures
SIRI WILLSKYTT
Environmental Systems Analysis
Department of Technology Management and Economics
Chalmers University of Technology

Abstract

The global population growth paired with increasing consumption per capita puts resource efficiency and sustainability on the political agenda. Consequently, the need for resource-efficient and sustainable products, including consumables, is expected to increase in the future. Strategies and measures for resource-efficient products are being developed, however, with less focus on consumables. This thesis aims to investigate how consumables can be made more resource efficient. The research was carried out in two parts. First, a life cycle assessment was carried out on a selected consumable, namely an incontinence product. The aim was to investigate the potential to improve the resource efficiency of incontinence products by assessing four different resource efficiency (RE) measures which could be applied within a short time frame using current technology. The measures included reduce losses in production, change material composition to a larger proportion of renewables, shift to a partly multiple-use product and improve the use of the product through customisation. The second part of this thesis focused on synthesising learnings from a number of assessment studies. The analysis was based on typologies formulated for mapping resource efficiency measures and product characteristics. This resulted in a number of findings detailing under which circumstances resource efficiency measures yield environmental and resource benefits, as well as when there are possible trade-offs. The assessment studies of consumables were selected for a more detailed analysis in this thesis.

Based on the review of cases and the typology of RE measures, the following RE measures were found applicable to consumables: reduce losses in production, reduce material use in products, change material in product, use effectively, shift to multiple-use products, reduce use of auxiliary materials and energy, recycle, digest anaerobically or compost, recover energy, and landfill. These are more measures which could potentially be applied to consumables than commonly discussed in the circular economy literature. Moreover, the identified measures among the cases all showed potential to improve resource efficiency. For the measure shift to multiple-use product, it was important for the product to last enough times to outweigh the environmental impact from production. In addition, an efficient maintenance system using electricity with low fossil content was an important element for achieving RE. When changing the material in a product, a risk of burden shifting between environmental impact categories was identified. Moreover, the measures applied to the incontinence products were found to be widely combinable, which could ultimately lead to greater resource efficiency. Others findings were that some measures are interdependent and that many, if not most, are dependent on design.

List of Appended Papers

Paper 1

Willskytt, S., and Tillman, A-M., 2018. Resource efficiency of consumables - Life cycle assessment of incontinence products. Submitted to scientific journal (currently under review)

Paper 2

Böckin, D., Willskytt, S., André, H., Tillman, A-M. and Ljunggren Söderman, M., 2018. What makes resource efficiency measures environmentally beneficial? - A systematic review of assessment studies. Submitted to scientific journal (currently under review).

Other related papers

Willskytt, S., Böckin, D., André, H., Tillman, A-M. and Ljunggren Söderman, M., 2016. Framework for analysing resource-efficient solutions. Paper presented at the 12th Biennial International Conference on EcoBalance. 3-6 October, 2016, Kyoto, Japan.

Böckin, D., Willskytt, S., Tillman, A-M. and Ljunggren Söderman, M., 2016. What makes solutions within the manufacturing industry resource efficient and effective? Paper presented at the 12th Biennial International Conference on EcoBalance. 3-6 October, 2016, Kyoto, Japan.

Contribution to Appended Papers

Paper 1

The author carried out the bulk of research work, including data collection, analysis and writing the draft of the manuscript. She was aided by the co-author in research design and analysis and in the form of multiple rounds of reviews and comments.

Paper 2

All authors designed the research and formulated the framework and typologies used for analysis and conclusions. The first, second and third authors carried out literature review and data analysis and cowrote the paper, with valuable assistance and feed-back form co-authors. The author wrote the sections covering methodology.

Acknowledgment

This research was supported by the Mistra REES (Resource-Efficient and Effective Solutions) program, funded by Mistra (The Swedish Foundation for Strategic Environmental Research) and Chalmers Area of Advance Production. Thanks to Attends Healthcare, and the studied elderly home, for providing data and knowledge about the studied product and its system in Paper 1. Moreover, a special thanks to Anne-Marie Tillman for her great support, supervision and challenging me to develop, and to Daniel Böckin, Hampus André and Maria Ljunggren Söderman for all the great work together. I would also like to thank Tomohiko Sakao at LiU for your support as sub-supervisor. In addition, I would like to thank the other colleagues at Mistra REES, and all colleagues at ESA for a warm and inspiring working environment. Lastly, I would like to thank my friends and family and specially Sebastián for all the support and encouragement over the three years. Without you none of this work would have been possible.

Table of Contents

1 Introduction

The global population growth paired with increasing consumption per capita puts resource efficiency (RE) and sustainability on the political agenda (UNEP, 2017). A manifestation of RE and sustainability that has gained a lot of attention recently is the concept of circular economy (CE) (Kirchherr et al., 2017). It is clear from the RE and CE discourse that the need for resource-efficient and sustainable products is expected to increase in the future. Strategies and measures for resource-efficient products are being developed. However, as will be argued in the following, with less focus on consumables. For this reason, this thesis sets out to investigate how consumables can be made more resource efficient.

Consumables can be defined in a multitude ways: goods that are capable of being consumed; that may be destroyed, dissipated, wasted or spent (Locke, 1913), products that need to be replaced after they have been used for a period of time (Webster, 2018), goods that people buy regularly because they are quickly used and need to be replaced often (Cambridge, 2011) or commodities that are intended to be used up relatively quickly (Oxford, 2010).

In this thesis, a consumable is defined as a product that is consumed either immediately or gradually (e.g. food and toothpaste), a product that declines significantly in quality and function while being used and needs to be replaced (e.g. an AA battery), or a product that is designed to deliver a function for a limited period of time (e.g. a component in a long-lived product). The concept of consumables includes both consumer goods, e.g. food and toilet paper, and goods to businesses, meaning either office supplies (products that are consumed either immediately or gradually) such as paper and ink cartridges, or components which are replaced frequently in long-lived products, such as brake pads and filters. Moreover, in this thesis resource efficiency is defined as the same function being fulfilled using less natural resources in terms of both resource use and environmental impact (Paper 2).

On the European level, the European Commission’s policy work on circular economy put much emphasis on waste. Moreover, few of the presented strategies are intended for consumables. For example, in the waste management strategy it is argued that “turning waste into a resource is one key to a circular economy. If we re-manufacture, reuse and recycle, and if one industry's waste becomes another's raw material, we can move to a more circular economy where waste is eliminated and resources are used in an efficient and sustainable way” (EC, 2018b). In the CE action plan (EC, 2015), focus is on product design (improving the reparability, upgradability, durability and recyclability of products), production processes (e.g. producing less waste, industrial symbiosis), consumption (again exemplified by improving the reparability, upgradability and durability of products), and turning waste into resources (increasing the use of secondary raw materials and returning nutrients from organic waste to soil). Few strategies and policies explicitly target consumable products. The focus is instead on waste and durable products.

One of the leading proponents of circular economy, the Ellen MacArthur Foundation (EMF), states that circularity introduces a strict differentiation between consumables and durable components of a product (EMF, 2013). They argue that consumables need to be made of bio-based materials which can be safely returned to the biosphere. This is in contrast to durables, which are made from materials such as metals and plastics which are unsuitable to be returned to the biosphere. According to the EMF, durable products should be designed for reuse from the start (EMF, 2013). An additional strategy suggested for short-lived products is to redesign them into durables.

The Netherlands Environmental Assessment Agency have also created a framework of resource efficiency strategies to underpin political and administrative decision making (Potting et al., 2017). The report presents nine circularity strategies targeting different phases in the product chain. These include more efficient production of products, smarter use of products, including extended lifespan of products and their components, recycling of materials and lastly recovery of the energy in materials. Of these strategies, only a small share can be considered applicable to consumables, namely refuse (to make a product redundant e.g. by offering the same function with a radically different product), reduce (increase efficiency in product manufacture to consume less natural resources), recycle and recover.

In Sweden, the Royal Academy of Engineering Science has sought ways to improve resource efficiency in a number of different sectors (IVA, 2016). One of these concerned a consumable type of product, i.e. food. A sub-project aimed to investigate what could be done to reduce resource leakage in the food industry and thus improve resource efficiency (Gunnartz, 2016). The study found a number of strategies to reduce resource leakage by conducting an MFA (material flow analysis) over the Swedish food industry. These included smarter packaging and new digital systems for RE in production, retail, distribution and consumption of foodstuff. The study also concluded that one reason for the large resource losses in the sector is the low price of food.

Although strategies and measures to make consumables more resource efficient do exist, they need to be elaborated. For instance, not all consumables can be made reusable, made completely from bio-based materials or made out of one single material (for improved recycling), at least not in the short term. Moreover, knowledge is needed on the effect of these strategies, whether they really lead to resource efficiency. This is why resource and environmental assessment of measures to make products more RE are needed. There are many different environmental assessment methods, with life cycle assessment (LCA) being the most widely used and well-established. LCA provides knowledge of resource use and environmental impact across the product value chain (Baumann & Tillman, 2004). Using LCA to investigate presumably resource efficient measures and under which circumstances they are effective makes it possible to assess the suitability of the measure.

Numerous LCA studies investigate different improvement measures specific to consumables. However, their scope does not always include understanding under which circumstances the measure leads to RE. This could be circumstances such as background system (e.g. energy source and waste management) and identification of trade-offs.

For example, many reviews that investigate the preference of single-use vs multiple-use products have been carried out for healthcare products. One such is Rutala and Weber (2001), who reviewed studies comparing single-use and multiple-use gowns and drapes in healthcare. Functional requirements, environmental impact, and financial aspects were evaluated. However, they could not find a clear superiority between reusable and single-use gowns and drapes. In contrast, (Overcash, 2012) reviewed studies of reusable and disposable perioperative textiles (surgical gowns and drapes) and found that the reusable options generally provided substantial sustainability benefits (in terms of energy use, water use, carbon footprint, volatile organics and solid waste) compared to the single-use options.

Critical reviews of LCA studies of solid waste management systems (SWMS) have also been carried out. One example is a study by Laurent et al. (2014) which critically reviews a large number of published LCA studies of SWMS. The studies included different end-of-life treatments of plastic, paper, organic and mixed household waste fractions with different waste treatment technologies. The analysis showed that, with the exception of the poor environmental performance of landfilling, there was generally little decisive agreement among the studies. The reason for this, the authors claimed, was that "the strong dependence of each SWMS on its context or local specificities (such as waste composition and energy system) prevented a consistent generalization of LCA results as we find it in the waste hierarchy" (Laurent et al., 2014). The study thus points to the importance of understanding the underlying circumstances which determine whether a measure such as incineration or recycling is preferable for e.g. plastic and paper waste.

Clearly, knowledge is still needed to understand which types of strategies and measures can be applied for consumables to improve their resource efficiency. Moreover, knowledge is needed about for which type of consumables and under which circumstance a particular RE measure is effective.

1.1 Scope and purpose

The overall purpose of this thesis is to systematically investigate: *How can consumables be made more resource efficient and cause less environmental impact?* To answer this question, some specific research questions are addressed in this licentiate thesis:

RQ1. Which RE measures can be applied to consumables?

RQ2. Under which circumstances are the identified measures effective and to what extent? For example, are there any trade-offs related to the identified RE measures based on the background system, such as energy source or waste management system?

RQ3: Which design implications exist for the identified measures?

To this end, a case study was carried out for one selected type of consumable, namely incontinence products as presented in Paper 1. The paper investigates how incontinence products can be made more resource efficient by answering: *Which resource efficient measures, possible to implement in a short-term perspective using existing technology, are effective for reducing use of natural resources and environmental impact for incontinence products? Which measures have the largest potential for resource efficiency?*

Paper 2, on the other hand, had a broader perspective. The paper´s aim was to systematically review assessment studies of different product systems from various sectors, covering both durable and consumable products, to see how they could be made more RE by using different physical measures. The research question in this paper was: *What physical measures aimed at RE on a product system level result in the intended outcome in terms of reduced physical flows and associated environmental impacts and for what types of products?*

In this thesis, the assessment studies reviewed in Paper 2 which concern consumables were analysed more deeply.

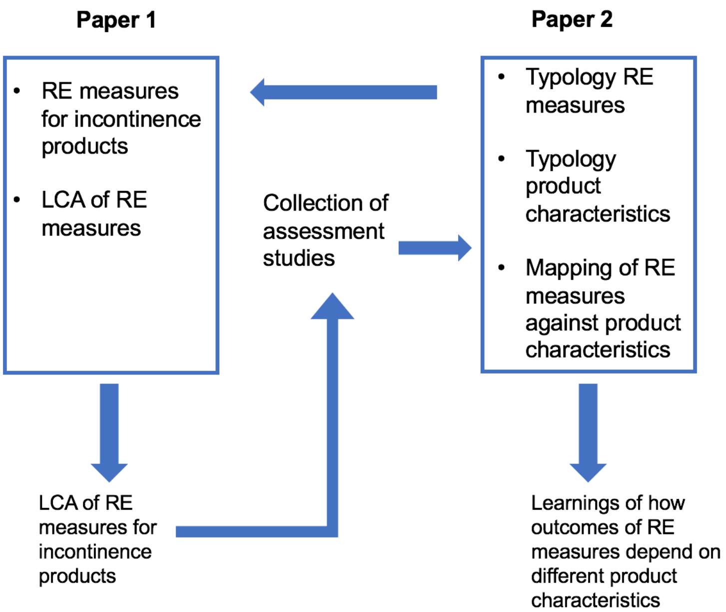

Figure 1. Overview of the two papers and how they relate to each other.

The two papers were developed in parallel, as illustrated in Figure 1. The typology of RE measures developed and presented in Paper 2 was used in the LCA study of incontinence products reported in Paper 1 in order to determine what RE measures were to be assessed. A second way in which the two papers are connected is that the LCA in Paper 1 was included among the assessment studies reviewed in Paper 2.

1.2 Limitations

This thesis is limited to a focus on physical measures that can steer the material flows of a product system in a resource efficient manner. Consequently, measures such as new business models or policy measures to achieve RE were outside the scope of the study. Moreover, the thesis is limited to the scope and limitations of Paper 1 and Paper 2, which means that measures such as biological treatment, energy recovery and landfilling were not focused on. The LCA study in Paper 1 was limited to evaluation of RE measures capable of being implemented with currently available technology and infrastructure. Hence, measures such as recycling materials in discarded products and fully reusable incontinence products were not included.

The review in Paper 2 was not based on an exhaustive collection of all assessment studies investigating RE measures for different products. Instead, studies of the measures most prominently brought forward in the CE literature were collected. For completeness, a number of assessment studies of recycling and measures for RE in production were added.

1.3 Thesis outline

The thesis is structured as follows: Chapter 2 is the research methodology chapter and introduces the methodologies used and the analytical framework developed for this research. In Chapter 3, the results in appended Paper 1 are summarised. The results of Paper 2 are not summarised as a whole. There is instead a more detailed analysis of the assessment studies of consumables. Chapter 4 is the discussion chapter, where the findings in Chapter 3 are discussed as are the findings related to the circumstances under which the identified measures are RE and design implications for the measures. Thereafter, in Chapter 5, the research questions are answered and concluded. Lastly, future research plans are presented in Chapter 6.

2 Method

This chapter presents the methods used for this research. The research in this thesis was carried out by conducting a life cycle assessment of incontinence products and the different RE measures, and by synthesising learnings from a large number of assessment studies covering consumables. The methods described in this chapter are thus life cycle assessment and the method for synthesising learnings from case studies.

2.1 Analytical framework for resource efficient product systems

In Paper 2, a framework was developed to enable a systematic review of assessment studies that analysed measures intended to increase the resource efficiency of different products. The framework consists of three parts. The first part presents a typology for resource efficient measures (see Table 1). The typology is divided into three overarching categories, distinguished by where in the life cycle the measures can be implemented; extraction and production, use or post-use. The typology draws on frameworks in the CE literature (Allwood et al., 2011; EC, 2008; EMF, 2013; Walter R Stahel, 2010; W.R. Stahel & Clift, 2016). This was complemented by life cycle thinking based on the collected assessment studies and experience from other studies and eco-design literature, e.g. the Ten Golden Principles (Luttropp & Brohammer, 2014), the Eco-design Strategy Wheel (Brezet & van Hemel, 1997) and other eco-design guidelines as described by e.g. Ceschin and Gaziulusoy (2016) and Sundin (2009).

Table 1. Typology for resource efficient measures and in which life cycle phase they can be implemented.

Life cycle phase	Measure
Extraction and production	
	Reduce losses in production
	Reduce material quantity in product
	Change material in product
Use	
	Use effectively and efficiently
	Use effectively
	Reduce use of auxiliary materials and energy
	Share
	Extend use
	Use more of technical lifetime (including reuse)
	Increase technical lifetime
	Shift to multiple use
	Maintain
	Repair
	Remanufacture
	Repurpose
Post-use	
	Recycle
	Digest anaerobically or compost
	Recover energy
	Landfill

The second part consists of a typology for characterising products which makes it possible to describe products in regard to aspects that were believed to be of importance for RE (such as lifespan, durable or consumable product, maintenance needs or energy use during use-phase). The third part consists of a tool to describe assessment studies of RE measures in a comprehensive and comparative manner. This includes which RE measure was investigated in a particular study and what characterised the investigated product system according to the typologies, details on how the study was conducted (e.g. whether an LCA or MFA study and used system boundaries) and the results and conclusions of the study.

2.1.1 Use of analytical framework

In Paper 2, the framework was used for its intended purpose, to systematically review assessment studies of presumably resource efficient product systems. Information was extracted from the collected assessment studies according to the framework and listed in a spreadsheet to allow sorting and analysis across cases on multiple levels and dimensions. Firstly, the cases were sorted based on the different measure defined in the typology. Then, the results reported in each assessment study were investigated. The cases were sorted according to whether they resulted in a positive or negative outcome in regard to environmental impact and resource use. This sorting allowed for identification of RE measures and product characteristics that correlated to positive or negative outcome as well as identification of different trade-offs arising in different circumstances. Lastly, this sorting made it possible to gather generalised knowledge about what product characteristic could enable each RE measure to achieve the intended outcome.

The typology for possible RE measures (Table 1) was used also in Paper 1. It was used to generate potential measures to make incontinence products more resource efficient. The measures considered implementable using current technology and infrastructure were selected. As a result, the measures recycling of used incontinence products and reuse of complete products were excluded.

2.2 LCA methodology

Life cycle assessment (LCA) is a structured, comprehensive and internationally standardised method that quantifies all relevant emissions and resources consumed associated with a product's life cycle (ILCD, 2010). It includes all phases of the product's life cycle, from extraction of raw material, production and use to recycling and disposal of the remaining waste.

Figure 2 presents the tree main stages of an LCA study: goal and scope, inventory analysis, and impact assessment (ISO 14040, 1997). The goal and scope define the goal of the study, the intended application, the reason for carrying it out and to whom the results will be communicated. As Figure 2 conveys, LCA is an iterative process and some of the earlier decisions for the study may be changed later in the process. According to Baumann and Tillman (2004), a goal and scope should include a functional unit, which is a reference unit all flows are related to, system boundaries, which processes shall or shall not be included in the study (geographical, time, and technical boundaries), impact categories to be considered, and data requirements.

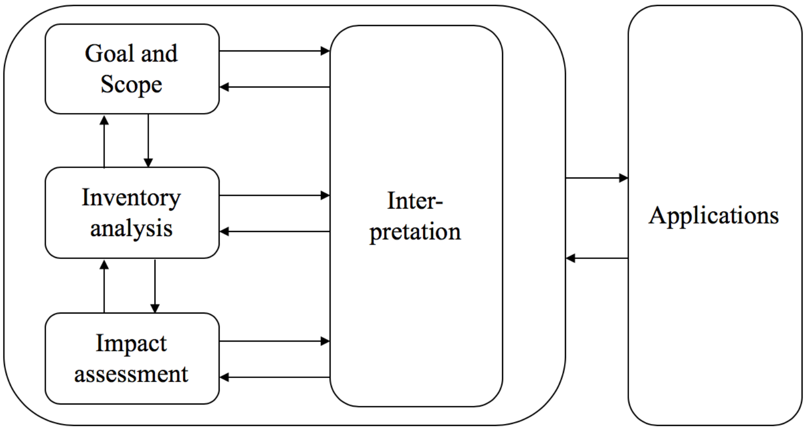

Figure 2. Phases of an LCA according to ISO 14140 (ISO 14040, 1997).

Inventory analysis is the second stage in the LCA. Here, the studied system data is modelled according to the defined scope. The inventory model can be seen as an incomplete mass and energy balance over the system that only includes flows relevant to the environment. This section includes setting up a flow chart according to the system boundaries, data collection for all activities with input and output flows, and calculation of the environmental loads of the system in relation to functional unit (Baumann & Tillman, 2004).

The third main stage in the LCA is the impact assessment, which is intended to describe the environmental consequences of the environmental loads quantified in the inventory analysis. This is done by interpreting the environmental loads from the inventory analysis result into potential environmental impacts such as global warming, acidification, and effects on biodiversity. The last stage involves interpreting and presenting the results. In ISO 14040, the stage is defined as: "… the phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are combined consistent with the defined goal and scope in order to reach conclusions and recommendations" (ISO 14040, 1997).

3 Results

The results of this research are presented in detail in the appended Papers 1 and 2. In this chapter, the results of Paper 1 are summarised. The results of Paper 2 are not summarised as a whole. Instead, there is a more detailed analysis of the assessment studies of consumables.

3.1 Resource efficient incontinence products

Paper 1 aimed to investigate the potential to improve the resource efficiency of one type of consumables, incontinence products, by assessing four different RE measures. The measures were chosen based on the typology of RE measures presented in Paper 2, but were limited to those capably of being applied using current technology.

- *Reduce losses in production* aimed at improvements in manufacturing. This was accomplished by recycling the waste generated in the manufacturing process. This measure was compared to incineration.
- *Change materials in product* aimed at changing the material composition to more bio-based materials, thus using less fossil-based materials. This measure was exemplified with two products having the same function but with different material composition.
- *Shift to multiple-use product* aimed at making the product reusable. A completely washable incontinence product was, however, not considered feasible with current technology. Instead, the measure was exemplified by a partly reusable incontinence product. A washable pants with single-use absorbing insert pads was compared with a disposable all-in-one product of the same size and absorption capacity.
- *Effective use through customisation* aimed at making sure that right product was used for a user's needs and requirements. This was done by measuring the degree of incontinence in individual patients and mapping this against suitable incontinence products. In our investigation, products recommended based on the measurements were compared to the products which were used before the measurements were conducted.

The four measures were evaluated using life cycle assessment. The results of the LCA were first evaluated with two different weighting methods, the EPS method (Steen, 1999) and the ReCiPe single score method (Hischier et al., 2010). This was done in order to identify relevant impact categories on which subsequent analysis was based. Figure 3 conveys the results from the four measures with the ReCiPe single score method. As shown, mainly three impact categories contributed to the product system's environmental impact, agricultural land occupation, fossil depletion and climate change. Similar results were found when using the EPS method (Paper 1). The EPS results were dominated by abiotic stock resources (with natural gas and crude oil as main contributors) and emissions to air (where carbon dioxide dominated). Based on the EPS and ReCiPe results, land use, global warming potential and fossil resource depletion were selected as relevant midpoint impact categories. For further analysis of the selected midpoint impact categories, ReCiPe with hierarchy perspective (Goedkoop et al., 2009) was used.

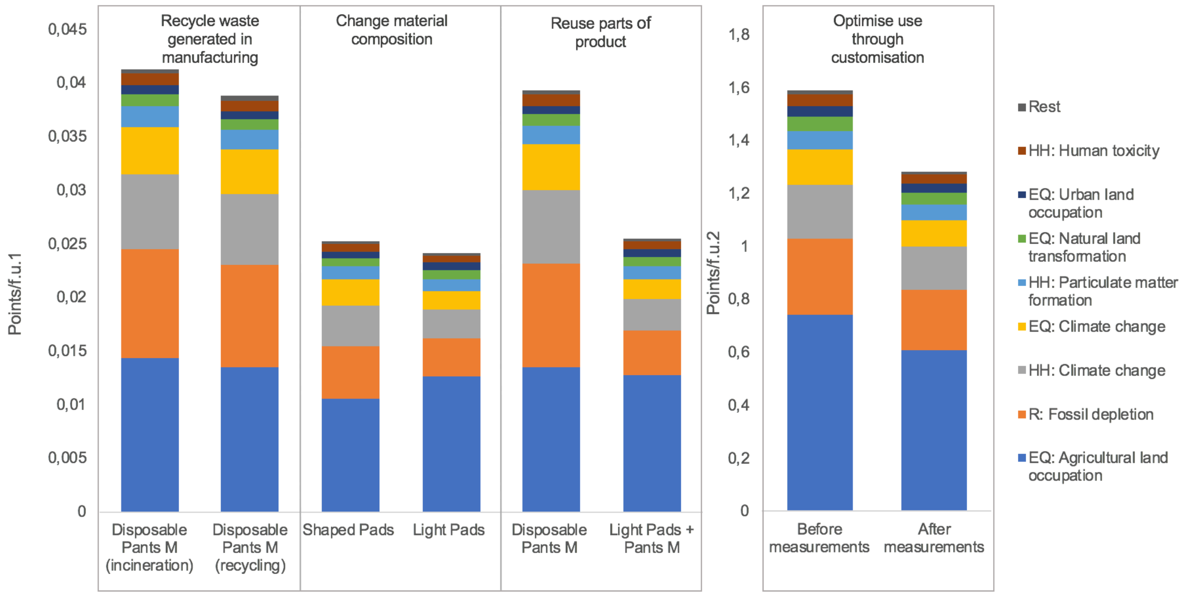

Figure 3. ReCiPe single score results for the products used in the first three investigated measures to the left (with the functional unit "hygiene function of one absorbent product") and products used in the fourth measure (effective use through customisation) to the right (with the functional unit "hygiene function for one day at the studied ward in an elderly care home"). EQ is Ecosystem Quality, R is Resources, and HH is Human Health.

The results of the analysis using the selected the impact categories were:

- *Recycling of manufacturing waste* leads to moderate improvements. A 4–7% decrease in the impact of the selected impact indicators was obtained without any trade-offs between impact categories.
- The strategy of *changing materials* to more bio-based and less fossil-based materials resulted in a 30% decreased impact on global warming potential (GWP), but a 20% greater impact on land use.
- *Reuse parts of the product* was the measure that resulted in the largest improvements in terms of fossil resource depletion and global warming, a 50–60 % decrease. Moreover, there were no trade-offs between the impact categories in this measure.
- *Optimise use of products* through customisation leads to at least 20% reduction in all selected environmental impact and there were no trade-offs here either.

In conclusion, there is considerable potential for lowering the environmental impact of incontinence products using current technology. An additional and unexpected observation from the study was that the four identified measures are capable of being combined without being dependent on each other. This is important since greater resource efficiency gains may be achieved by combining measures. With that said, the measures effective use through customisation and reuse parts of incontinence products (shift to multiple-use product) cannot be combined totally freely. All users have different degrees of incontinence and general health status, thus a two-piece product solution might not be suitable for every user.

3.2 Resource efficient consumables

Paper 2 aimed at investigating which RE measures result in reduced physical flows and associated environmental impacts for what types of products. In addition, it investigated which underlying circumstances made the measures successful and which trade-offs could exist. The range of products investigated was wide, spanning both consumable and durable products. This section presents and further analyses the assessment studies regarding consumables in Paper 2. Table 2 shows an overview of assessment studies of consumables, the investigated resource efficient measures together with the results in terms of life cycle material and energy usage and environmental impact. As shown, five measures were found to be applicable to consumables, namely: reduce losses in production, change materials in product, shift to multiple-use product, use effectively and recycle.

Table 2. Studies assessing RE measures (seen as headings under type of consumable in the table) of consumable products, describing the difference between the RE alternative and the reference scenario as well as the result in terms in life cycle material usage, energy usage and environmental impact.

Type of consumable	Resource efficient scenario	Reference scenario	Material result	Energy results	Environment results	Source
Reduce losses in production						
Food (dairy products - "A" & "B")	Improved production sequencing	Random production sequencing	21–26% reduced waste	n.a.	1.3–1.5% reduced GWP, EUP, ACP, POCP	Berlin and Sonesson (2006)
Paper	Location of production (reduce transportation)	Paper made from forestry and landfilled at EoL	n.a.	No improvement	1% reduced GWP	Counsell and Allwood (2007)
Incontinence product	Recycle production waste	Production waste is incinerated	6% reduced land use; 7% reduced FRD	n.a.	4% reduced GWP	Willskytt and Tillman (2018)
Change materials in product						
Paper	Change raw material from wood to annual crop	Paper made from wood	n.a.	22% reduced GJ	3% reduced GWP	Counsell and Allwood (2007)
Cup	Disposable paper cup	Disposable polystyrene cup	70% reduced ADP	n.a.	71% reduced GWP	Ligthart and Ansems (2007)
Incontinence product	Increased proportion of renewable-based materials	Mainly fossil-based product	20% increased land use; 22% reduced FRD	n.a.	30% reduced GWP	Willskytt and Tillman (2018)
Shift to multiple-use product						
Cup	Reusable earthenware mug – washed by hand	Disposable polystyrene cup	26% increased ADP	n.a.	84% increased GWP	Ligthart and Ansems (2007)
Cup	Reusable porcelain mug and saucer – washed in industrial washer	Disposable polystyrene cup	40% reduced ADP	n.a.	8.6% reduced GWP	Ligthart and Ansems (2007)
Bedpan	Partly disposable with reusable back cover (moulded cardboard)	Disposable PE bedpan	n.a.	n.a.	34% increased GWP	Sørensen and Wenzel (2014)
Bedpan	Reusable stainless steel-based bedpan	Disposable PE bedpan	n.a.	n.a.	100% increased GWP	Sørensen and Wenzel (2014)
Bedpan	Reusable polyethylene-based bedpan	Disposable PE bedpan	n.a.	n.a.	96% increased GWP	Sørensen and Wenzel (2014)
Bed pad	Multiple-use bed pad	Disposable and mainly fossil-based bed pad	n.a.	n.a.	24% increased GWP	Helgestrand et al. (2011)
Incontinence product	Partly reusable product (reusable pant and disposable absorbing core)	Disposable incontinence product	6% reduced land use ;60% reduced FRD	n.a.	44% reduced GWP	Willskytt and Tillman (2018)
Core plug	Multiple-use and recyclable core plug	Single use core plug	n.a.	n.a.	91% reduced eco-indicator point, 89% reduced GWP	Lindahl et al. (2014)
Fuel filter	Reusable and washable fuel filter	Disposable fuel filter	95% reduced material; 99% reduced ADP	60% reduced transport	90% reduced GWP	Bergstrand and Jönsson (2017)
Paper	Reusable paper through un-printing technology	Paper made from wood	n.a.	76% reduced energy	95% reduced GWP	Counsell and Allwood (2007)
Use effectively						
Incontinence product	Customization of products to patients trough measurements	Products chosen based on personnel's knowledge	18% reduced land use; 20% reduced FRD	n.a.	33% reduced GWP	Willskytt and Tillman (2018)
Recycle						
Paper	Paper recycling at EoL instead of landfill	Paper made from wood and landfilled at EoL	n.a.	51% reduced energy	76% reduced GWP	Counsell and Allwood (2007)

GWP = global warming potential
EUP = eutrophication potential
ACP = acidification potential
ADP = abiotic resource depletion potential
POCP = photochemical ozone creation potential
Eco-indicator points = Eco Indicator 99
FRD= fossil resource depletion

3.2.1 Reduce losses in production

As can be seen in Table 2, the cases related to reducing losses in production covered dairy products, incontinence products and paper. All reviewed cases showed reduction in global warming potential, which was the most commonly used indicator for environmental impact.

In the case of dairy products, Berlin and Sonesson (2006) investigated environmental gains and waste reduction through improved production sequencing of yogurt flavours. The study found that at least 20–25% of the production waste could be eliminated through improvements in the production sequence. The resulting environmental improvement on a life cycle basis was around 1.5%. For the incontinence products (Paper 1), the manufacturing waste was recycled and reused in manufacturing instead of being sent to incineration, leading to a 5% reduction for the three investigated impact categories (land use, fossil resource depletion and global warming potential). Counsell and Allwood (2007) investigated the impact of changing the location of paper production. The hypothesis tested was that transport could be decreased by locating pulping and paper-making factories close to the point of paper consumption. However, only a 1% savings of climate change emissions over the life cycle was achieved through this measure.

These three studies are just a few examples of how production can be improved to reduce different types of losses in production. There is an abundance of additional ways to reduce losses in production, e.g. through increasing yields, valorising and using by-products. Nevertheless, the three examples show that the measure can be considered effective and lead to an overall improvement in RE.

3.2.2 Change materials in product

The measure to change materials in consumables was found in four of the case studies in Paper 2, as can be seen in Table 2. The gathered cases all showed reduction in global warming potential, though to largely varying extents (3–70%).

The study of paper investigated how a shift from wood-based paper to paper based on annual crop could influence the environmental impact (Counsell & Allwood, 2007). It was found that an approximately 22% reduction of the energy over the life cycle could be achieved together with a 3% GWP reduction. Other studies investigated shifting to more renewable-based materials in products. In Ligthart and Ansems (2007), a disposable polystyrene cup was compared with a disposable paper cup. As can be seen in Table 2, this measure resulted in a 70% reduction in abiotic mineral resource depletion potential (ADP) and a 71% GWP reduction. However, other impact categories related to production of biomass, such as those related to land use, were not included in the investigation. In Paper 1, only a part of the non-renewable material in the incontinence product was changed to bio-based. Thus, the benefit from the shift in resources use was not as large as in the aforementioned case study. However, despite moderate changes in product composition, a 30% reduction in GWP and 22% decrease in fossil resource depletion were obtained, but at the cost of a 22% increase in land use.

From these studies it can be concluded that changing from fossil-based to renewable-based materials has the potential to lower the GWP and fossil resource depletion of consumables substantially. However, there is an associated burden shift between land use and related impacts as exemplified in Willskytt and Tillman (2018) (Paper 1).

3.2.3 Shift to multiple-use products

Shift to multiple-use products was the measure that was assessed in most of the studies concerning consumables that were included in Paper 2. The products included household articles (drinking cups), healthcare and hygiene products (bed pans, bed pads, incontinence products), components in heavy machinery (fuel filters in a wheel loader and core plugs in paper production) and office supplies (office paper) (see Table 2). A common factor for each was that in order to be reusable, the product requires maintenance (e.g. washing) between uses. However, as can also can be seen in Table 2, the environmental savings (or non-savings) from this measure varies largely between the cases.

In Ligthart and Ansems (2007), two durable cups (earthenware and porcelain) were compared with a disposable polystyrene cup. The earthenware mug was washed by hand, resulting in an increased environmental impact (26% for abiotic resource depletion potential (ADP) and 84% for GWP). The porcelain mug, on the other hand, was washed in a dishwasher, resulting in a reduced ADP (40%) and GWP (9%). Sørensen and Wenzel (2014) evaluated three different types of reusable bedpans and compared them with a disposable bedpan. They found that the disposable option performs significantly better than the reusable ones (see Table 2). A similar product is bed pads, which was evaluated by Helgestrand et al. (2011). Here, the reusable option was found to result in 24% increased GWP. In Paper 1, another healthcare product was evaluated, incontinence products. Here, a partly reusable product was compared to a single-use product. In contrast to the precious studies of healthcare products, the partly reusable product was found to be significantly more resource efficient.

It is not just consumables used in households or in the healthcare sector that can be turned into multiple-use products. Components used in heavy machines, such as core plug and fuel filters, were evaluated by Lindahl et al. (2014) and Bergstrand and Jönsson (2017), respectively. Both of the multiple-use products resulted in a significant reduction of resource use and environmental impact compared with the disposable option (Table 2). The last case of comparing multiple-use and single-use products was a study of un-printing of office paper, resulting in reduced GWP (Counsell & Allwood, 2007).

As shown in Table 2, the effect of moving to a multiple-use product instead of a single-use product varied greatly among the cases. The reasons for the variability were investigated by analysing key aspects of the studies, as shown in Table 3.

Table 3. Maintenance details for the cases investigated in shift to multiple-use products, expressed per product.

Type of product	Energy for maintenance per use	No. of uses	Fossil content of electricity	Relative contribution from maintenance to life cycle GWP
Cup (Earthenware – washed by hand)	0.109kWh	3000	~ 50%	~ 100%
Cup (Porcelain – washed in industrial washer)	0.018 kWh	3000	~ 50%	~ 90%
Bedpan (stainless steel)	1.4 kWh	1000	~ 100%	~ 90%
Bedpan (polyethylene)	1.4 kWh	1000	~ 100%	~ 100%
Bedpan (partly reusable)	n.a.	1000	~ 100%	~ 40%
Bed pad	0.5 kWh	183	~ 5%	~ 40%
Incontinence product (reusable pant and disposable absorbing core)	0.012 kWh	20	~ 5%	~ 1%
Fuel filter	229 kJ	40	~ 5%	17%

As shown, the maintenance phase's relative contribution to GWP varies greatly between the different cases. For the hand-washed earthenware cup (more impacting than the single-use option), almost 100% of the environmental impact was derived from the maintenance phase. The corresponding figure for the porcelain mug (less impacting than the single-use option because it was washed in a dishwasher) was nearly 90%. The main difference between the two was the energy required for maintenance, with more than 6 times more energy needed for hand washing. Electricity use had a large impact on both GWP and ADP due to the source of electricity, which in this study is represented by UCTE data (50% fossil-based) (Dones et al., 2007). Similar relative contribution from the maintenance phase could be found for the bedpans, 40–100% in terms of GWP. The large electricity need for washing combined with use of marginal electricity in the study (100% fossil-based) were the main reasons for the large contribution from maintenance and why the single-use option was superior in the comparison.

Another healthcare product, bed pads (Helgestrand et al., 2011), also showed a considerable relative contribution from the maintenance phase (40%). However, the main reason why the multiple-use option performed worse in this study was the material production, since a rather large number of products were assumed to be needed (five products per patient and year).

For the partly reusable incontinence products, the relative contribution from maintenance was significantly smaller than the former products. Only 1% of the GWP over the life cycle came from washing and drying of the reusable pants. This resulted in the partly reusable product system being found superior compared to the disposable one. To verify the robustness of this result, extensive sensitivity analyses were carried out. These tested how a change in electricity mix, the role of energy use in maintenance (by testing different loads in the washing machine), and whether the pants was washed at an industrial washing facility would influence the results. The analyses showed that it was only in the worst-case scenario, i.e. the pants being washed and dried as the only garment in the machine, that the impact increased significantly and the order of ranking between the compared alternatives changed.

The last case in which data on maintenance was given was the one by Bergstrand and Jönsson (2017) concerning fuel filters. Here, the maintenance activity, which involved not only washing and but also replacement of worn-down steel and rubber parts in 10% of the filters, contributed to 17% of the life cycle GWP. Clean electricity was used for the washing operation. In this case, the environmental impact of the reusable option was only 10% of that of the single-use option.

To conclude, maintenance varies greatly and is largely what determines whether the multiple option is more resource efficient than a single-use option. This means that low energy requirements for maintenance and use of electricity based on a large proportion of renewables for maintenance increase the chances of the multiple-use product being more resource efficient.

3.2.4 Use effectively

For this measure, only one case that concerned a consumable was included in the studies reviewed in Paper 2. As described in section 3.1, this case involves making sure that the right incontinence product was used by each patient by measuring the incontinence degree and thereafter selecting the most suitable product with respect to absorption capacity and size. As seen in Table 2, an 18–30 % decrease in land use, fossil resource depletion and global warming potential was obtained.

3.2.5 Recycle

For the one case involving the measure of recycling of a consumable included in Paper 2, paper was assumed to be recycled instead of going to landfill (Counsell & Allwood, 2007). As expected, this resulted in large energy and environmental benefits. Approximately 50% of the energy usage in the paper's life cycle could be decreased and more than 75% of the global warming impact could be cut.

4 Discussion

4.1 RE measures for consumables

One of the objectives of this thesis is to investigate which RE measures are possible for consumables.

The Ellen Mac Arthur Foundation emphasises that consumables should be avoided to the greatest extent possible. If not, consumables could either be redesigned into multiple-use products, or be made from bio-based materials and biodegradables so they can be returned to the biosphere (EMF, 2013). In order for a product to be returned to the biosphere, the entire product must be biodegradable so that no other material prevents its complete digestion.

The framework with circular measures for products presented in Potting et al. (2017) includes nine different measures, some of which are applicable to consumables. For example, Potting et al. exemplify which measures are possible for plastic containers for food and beverages in a case study: refuse by completely avoiding the container, reuse, which requires washing of the container, recycle, which requires the sorting of waste and is facilitated by use of fewer types of plastic, and lastly energy recovery through incineration.

In Paper 2, cases of the following measures applied to consumables were found:

- *reduce losses in production*
- *change material in product*
- *use effectively*
- *shift to multiple-use product together with reduce use of auxiliary materials and energy*
- *recycle*

In addition, the following RE measures are applicable to consumables using the typology in Paper 2:

- *reduce amount of material in products* (e.g. lighter wine bottles due to reduced amount of glass (Systembolaget, 2018))
- *digest anaerobically or compost* (e.g. Xu et al. (2015))
- *recover energy (e.g. incineration of paper instead of landfill* (Counsell & Allwood, 2007))
- *landfill (e.g. discard product in controlled landfill, which is better than littering in nature)*

Hence, there are more measures which can be used for consumables than have been mentioned in previous CE literature.

Many measures are directly dependent on each other. Moreover, it was clear from the collected studies that many strategies require a combination of measures and can thus not be implemented singly. For the measure shift to multiple-use product, a combination of measures is needed.

Often, change in material composition to more durable materials that can withstand reuse and some kind of maintenance is needed. Also, a maintenance system is needed to enable washing or other maintenance for reuse. To ensure the maintenance is resource efficient, the measure reduce use of auxiliary materials and energy may also be essential. Similarly, if a product should be capable of being recycled or treated biologically, the consumable may require redesign and a change of the materials.

Interestingly, the study in Paper 1 showed that the measures investigated there (reduce losses in production, change material in product, shift to multiple-use product and use effectively) could all be combined without being dependent on each other. For example, the recycling of production waste does not hinder the measure of designing a product with more renewable materials or the use of a partly reusable product. Hence, combining measures enables larger RE improvements.

Combining measures was not investigated among the other studies covered by Paper 2. However, it is possible that larger RE improvements could be achieved by combining different measures, including for products other than incontinence products.

It is assumed that the measure of changing the materials used in consumables will become more common in the future. New regulations have been presented by the EU to reduce the use of unnecessary plastic-based single-use products (EC, 2018a) as a means of reducing marine litter. According to the new regulation, "where alternatives are readily available and affordable, single-use plastic products will be banned from the market. The ban will apply to plastic cotton buds, cutlery, plates, straws, drink stirrers and sticks for balloons which will all have to be made exclusively from more sustainable materials instead". Applying the measure, however, can lead to trade-offs. For example, there is a trade-off between reducing the fossil-based material by increasing the proportion of renewable-based material, and having an increased impact on land use. This trade-off was shown in Paper 1 and was previously demonstrated by Mirabella et al. (2013).

4.2 Circumstances that enable RE

Another objective of this thesis is to investigate under which circumstances RE measures are effective for consumables. As this thesis is limited to physical measures, circumstances such as business model and policy are not included.

The system surrounding the product, such as energy source in production, maintenance, use and waste management, can be of great importance for the outcome of a RE measure. For shift to multiple-use product, the type of maintenance (mainly washing) was decisive for whether the measure was proven effective or not in increasing the RE, as shown in section 3.2.3. In Ligthart and Ansems (2007), two reusable mugs made from different materials were compared with a plastic-based disposable cup. The reusable mugs differed largely in the energy needed in maintenance since one was washed by hand (the earthenware mug) and the other was washed in a dishwasher (the porcelain mug). The energy usage and the large proportion of fossil-based electricity were the reasons why the maintenance of the mugs dominated the life cycle and why the earthenware mug was the least resource efficient option. If the earthenware mug would also have been washed in an energy-efficient dishwasher together in combination with use of electricity with smaller proportion of fossil-based electricity, the outcome of the measure would have been reversed. Thus, simultaneously applying an energy-efficient maintenance system is of great importance to the RE of multiple-use products. Another important aspect is for the reusable product to be used enough times to outweigh the environmental impact from production since multiple-use products generally require more materials than single-use products. This means that reusable products need to not only be designed to last long enough, but also actually used a certain number of times, i.e. at least until the break-even point is reached.

There may be limitations to the measure involving redesign of a multiple-use product, even if it is theoretically possible to do so. Due to security and other practical requirements at hospitals and other healthcare institutions, such redesign measures might not be a viable option (Campion et al., 2015).

For post-use measures, an important precondition is that the collection infrastructure, technologies, capacity, and treatment facilities are in place. In addition, especially for recycling collection of large enough volumes is important, since recycling occurs in large scale plants.

4.3 Design implications for resource efficient consumables

All discussed measures are in one or another way dependent on design, either as a measure in itself, e.g. changing the material of the product, or as a necessary precondition for another measure such as shift to multiple-use product.

As mentioned, creating a reusable product involves more than just redesigning the product and instead extends to the whole system surrounding the product. In many cases, both a maintenance system (including reversed logistics) and an associated business model must be designed. In the study by Bergstrand and Jönsson (2017), a fuel filter in a wheel loader was redesigned to last more than the 500 h the current single use filter lasts. The new filter was designed to have the same life span as the wheel loader (200,000 hours in use). In order to last that much longer, the filter needed to be changed every 500 h for a quality check, cleaning, and replacement of worn components. This involved not only redesigning the whole filter but also designing a maintenance/remanufacturing system to ensure the filters could be restored to use. Moreover, a new business model and take-back system were also designed to ensure the filters were brought back to the remanufacturing company and that the new product system was economically worthwhile.

In some rare cases, the product itself does not need to be redesigned in order to make the product reusable. Instead, a maintenance system can be designed which itself can make the product reusable. One such example is the office paper un-printing machine described by Counsell and Allwood (2007) that removes the ink on the paper so the paper can be reused.

For the measure of use the product effectively, design measures could either be applied to the product or the system around the product to promote correct or improved user behaviour (Shu et al., 2017) and make sure the right product or the right amount of product is used each time. Examples include design of a dispenser to make sure only one napkin or piece of toilet paper is taken each time, redesign of soap into foam instead of liquid, and design packaging that reduces food losses (e.g. Williams et al. (2008)).

Redesigning a product to contain less materials can in some cases not be possible without at the same time changing the materials in the product. Exclusively reducing the amount of material might not be possible due to reduced function provided from the material. For example, diapers and incontinence products have historically reduced their product weight by introducing super absorbents that not only resulted in lighter products (less material) but also achieved better absorption (Cordella et al., 2015). Also, in order to change material in a product to one that is less environmentally burdensome or less toxic and/or scarce, another material must exist that could meet the function requirements. Thus, even if the material is more environmentally beneficial, the desired function of the material may still determine whether a change of material is possible (Sakao & Fargnoli, 2010).

Most types of products can be recycled if collected. Note, however, that recycling happens on a material level and that the materials in a product must be separated into their constituent materials in order to recycle them. Hence, the recyclability of products depends on their design since the design determines the possibility of separating materials.

In conclusion, the design of products and systems matters greatly and determines which type of measure is capable of being applied and also governs the possibility of combining different measures.

5 Conclusions

The purpose of this thesis is to investigate in which ways consumables can be made more resource efficient and less environmentally burdensome. The thesis identifies a number of measures to achieve and under which circumstances they are effective.

- Based on the analysed cases in Paper 2, the measures *reduce losses in production, change material in product, use effectively, shift to multiple-use product, and recycle* were found to be applicable to consumables.
- Moreover, based on additional literature and the typology for RE measures, the measures *reduce material quantity, reduce use of auxiliary materials and energy, digest anaerobically or compost, recover energy* and *landfill* were found to be possible RE measure for consumables.

In summary, there are more measures applicable to consumables than those commonly discussed in the CE literature. Moreover, all identified measures showed potential to improve RE, although to a varying extent and under differing circumstances.

For the measure shift to multiple-use product (redesign a single-use product into a durable product) to be an effective, some specific aspects need to be fulfilled. The product needs to be designed to last many times and used enough times to outweigh the environmental impact from production. In addition, an energy-efficient maintenance system using electricity with low fossil-content is essential for multiple-use products. Moreover, when redesigning a product for multiple-use, focus must extend beyond the design of the product and incorporate the whole product system, including the maintenance system and business model.

When changing the materials in a product, there is a risk of burden shifting between environmental impact categories. For example, there is a trade-off between GWP and fossil resource depletion and impact from land use when decreasing the amount of fossil-based materials and increasing the amount of renewable-based ones.

As identified in Paper 1, RE measures can be possible to combine without being dependent on each other. Combining measures may also lead to larger resource efficiency.

However, many of the measures for consumables were found to be dependent of each other. For example, shifting to a multiple-use product requires redesign of the product to make it more durable, which in many cases requires a change of the materials in the product. Similarly, if a product should be capable of being recycled or treated biologically, the consumable product may require a redesign or change in materials to enable the measures.

6 Future research

As discussed, many, if not most, RE measures for consumables depend on design. This means that design plays a central role in which measures can be applied to a product and, in some cases, also whether the measure is going to be effective. There is therefore a need to translate the knowledge from the assessments of RE measures for consumables and the typology of RE measures into design support. In addition, evaluation the resource efficiency of new design is needed.

In the research work following this thesis, I will explore how the obtained knowledge about how RE measures relate to different product characteristics can be used in the design of product systems. In collaboration with colleagues knowledgeable in the design area two design methods based on life cycle assessment, and the framework and findings in Paper 2, respectively, will be developed and evaluated. The two design methods will both focus on resource efficient products and product service systems (e.g. Tukker (2015)). The first design method will be based on life cycle thinking and validated with the LCA results in Paper 1. The second design method will build on the Ten Golden Principles (Luttropp & Brohammer, 2014) by adding knowledge of RE measures and product characteristics generated from Paper 2. Evaluation, such as life cycle assessments of the outcomes using the two design methods, is believed to be of importance to see whether the methods really lead to the intended outcome.

7 References

Allwood, J. M., Ashby, M. F., Gutowski, T. G., & Worrell, E. (2011). Material efficiency: A white paper. *Resources, Conservation and Recycling, 55*(3), 362-381. doi:10.1016/j.resconrec.2010.11.002

Baumann, H., & Tillman, A.-M. (2004). *The Hitch Hiker's Guide to LCA: an orientation in life cycle assessment methodology and application*. Lund: Studentlitteratur.

Bergstrand, H., & Jönsson, C. (2017). *Preparing for tomorrow - Exploring design adaptations of a wheel loader for a circular business model (M.Sc)*. Retrieved from Chalmers University of Technology, Enviornmental systems analysis.

Berlin, J., & Sonesson, U. (2006). Minimising environmental impact by sequencing cultured dairy products: two case studies. *Journal of Cleaner Production, 16*(4), 483-498. doi:10.1016/j.jclepro.2006.10.001

Brezet, H., & van Hemel, C. (1997). *Ecodesign : a promising approach to sustainable production and consumption*. Paris, France: UNEP.

Cambridge, U. P. (Ed.) (2011) Cambridge Business English Dictionary.

Campion, N., Thiel, C. L., Woods, N. C., Swanzy, L., Landis, A. E., & Bilec, M. M. (2015). Sustainable healthcare and environmental life-cycle impacts of disposable supplies: a focus on disposable custom packs. *Journal of Cleaner Production, 94*, 46-55. doi:10.1016/j.jclepro.2015.01.076

Ceschin, F., & Gaziulusoy, I. (2016). Evolution of design for sustainability: From product design to design for system innovations and transitions. *Design Studies, 47*, 118-163. doi:10.1016/j.destud.2016.09.002

Cordella, M., Bauer, I., Lehmann, A., Schulz, M., & Wolf, O. (2015). Evolution of disposable baby diapers in Europe: life cycle assessment of environmental impacts and identification of key areas of improvement. *Journal of Cleaner Production, 95*, 322-331. doi:10.1016/j.jclepro.2015.02.040

Counsell, T. A. M., & Allwood, J. M. (2007). Reducing climate change gas emissions by cutting out stages in the life cycle of office paper. *Resources, Conservation and Recycling, 49*(4), 340-352. doi:10.1016/j.resconrec.2006.03.018

Dones, R., Bauer, C., Bolliger, R., Bruger, B., Fasit Emmenegger, M., Frischknecht, R., . . . Tuchschmid, M. (2007). *Life Cycle Inventories of Energy Systems: Results for Current Systems in Switzerland and other UCTE Countries* Retrieved from Swiss Center for Life Cycle Inventories, Dübendorf, CH

EC. (2008). L 312, 19.11.2008. Directive 2008/98/EC of the European Parliament and of the Council of 19 november 2008 on waste and repealing certain directives. *Official Journal of EU*.

EC. (2015). *Closing the loop - An EU action plan for the Circular Economy*. Retrieved from Brussels. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0614

EC. (2018a, 28 May 2018). European Commission - Press release, Single-use plastics: New EU rules to reduce marine litter. Retrieved from http://europa.eu/rapid/press-release_IP-18-3927_en.htm

EC. (2018b, 2018-04-10). European Commission, Environment, Waste. Retrieved from http://ec.europa.eu/environment/waste/index.htm

EMF. (2013). *Towards the Circular Economy. Economic and business rationale for an accelerated transition*. Retrieved from Ellen MacArthur Foundation. https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf

Goedkoop, M., Heijungs, R., de Schryver, A., Struijs, J., & van Zelm, R. (2009). *ReCiPe 2008- A life cycle impact assessment method which comprises harmonized category indicators at the midpoint and the endpoint level / Report I:Characterisation*. Retrieved from Den Haag, Netherlands. Ministerie van VROM

Gunnartz, K. (2016). *Livsmedel- En branchrapport, IVA- projektet: Resurseffektiva affärsmodeller- stärkt konkurenskraft*. Retrieved from Stockholm, Kungl. Ingenjörvetenskapsakademin (IVA). https://www.iva.se/globalassets/info-trycksaker/resurseffektiva-affarsmodeller/rask-branschrapport-livsmedel.pdf

Helgestrand, A., Lindahl, M., & Svensson, N. (2011). Livscykelanalys och Livscykelkostnadsanalys av lakansskydd- En jämförande studie *Linköpings universitet*.

Hischier, R., Weidema, B., Althaus, H.-J., Bauer, C., Doka, G., Dones, R., . . . Nemecek, T. (2010). *Implementation of Life Cycle Impact Assessment Methods*. Retrieved from Dübendorf. Swiss Centre for Life Cycle Inventories

ILCD. (2010). *ILCD Handbook- International Reference Life Cycle Data System* (First Edition). Retrieved from Luxembourg. Publications Office of the European Union.

ISO 14040. (1997). Environmental management -- Life cycle assessment -- Principles and framework. In.

IVA. (2016, 17 Juni 2016). Resurseffektiva affärsmodeller - branschrapporter. Retrieved from https://www.iva.se/publicerat/branchrapporter-samlingssida/

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling, 127*, 221-232. doi:10.1016/j.resconrec.2017.09.005

Laurent, A., Bakas, I., Clavreul, J., Bernstad, A., Niero, M., Gentil, E., . . . Christensen, T. H. (2014). Review of LCA studies of solid waste management systems--part I: lessons learned and perspectives. *Waste Manag, 34*(3), 573-588. doi:10.1016/j.wasman.2013.10.045

Ligthart, T. N., & Ansems, A. M. M. (2007). *Singe use Cups or Recycleble (coffee) Drinking systems: An environmental comparisson* (2006-A-R0246(E)/B). Retrieved from Ansems, The Netherlands.

Lindahl, M., Sundin, E., & Sakao, T. (2014). Environmental and economic benefits of Integrated Product Service Offerings quantified with real business cases. *Journal of Cleaner Production, 64*, 288-296. doi:10.1016/j.jclepro.2013.07.047

Locke. (Ed.) (1913) Webster´s Dictionary (1913 ed.).

Luttropp, C., & Brohammer, G. (2014). *EcoDesign Roadmap* (1 ed.). Lund: Studentlitteratur.

Mirabella, N., Castellani, V., & Sala, S. (2013). Life cycle assessment of bio-based products- a disposable diaper case study. *Int J Life Cycle Assess 18*, 1036–1047. doi:10.1007/s11367-013-0556-6)

Overcash, M. (2012). A comparison of reusable and disposable perioperative textiles: sustainability state-of-the-art 2012. *Anesthesia & Analgesia, 5*(114), 1055–1066. doi:10.1213/ANE.0b013e31824d9cc3

Oxford. (Ed.) (2010) Oxford Advanced American Dictionary.

Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (2017). *Circular Economy: Measuring Innovation in the Product Chain*: PBL.

Rutala, W. A., & Weber, D. J. (2001). A Review of Single-Use and Reusable Gowns and Drapes in Health Care. *Infection Control and Hospital Epidemiology,, 22*(4), 248-257.

Sakao, T., & Fargnoli, M. (2010). Customization in Ecodesign, A Demand-Side Approach Bringing New Opportunities? *Journal of Industrial Ecology, 14*(4), 529-532. doi:10.1111/j.1530-9290.2010.00264.x

Shu, L. H., Duflou, J., Herrmann, C., Sakao, T., Shimomura, Y., De Bock, Y., & Srivastava, J. (2017). Design for reduced resource consumption during the use phase of products. *CIRP Annals, 66*(2), 635-658. doi:10.1016/j.cirp.2017.06.001

Sørensen, B. L., & Wenzel, H. (2014). Life cycle assessment of alternative bedpans – a case of comparing disposable and reusable devices. *Journal of Cleaner Production, 83*, 70-79. doi:10.1016/j.jclepro.2014.07.022

Stahel, W. R. (2010). *The performance economy* (Vol. 572): Palgrave Macmillan London.

Stahel, W. R., & Clift, R. (2016). Stocks and Flows in the Performance Economy. In R. Clift & A. Druckman (Eds.), *Taking Stock of Industrial Ecology*: Springer, Cham.

Steen, B. (1999). *A systematic approach to environmental priority strategies in product development (EPS). Version 2000 – General system characteristics* (1999:4). Retrieved from Chalmers University of Technology, Technical Environmental Planning

Sundin, E. (2009). Life-Cycle Perspectives of Product/Service-Systems: In Design Theory. In L. M. e. Sakao T. (Ed.), *Introduction to Product/Service-System Design*. London: Springer.

Systembolaget. (2018). Klimatsmartare flaskor. Retrieved from https://www.omsystembolaget.se/hallbarhet/klimat-miljo/lattare-glasflaskor/

Tukker, A. (2015). Product services for a resource-efficient and circular economy – a review. *Journal of Cleaner Production, 97*, 76-91. doi:10.1016/j.jclepro.2013.11.049

UNEP. (2017). *Resource Efficiency: Potential and Environmental Implications. A Report by the International Resource* Retrieved from http://www.resourcepanel.org/sites/default/files/documents/document/media/resource_efficiency_report_march_2017_web_res.pdf

Webster, M. (Ed.) (2018) Merriam- Webster online dictionary.

Williams, H., Wikström, F., & Löfgren, M. (2008). A life cycle perspective on environmental effects of customer focused packaging development. *Journal of Cleaner Production, 16*(7), 853-859. doi:10.1016/j.jclepro.2007.05.006

Xu, C., Shi, W., Hong, J., Zhang, F., & Chen, W. (2015). Life cycle assessment of food waste-based biogas generation. *Renewable and Sustainable Energy Reviews, 49*, 169-177. doi:10.1016/j.rser.2015.04.164