Reducing Isala's operating room waste: A case study with a circular approach

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PREFACE

Dear reader,

You are about to read the bachelor's thesis "Reducing Isala's operating room waste: A case study with a circular approach." This research was executed at the Isala Hospital in Zwolle as the final assignment to obtain my bachelor's degree in Industrial Engineering and Management at the University of Twente.

I want to thank Isala for letting me do my bachelor's thesis at their hospital. This experience was my first time working in a more professional environment and applying the theory I learned from the university to practice. It was an informative experience from which I learned a lot, and I would like to thank my colleagues for welcoming me with open arms. I am also grateful for integrating my passion for sustainability, particularly the circular economy, into this bachelor assignment at Isala.

Special thanks to my two supervisors at Isala, Hamid Aslami and Jacqueline Bosker. Jacqueline welcomed me at Isala and helped me from the start in finding a suitable research topic. When I found my research topic, Hamid was able to guide me for the rest of this research as the subject was closely related to his interest and expertise. I would like to thank them both for their time, guidance, and feedback.

And, of course, a special thanks to my UT supervisor Devrim Yazan. The regular meetings and feedback were beneficial for my research. I was also always able to ask Devrim questions when I needed him.

Additionally, I would like to thank my second supervisor, Erwin Hans. When I approached Erwin, he provided me with this assignment and introduced me to Isala.

Finally, I want to thank my family, friends, and roommates for their support during the execution of this research and particularly the ones who read my work and gave me feedback. They have always supported me.

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MANAGEMENT SUMMARY

This research is conducted at the Isala Hospital in Zwolle. Here, the operating rooms (OR) produce excessive amounts of material waste. Isala would like to reduce this quantity to reach the sustainability targets set in the 'Green Deal' (Rijksoverheid, 2018). One of these targets is to encourage working more circularly in healthcare. Currently, Isala releases its material waste in a cradle-to-grave fashion, by disposing of the materials in an incinerator after use. A circular supply chain must replace the current linear supply chain to prevent this. Therefore, this research aims to answer the following question:

"How to redesign the current linear supply chain of Isala's ORs into a new circular supply chain to reduce hospital waste?"

The theoretical framework covers theories on the following topics: the circular economy, the material science of plastics, life-cycle analysis (LCA), and industrial symbiosis. These theories are used in this thesis to help answer the main research question.

This research analyses a small group of ten medical disposables. These disposables are frequently utilised during daily surgeries and hence form a significant share of the waste pile. The methodology is as follows: Firstly, this research assesses the current supply chain of these disposables. Secondly, a new circular supply chain is designed to reduce hospital waste. Moreover, this methodology includes consideration of the CO_2 emissions during the transportation of these disposables, before and after the implementation of the circular supply chain. This is performed by executing a station-to-wheel LCA of both the current linear and the new circular supply chain.

For the design of the new circular supply chain, this research explored what the most suitable circular strategy for this problem is, using the 10R-model for circularity. Although reducing or reusing materials are more circular options, these strategies were unfeasible due to regulatory constraints. Recycling emerges therefore as the best alternative solution for a circular supply chain design. However, only 4.32% of the waste this group of disposables yearly emits is recyclable, including packaging. The complex material specifications of these disposables make it impossible to recycle the materials properly and use them as input for new processes. Therefore, rethinking the materials first is essential before Isala can recycle. This means that the most sensible strategy is to first rethink and then recycle the materials.

The packaging of the disposables is currently also not recyclable. A hypothetical scenario is created to still design a circular supply chain. In this hypothetical scenario, the plastic foils of the packaging are made from 100% low-density polyethene (LDPE). Here, the materials are rethought and then recycled. Isala can establish a circular supply chain for plastic foils in this hypothetical situation. This scenario creates a circular supply chain in which 925 kg of plastic foils could be saved annually from solely these ten disposables. If more packaging was made from 100% LDPE foils outside this group of disposables, then Isala could save even more amounts of waste by functioning this circular supply chain.

In conclusion, currently, only a fraction of the materials this research has analysed are recyclable. However, if there was a change in packaging materials, Isala could recycle the packaging. That is why this research recommends that Isala first rethink its materials. Advice for future research would be to investigate how suppliers could package their disposables in a more environmentally friendly way. At this point, Isala could potentially recycle a significant share of the material waste and thus reduce its operating room waste.

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READING GUIDE

The reading guide shows how this research is performed. Below, all 6 chapters are briefly introduced.

Chapter 1: Introduction

The first chapter is the introduction. Here the problem that Isala is facing is identified. Chapter 1 provides the approach and methodology to solve this problem, including the research design.

Chapter 2: Theoretical framework

The second chapter is the theoretical framework. Here, certain theories are provided and explained why and how they are used for this research. This theoretical framework covers the circular economy, the material science of plastics, life-cycle analysis, and industrial symbiosis.

Chapter 3: Current linear supply chain

Chapter 3 investigates how Isala's operating rooms dispose of its materials currently. This chapter provides data on how much waste the OR emits and contains a visualisation of the current linear supply chain. Chapter 3 ends with a station-to-wheel LCA of one of the selected disposables.

Chapter 4: Design of the new circular supply chain

A circular supply chain is introduced in chapter 4 to reduce the quantity of material waste produced by the operating room. The 10R-model for circularity is used and suppliers have been contacted to find out the material specifications of the products. With this knowledge, a circular supply chain for the OR is designed.

Chapter 5: Analysis of the circular supply chain

Chapter 5 analyses the new circular supply chain. The new supply chain is assessed by calculating how much kg of material waste Isala saves by running a circular supply chain instead of a linear version. This chapter ends with station-to-wheel LCAs of the old and new supply chains in which this research compares the two.

Chapter 6: Conclusion, recommendations, and future research

The last chapter of this thesis provides the conclusion of this research. Based on the findings, recommendations for Isala are constructed, and these lead to what Isala can research after this thesis in the future.

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List of acronyms

CO_2 – Carbon dioxide

DALY - Disability-adjusted life years

DSRM – Design Science Research Methodology

EIO-LCA – Enterprise Input-Output Life Cycle Approach/Assessment

GNP – Gross National Product

HDPE - High-Density Polyethylene

HL – Hospital Logistics

IS – Industrial Symbiosis

JIT – Just in Time

LCA – Life Cycle Approach/Assessment

LDPE - Low-Density Polyethylene

MPSM – Managerial Problem-Solving Method

MSN – Milieu Service Nederland

OR – Operating Room

PET - Polyethene Terephthalate

PP - Polypropylene

PS – Polystyrene

PVC - Polyvinyl Chloride

SHW – Specified Hospital Waste

SLR – Systematic Literature Review

1 INTRODUCTION

The first chapter of this thesis is the introduction, here is the problem that Isala faces identified. Chapter 1 provides the approach and methodology to solve this problem, including the research design. The problem is identified with the use of the Managerial Problem-Solving Method (MSPM) and the research design is constructed based on the Design Science Research Methodology (DSRM).

1.1 PROBLEM IDENTIFICATION

The first sub-chapter of this thesis is devoted to identifying the problem, this commences with background information on this topic and the problem context. Next, the problem identification method is explained, which is performed using the MPSM.

1.1.1 Background and problem context

This thesis is conducted at the Isala Hospital in Zwolle, which is one of the most significant clinical hospitals in the Netherlands (Bureau STZ, n.d.). Due to the agreement of the 'Green Deal,' signed by Isala and multiple other Dutch healthcare institutions, sustainability has become an increasingly important topic in healthcare in recent years. 'The Green Deal Sustainable Healthcare for a Healthy Future' is about the contribution the healthcare industry could make to improving the environment. The parties involved try to do this in the following four ways (Rijksoverheid, 2018):

- A 49% reduction in carbon emissions by 2030
- **Encouraging working more circularly in healthcare**
- Fewer pharmaceutical residues in drinking water
- A healthy environment for care workers and patients

This research focuses on the second aim of the Green Deal, which is to encourage working more circularly in healthcare.

This thesis is conducted in the purchasing department. Here many various products are acquired for hospital-wide use. The hospital consumes these products in high volumes, which leads to a high volume of material waste. For almost all the products the purchasing department procures for healthcare practices, the waste collector accumulates and incinerates the materials after use. The incineration of all this waste leads to high CO_2 emissions, whilst the hospital is actively trying to reduce its CO_2 emissions to achieve the targets in the Green Deal. According to Gupta Strategists (de Bruin, Houwert, & Merkus, 2019), the Dutch healthcare sector is one of the most significant contributors to CO_2 emissions in the country, with a yearly CO_2 output of 11 Mt [1]. This is about 7% of the total CO_2 footprint of the Netherlands.

This research focuses on the operating rooms (OR) of the Isala Hospital because this department is the biggest polluter. Around 30% of the material waste that hospitals in the Netherlands produce come from the OR department (NOS, 2021).

The high CO_2 emissions from the healthcare sector cause significant environmental pollution, which leads to more pollution-based diseases. Research from the US estimates health damages from pollution are at 470,000 DALYs from pollution-related disease, or 405,000 DALYs when adjusted for recent shifts in power generation sector emissions (Eckelman & Sherman, 2016). DALYs (Disability-adjusted life years) for a disease or health condition are the sum of the years of life lost due to premature mortality (YLLs) and the years lived with a disability (YLDs) due to widespread cases of the disease or health condition in a population (World Health Organization, 2022). According to the WHO, one DALY represents the loss of the equivalent of one year of full health.

[1] 11 Mt = 11000000000 kg

According to that same US study, these indirect health burdens equal the 44,000–98,000 people who die in hospitals each year in the US because of preventable medical errors but are currently not attributed to their health system. Thus, reducing the waste and CO_2 emissions from healthcare processes would benefit the environment and make people less likely to become ill, leading to fewer healthcare costs.

Due to these reasons, it is paramount that the application of more circular strategies in healthcare, specifically in the operating rooms, is encouraged. To eventually reduce waste and achieve the goals set in the Green Deal.

1.1.2 Problem identification method

The first part of this research follows the Managerial Problem-Solving Method (MPSM), constructed by Hans Heerkens (Heerkens & van Winden, 2017). The first phase of the MPSM is the problem identification phase. Here, the problem is defined by first supplying background information on the issue and stating the action problem. Then, a problem cluster is made to visualize the current issues the problem owner is facing in their organization and the relations between the problems. This activity is performed to find the core problem eventually, which is the root cause of all the issues that the problem owner is facing, and that the researcher can influence. By solving the core problem, the action problem should be resolved as well and solving the action problem is the goal of this research.

1.1.3 Action problem

According to the Managerial Problem-Solving Method (MPSM), the action problem is the difference between the norm and reality perceived by the problem owner (Heerkens & van Winden, 2017, 22). In this case, the problem owner is Isala with the problem being its excessive waste production in the OR. This reality contrasts with the sustainability norms set in the Green Deal. The second target of the Green Deal is to encourage the implementation of more circular economic principles in healthcare. By working more circularly, Isala can reduce its waste output and close the gap between reality and the norms set in the Green Deal. Therefore, reducing the residual waste output in the OR is the action problem.

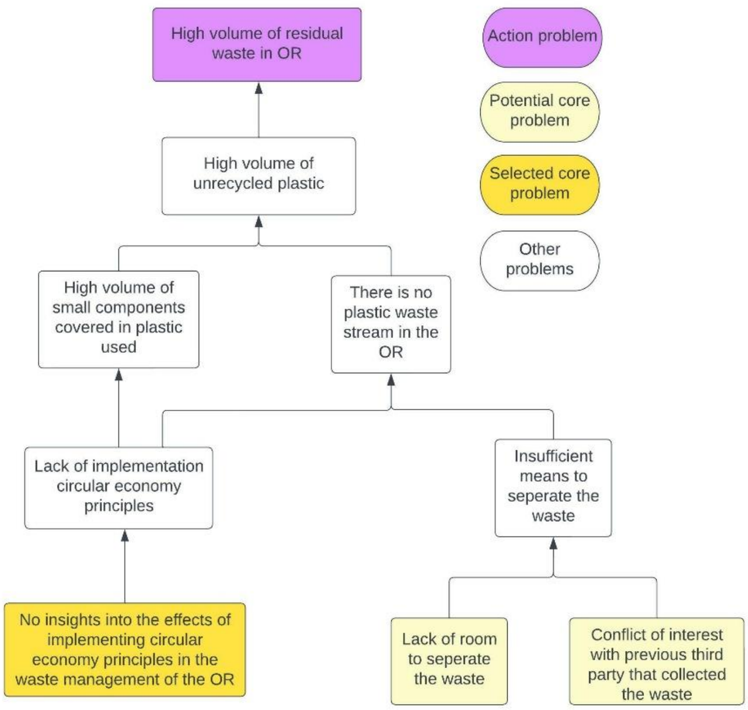

Figure 1: Problem cluster

1.1.4 Problem cluster

The MPSM uses a problem cluster (see figure 1), this is a tool to visualize all problems and their connections. The goal is to bring order to the problem context and eventually identify the core problem (Heerkens & van Winden, 2017, 42).

The problem cluster starts at the top with the action problem. As established in the earlier section, the action problem is the high volume of residual waste in the OR that Isala would like to reduce to close the gap between reality and the norms of the Green Deal. The direct cause of this high residual waste output is the high volume of unrecycled plastic, which is currently a significant share of this residual waste output.

Two causes of this high volume of unrecycled plastic include the absence of a plastic waste stream in the OR and the increased use and disposal of plastic items packaged in plastic in the OR. These two problems share one common cause: the lack of implemented circular economy principles in the OR and healthcare in general. An added reason for the current absence of an additional plastic waste stream is the insufficient means to separate the waste, as there is no room for it, according to Isala. Moreover, Isala's previous waste collector aimed to accumulate as much residual waste as possible to maximize profits. This conflict of interest prevented Isala from implementing a plastic waste stream to reduce the waste output. The last two mentioned issues are potential core problems because there is no direct cause of these individual challenges. Neither is the selected core problem for this research, however, because it is exceedingly difficult for the researcher to change this.

1.1.5 Core problem

This research aims to show that implementing a circular supply chain at the disposal side of the OR could be beneficial for Isala in its pursuit of reducing waste and working more circularly to meet the Green Deal norms. The selected core problem for this research is the lack of insights into the effects of implementing circular economy principles in the OR supply chain for outflowing materials. This problem has been selected as the core problem because it is the most feasible to solve and has the greatest potential to have a significant impact. By creating more insights into these effects, it is possible to show a potential reduction in waste for the problem owner, Isala. Together with the sustainability norms of the Green Deal, this might persuade Isala to work more circularly.

1.2 Problem-solving approach

The next step after identifying the problem is formulating an approach to solve it. For the problem-solving approach, this research uses the D3 method of the MPSM. D3 stands for Do, Discover, and Decide. According to the MPSM, 'Do' encompasses all activities one needs to perform to solve the problem successfully. 'Discover' entails everything one needs to know and understand and 'Decide' is about selecting the correct options (Heerkens & van Winden, 2017).

1.2.1 Do

This research aims to create insights into the possible waste reduction in the OR by implementing a new circular supply chain at the output side. Creating insights into everything used and disposed of during surgeries in Isala's ORs seems unnecessary and time-consuming. Therefore, the first activity is to select a small group of disposables that become the focus of this study. A disposable, in this context, is a medical product designed to be used once and then thrown away (Merriam-Webster, n.d.). This select group of disposables is constructed based on two criteria:

- The materials must have at least the potential to be recycled. If the disposables cannot be potentially recycled, then it is inexplicable to separate the materials into a new plastic waste stream.
- The medical specialists working in the OR must use these disposables frequently. The most significant potential reduction in waste output from the OR is most visible when applied to the most used disposables.

This research analyses a group of ten medical disposables, which have been selected based on the previous two criteria. These are the following ten disposables:

- The six components of the most used infusion system in the OR
- The three components of the most used anaesthesia system in the OR
- The anaesthesia masks

Appendix B contains pictures of these medical disposables as a visual aid.

Other activities to solve the problem successfully include the following: Firstly, the product life cycles will be assessed. Furthermore, the current linear supply chain will be modelled and a design for a new circular supply chain is presented. Isala, the problem owner and decision-maker of this study, could choose to implement this new circular supply chain. Finally, the potential reduction in waste output is calculated.

1.2.2 Discover

To successfully perform the tasks in the 'Do'-section, it is necessary to discover added information. That is why a Systematic Literature Review (SLR) is conducted and what here is covered is presented in the 'Research Design' section. Appendix A provides the Systematic Literature Review.

Moreover, it is necessary to gain more knowledge on the current way of working at Isala, which is obtained through qualitative data by conducting semi-structured interviews with stakeholders of the problem. This knowledge gathering includes tours around the facilities, the operating room itself and the logistics behind the disposed of products to better understand the current situation and how and what could be improved. The following people are necessary to interview to obtain this type of knowledge:

- The medical specialists who work in the OR and utilize these medical disposables
- The suppliers who know about the products life cycle before use and possess the material specifications
- The waste collectors who know what happens with the materials after use in the OR

Quantitative data is also used to model the current situation, this way it is possible to determine how much waste Isala's operating rooms emit from these ten disposables. Quantitative data is necessary to calculate how much material waste the circular supply chain saves. The procurement department provides this type of data.

1.2.3 Decide

Specific aspects of this research must be decided on, a few have already been decided. For example, it has already been decided which disposables are selected to focus on for this research. In the next section (the research design), other decisions regarding the execution of this research will be discussed.

1.3 RESEARCH DESIGN

This section provides the research design, which commences with the introduction of the research objective and then the discussion of the methodology. Furthermore, the research questions and deliverables are addressed and finally, the limitations and constraints of the research design are listed.

1.3.1 Research objective

The research objective is to tackle the core problem and eventually solve the action problem. The core problem was the lack of insights into the effects of implementing circular economy principles in the OR supply chain for outflowing materials. The action problem was the high material waste output in Isala's ORs. Therefore, the research aims to show how Isala can eventually implement more circular principles in its supply chain to reduce waste, which is to replace its current linear supply chain with a new circular one

1.3.2 Research methodology

To improve the existing supply chain present in the OR, the Design Science Research Methodology (DSRM) for information systems by Peffers is used. This research looks at the current linear supply chain and aims to make it more sustainable by designing a new circular supply chain for the OR. The MPSM is less suitable for the remainder of this thesis because this research method is primarily concerned with solving a managerial problem, which is not the case here.

Figure 2 shows the nominal process sequence of Peffers' DSRM (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). The first step is identifying and motivating the problem, which has already been performed in the problem identification section using the MPSM. This research starts with the second activity of the DSRM, which is to define the objectives of a solution. This phase of the DSRM is addressed by constructing research questions and listing the deliverables in the following sections. Activity three is the design and development, here the artefact is created. The artefact for this research is a new circular supply chain for the OR. Activity four requires a demonstration of this new system. In the next phase, the artefact is analysed, which is an iterative process, which means that improvement points are discovered and implemented continuously based on these last two activities. The artefact of this research is assessed based on whether the new circular supply chain creates enough waste reduction. Enough waste reduction for this research is any positive reduction. Thus, if the new circular supply chain does not improve the current linear supply chain, the process of designing a new circular supply chain will be re-evaluated. When this has been executed to satisfaction, then the final phase arrives. The last activity of this research is to communicate the newly found solution and show the new circular supply chain for the OR to the problem owner, Isala. The final phase also includes the conclusion, recommendations, and advice for future research.

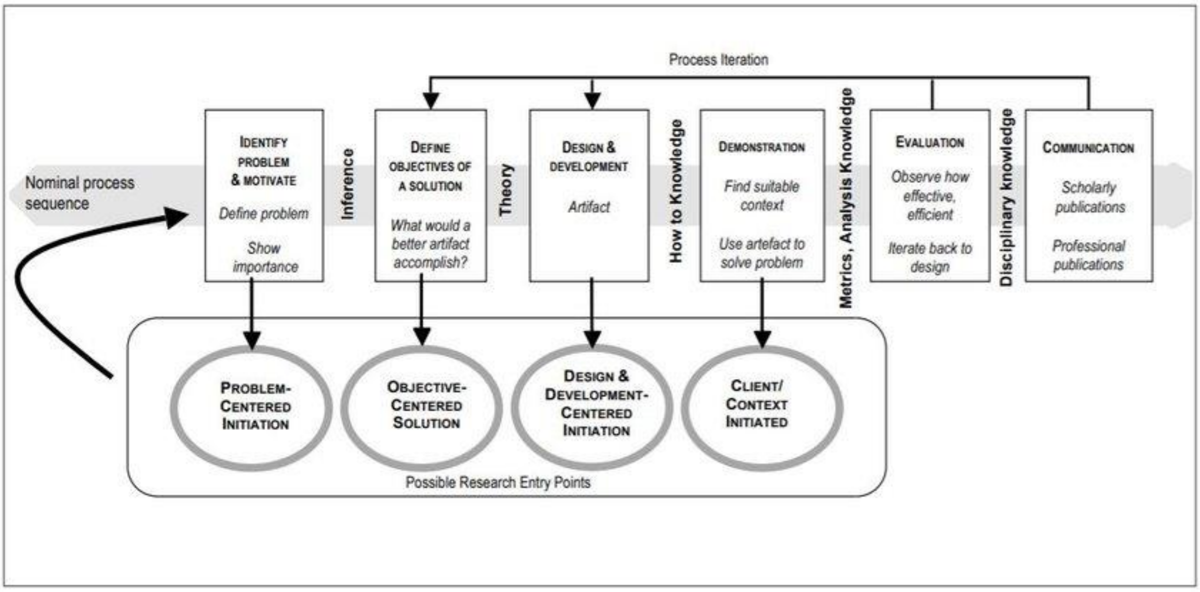

Figure 2: DSRM Process Model

1.3.3 Research questions

The second phase of the DSRM is to define the objectives for a solution. According to Peffers, these objectives are derived from the problem definition and knowledge of what is possible and feasible (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). This study defines these research objectives as research questions. Table 1 shows how the sub-research questions are addressed regarding research type, themes, data gathering methods, deliverables, and to which phase of the DSRM method the research question is related. Additionally, the table addresses which chapter answers the sub-research questions as well. The following research questions are here to answer the main research question:

"How to redesign the current linear supply chain of Isala's ORs into a new circular supply chain to reduce hospital waste?"

The main research question is based on reducing waste from Isala's operating rooms and designing a new circular supply chain. The main research question results in multiple sub-research questions, which are the following:

1. How to use the life cycle approach to model the life cycle of the selected group of disposables?

It is necessary to perform life-cycle analyses to gain insights into the ecological impact of the items disposed of in the OR. How to use and execute the life-cycle approach is explained with the help of the Systematic Literature Review (SLR). Based on the knowledge obtained from this literature review, and interviews with the suppliers, waste collectors and medical specialists, the life cycle of the selected disposables can be analysed.

2. What are the processes in the current linear supply chain of the OR and how much waste does Isala emit?

The second research question uses process modelling to model the current system. The current working method is investigated and then this process with the accompanying waste output is modelled. Interviews with medical specialists and the suppliers mentioned in section 1.1.2 are performed to create insights into this. With data from the procurement department, it is possible to determine how much waste the selected group of disposables currently emits in Isala's operating rooms.

3. What share of the selected group of disposables can be recycled?

None of these products, nor their packaging, are being recycled. For a variety of medical products, it is impossible to recycle because these products are contaminated by patients and must be burned due to health and safety guidelines. In addition to that, not all sorts of plastics are recyclable. That is why this research must find out which plastics are recyclable and what the material specifications are of the selected group of disposables. This is performed by interviewing medical specialists who use the disposables and who know which are contaminated and which ones could be recycled for different purposes. Additionally, the suppliers are contacted to determine the material specifications of these disposables. Also, together with the waste collector, the products are examined to find out which new waste streams can be created in the OR based on the material specifications. Only then, it is possible to calculate the potential waste reduction.

4. What would be the exact processes of a new circular supply chain?

The fourth research question also uses process modelling to design a new system. To develop this new supply chain, knowledge from the previous research question on what materials are recyclable is used. Moreover, knowledge is obtained through interviews with medical specialists to see if they are willing to help separate the materials into different waste streams after use. Also, the new circular supply chain is designed in collaboration with the waste collector to examine what is feasible.

5. What is the potential waste reduction for the OR by implementing the new circular supply chain?

A calculation is made in which the waste output from the new system is subtracted from the old system. This activity is executed to show Isala how the innovative design has reduced their waste output, i.e., solved their action problem. Additionally, a station-to-wheel LCA is performed to compare the transport emissions of both supply chains.

Research question (RQ)	Research type	Themes	Data gathering methods	Deliverables	Phase of DSRM
RQ1 – Chapter 2: Theoretical framework	Exploratory	LCA	Systematic literature review	Theories on lifecycles and circular economy	Define the objectives of a solution
RQ2 – Chapter 3: Current system	Descriptive	Analysing the current linear supply chain	Interviews + purchasing data	Visual representation of the current supply chain for disposables	Define the objectives of a solution
RQ3 - Chapter 2 and 3: Theoretical framework and the current system	Descriptive	Plastics	Desk research + interviews	Knowledge of how much of the materials are recyclable	Define the objectives of a solution
RQ4 – Chapter 4: Improved system	Exploratory	Designing a new circular supply chain	Desk research + interviews	Visual representation of the new circular supply chain for the disposables	Design and development
RQ5 – Chapter 5: Analysis of improved system	Evaluative	Waste reduction	Subtraction calculation	Quantitative insights	Demonstration and evaluation

Table 1: Research questions

1.3.4 Deliverables

This section provides the intended deliverables at the end of the research, which is the result of answering the research questions.

- A visual representation of the current linear supply chain and the new circular supply chain.

After analysing the current linear supply chain to show the reader the current situation, a new circular supply chain is designed. The new circular supply chain should reduce hospital waste and enclose the gap between reality and the sustainability norms crafted in the Green Deal.

- A calculation of how much waste the new supply chain saves for the selected group of disposables. Moreover, a station-to-wheel LCA is provided to compare the transport emissions of both supply chains.

Using the results of the modelled life cycles, it is possible to calculate the difference in waste reduction between the new and old supply chain and evaluate how effective the new circular supply chain is.

- The recommendations

Based on the results, the recommendations provide advice on how Isala can take future steps to achieve the aims of the Green Deal.

1.3.5 Limitations and constraints

This research aims to show how Isala can work more circularly to position itself in a more favourable spot in reaching the Green Deal targets. It is merely focused on the OR, however, because this department is the biggest polluter in the hospital. That is why the numbers this research presents are not illustrative for the entire hospital. Moreover, only a selected group of items are considered. Therefore, this research will not show the waste output of the entire OR before and after implementing the new circular supply chain.

Furthermore, this research only looks at the order data from 2019, 2020, and 2021 since this is the only data provided by the purchasing department.

Lastly, the only way this research compares the new and old supply chain is through the reduction in material waste. No costs or the total CO_2 emissions for the current and new supply chain are provided, due to a lack of data and this would be more suited for an extended master's thesis. Nevertheless, with the available data, transport-related CO_2 emissions can still be calculated by performing the station-to-wheel LCA.

2 THEORETICAL FRAMEWORK

This research uses certain theories and this chapter provides these theories and explains why and how they are used for this research. This theoretical framework starts by presenting principles of the circular economy and the 10R-model of circularity. Secondly, information on the several types of plastics is provided. Furthermore, this theoretical framework covers more theories related to the methodology, such as what LCAs are and how they are conducted. Finally, this chapter provides information on industrial symbiosis

2.1 THE CIRCULAR ECONOMY

2.1.1 Boulding's spaceman economy

In 1966, Kenneth E. Boulding drafted an essay called 'The Economics of the Coming Spaceship Earth' (Boulding, 1966). This essay is known as the first mention of the circular economy. In his article, Boulding describes how the traditional or linear economy is an open system. This open system has unlimited resources to create an unlimited amount of input for the system. For years, mankind thought that this was the case for everything. Earth was viewed as a place with an unlimited number of resources; whenever it looked as if these resources were running out, humans would move on. Later, however, it was discovered that this is not the case and that humans should live as if they were in a closed system, with a limited amount of input and output, which stays consistent. Boulding states in his essay: "The closed earth of the future requires economic principles which are somewhat different from those of the open earth of the past.". These economic principles he mentioned are later called the circular economy principles.

Boulding liked to call the open economy the 'cowboy economy'. This cowboy symbolises the limitless fields in which they operate and is linked with the recklessness and exploitative behaviour of open societies. The closed economy of the back then 'future' is called the 'spaceman economy.' Here, the earth has become a single spaceship with a limited number of resources to live from. Therefore, mankind must find its position in a recurring ecological system that can continuously reproduce materials, even though it cannot escape having energy inputs.

The most significant difference between these two economies is their attitude towards consumption and production. In the open 'cowboy economy', consumption is desired to be as high as possible. This is how the size of the economy and the welfare of a nation (GNP) are traditionally estimated. The aim is to maximize the throughput in this scenario. In the closed 'spaceman' economy, however, it is desired to minimize the throughput, i.e., the consumption and production in the economy. The goal of the spaceship is to have stock maintenance. In the closed economy, the aim is to maintain the amount of stock in the economy through technological change and innovation and minimize the throughput whilst providing enough materials for the current and future generations.

This final thought of the spaceman economy is also heavily linked with how Brundtland defined sustainability. In 1987, Brundtland defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission, 1987). This definition is still widely used today, 35 years later. Boulding inexplicitly used this definition a few decades before Brundtland to picture a more sustainable economy.

2.1.2 Circularity strategies

In a more recent publication by the University of Cambridge (Allwood, 2014), the question is asked whether a fully circular economy, as described by Boulding, is possible or desirable. The circular economy typically creates an image of a fixed number of particles which form the products of today. By reorganizing these particles, it is possible to create the products of tomorrow with the same number of particles in the economy without any input from outside. This concept is called a closed-loop system.

However, if demand grows, the system cannot stay closed as an input needs to be added to the economy to meet the demand. Occasionally it is also the case that recycling is more energy-intensive than simply producing products with new materials. Therefore, the focus should be laid on reducing the rate at which new material is required. This principle is later formed into the mantra 'reduce, reuse, recycle.' This slogan implies that for responsible production and consumption, it is vital to consider whether production can be reduced. Then, one should investigate if products can be reused to enhance the product life span, finally, only if the products have been reduced and reused, or at least tried to be reduced or reused, the product could be recycled at the end of its life span. Recycling is the final option because it requires more energy-intensive processing than reducing or reusing materials.

The mantra 'reduce, reuse, recycle' has been expanded by introducing the waste hierarchy. Or better to be called 'material management hierarchy', as the term 'waste' should be avoided as there is no waste anymore when working circularly. In 2017, the Dutch government published a policy report (Potting, Hekkert, Worrell, & Hanemaaijer, 2017) on the circular economy and encouraged the use of it in production chains. Here, they refer to the 10R-model, a form of the material management hierarchy. Figure 3 shows this 10R-model for circularity strategies in the production chain, in order of priority. The 10R-model adds seven more activities to the mantra 'reduce, reuse, recycle'.

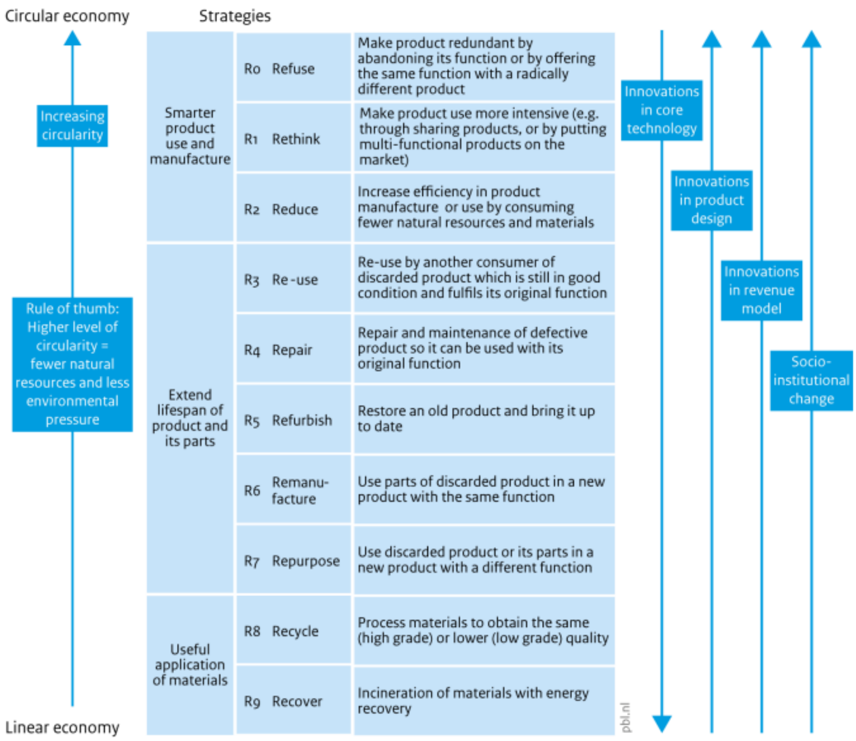

Figure 3: 10R-model of circularity *(Potting, Hekkert, Worrell, & Hanemaaijer, 2017)*

2.2 Plastics

The medical products that this research focuses on are made from plastics. Plastics is the term which applies to a wide variety of materials that, at some stage in the manufacturing, can flow such that they can be moulded, cast, extruded, spun or applied as a coating. Synthetic polymers are usually prepared by polymerization of monomers derived from oil or gas. Plastics are created from these by combining different chemical additives (Thompson, Swan, Moore, & vom Saal, 2009).

The composition of plastics can be adjusted easily to create an infinite variety of products, all consisting of many different chemical additives. Thermoplastics are typically straightforward to recycle because production scrap is often fed directly into the machine that created it (Allwood, 2014). However, this is only the case when the recycled materials are of consistent composition. This is rarely the case for plastics, as the broad range of additives to the material makes plastics a very desirable material to produce. Recycling plastic is therefore less efficient than using it for power generation (Subramanian, 2000). Using plastic waste as fuel for power generation contrasts with the circular economy and its principles. The most vital option for working circularly with plastics is the first R of the mantra, namely, to reduce. Reducing overall demand is the greenest option for plastic production due to the complexity of the composition of materials.

2.2.1 Types of plastic

Plastics are classified into seven categories. These are the following, numbered according to their recycling codes (Hardin, 2021):

1. **Polyethene Terephthalate (PET or PETE)**
   PET is one of the most used plastics and is a type of polyester. It is moulded or extruded into plastic boxes and bottles for packaging foods and drinks, personal care products, and many other consumer products (PETRA (PET Resin Association), 2015). Polyethene terephthalate can be recycled (Miller, 2019).
2. **High-Density Polyethene (HDPE)**
   HDPE is strong and resistant to dampness and chemicals, which makes it ideal for cartons, containers, pipes, and other building materials. HDPE products include detergent/shampoo bottles, milk cartons and plastic toys (Hardin, 2021). HDPE products can also be recycled (Miller, 2019).
3. **Polyvinyl Chloride (PVC or Vinyl)**
   PVC or Vinyl is a strong thermoplastic material. PVC products include pipes, medical devices, and wire and cable insulation. PVC is often used in the medical world because it is germproof, can be quickly disinfected, and functions as a disposable that reduce infections in healthcare. PVC is also the most dangerous plastic to our health, as it is known to percolate harmful toxins throughout the entire lifecycle (Hardin, 2021). Key methods for recycling PVC products include mechanical recycling, chemical recycling, and feedstock recycling (SpecialChem, n.d.).
4. **Low-Density Polyethene (LDPE)**
   Due to its lower density, LDPE is a more flexible, clearer, and softer version of HDPE. This makes LDPE perfect for, for example, plastic wrappings, grocery bags and other thin materials. LDPE can be recycled.
5. **Polypropylene (PP)**
   Polypropylene is one of the most durable forms of plastic and is well-resistant to heat. Therefore, it is often used for food packaging and storage. Dairy products such as yoghurt and butter are often packaged in PP. Also, plastic straws are an example of the application of polypropylene. PP can be recycled
6. **Polystyrene (PS or Styrofoam)**
   Polystyrene, also known as Styrofoam, is a rigid and inexpensive plastic that protects its contents very well. Due to these properties, disposable coffee cups and take-away meal boxes are often made from PS. PS shares the hazardous characteristics of PVC due to similar reasons. Polystyrene is also recyclable.
7. **Other**
   The plastic-type number 7 is not a regular type but a code to encompass all other types of plastic which do not belong in the classification of the previous six or are mixture of multiple types of plastic. Examples of code 7 plastics include eyeglasses, CDs/DVDs, and transparent plastic cutlery. Type 7 plastics are not recyclable (Hardin, 2021).

Figure 4 shows these types of plastic once more.

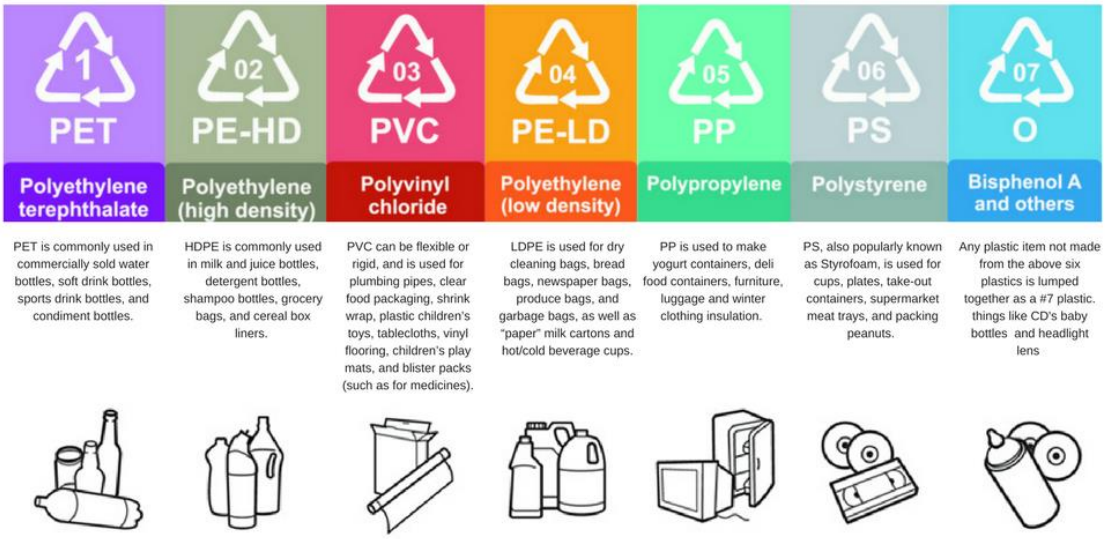

Figure 4: The seven types of plastic *(Greenpeace, n.d.)*

2.3 THE LCA

Life-cycle assessment (LCA) is a 'cradle-to-grave' approach for assessing industrial systems (Scientific Applications International Corporation (SAIC), 2006). 'Cradle-to-grave' starts with collecting raw materials from the earth to create the product and ends when all the materials are back on the earth. In an LCA, all stages of a product's life are evaluated from the viewpoint that they are independent. This means that one process leads to the subsequent. The difference between an LCA and a more traditional environmental analysis is that ecological impacts throughout the entire product life are considered and summed together in LCA. This includes stages such as raw material extraction, transportation, and final product disposal. Therefore, LCA provides a complete view of the environmental aspects of a product or process and a more accurate image of the actual ecological trade-offs in product and process selection.

'Life-cycle' refers to the main actions during the life span of the product; from its manufacture, use, and maintenance to its final disposal, including the raw material acquisition required to manufacture the product. The life cycle of a product often starts with acquiring raw materials, manufacturing, using/reusing/maintaining and finally, the recycling/waste management phase. The inputs of an LCA measured are typically the raw materials and energy put into the process. On the other hand, measured outputs include atmospheric emissions, waterborne wastes, solid waste, co-products, and other releases. According to the ISO[2], a co-product is any of two or more products from the same unit process or product system (Technical Committee ISO/TC 207, Environmental management, 2006).

In other words, LCA is a method to evaluate the environmental attributes and potential effects linked with a product, process, or service, by:

- Creating a list of relevant energy and material inputs and environmental outputs
- Assessing the potential environmental impacts related to the identified inputs and outputs
- Understanding the outcomes helps decision-makers make more informed decisions.

The process of conducting an LCA is systematic and consists of four phases. Figure 5 shows how these phases interact with each other. These are the following phases:

[2] The International Organization for Standardisation (ISO) is an independent, non-governmental international organization that develops standards to ensure the quality, safety and efficiency of products, services, and systems (BDC, n.d.).

1. **Goal Definition and Scoping** – In the first phase of the LCA, one must define the product, process, or activity. Here, the scope of the assessment is determined. This is performed by, for example, identifying the boundaries of the evaluation.
2. **Inventory Analysis** – When the goal of the LCA has been defined and scoped, the inventory analysis can be conducted. Here, one must identify and quantify the energy, water and materials usage and environmental releases, i.e., the inputs and outputs of the process.
3. **Impact Assessment** – In the third phase of the LCA, one must assess the potential human and ecological effects of the inputs and outputs identified in the previous phase
4. **Interpretation** – Finally, the results obtained from phases 2 and 3 are evaluated to select the preferred product, process, or service with a clear understanding of the uncertainty and the assumptions used to generate the results.

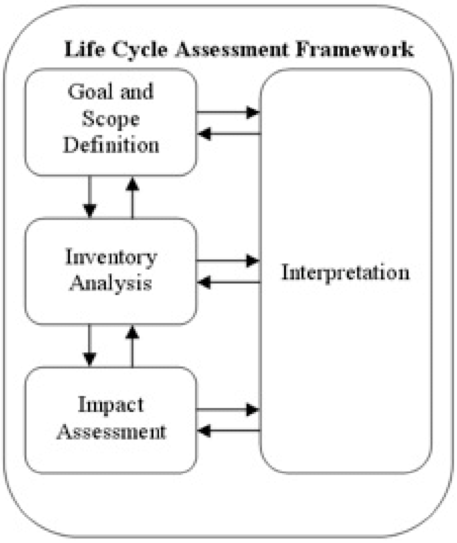

Figure 5: Phases of the LCA *(Technical Committee ISO/TC 207, Environmental management, 2006)*

2.3.1 The EIO-LCA

The enterprise input-output life cycle assessment approach (EIO-LCA) takes a more collective view of the sectors producing all the goods and services in the national economy (Hendrickson, Lave, & Matthews, 2006). Hendrickson uses the U.S. economy as an example in his book. The EIO-LCA has two significant simplifications concerning the 'regular' LCA. Firstly, there is the linearity property. An example from Hendrickson's book illustrates this concept: if 10% more output from a particular factory is needed, each of the inputs will have to increase by 10%. Secondly, all production facilities, which need inputs and create outputs that make products and provide services, can be aggregated into approximately five hundred sectors.

The EIO-LCA uses these two simplifications to produce an input-output table for an entire economy. The benefits of the EIO-LCA include that no boundaries need to be drawn. This would typically be the case in phase 1 of the LCA. This is because, in EIO-LCA, the entire economy is the boundary of the study, therefore, there is none. Moreover, this approach is less time-consuming than the regular LCA. According to Hendrickson, performing an EIO-LCA only takes a few hours and no extra costs when the data is available as an input-output table. However, the disadvantage of this approach is that it is on an aggregate level. To use an example from the automobile industry for clarification, here in an EIO-LCA, the sector 'steel and iron mills' would be used, rather than the specific steel or iron used in the process of making the vehicle (Hendrickson, Lave, & Matthews, 2006).

The book chapter "Use of input-output analysis in LCA" (Mattila, 2017), states that, initially, input-output modelling (IO) was developed for macroeconomic systems analysis and planning. However, since the late nineties, it has increased in popularity to be used with process-based LCA because it shares many approaches and methods with it. Conventional process-based LCA has a critical problem: the exclusion of some parts of the product system, also known as the cut-off. The product system of an LCA resembles that of a branching tree, with multiple tiers until all the identified inputs and outputs are either emissions emitted to the environment or resources extracted.

Input-output modelling does not start from a product, but from data collected, often from inventory, at the whole economy level. That is why it was initially developed as a macroeconomic systems analysis. The total economic, social, and environmental results are allocated to specific industries. This then shows how much direct impact each sector causes during a year of production. That the relationship between production and impacts is linear is a crucial assumption in IO. The two main benefits of this IO approach for LCAs are that it is fast and comprehensive. The 'regular' process-based LCA includes choices about system boundaries and is limited by the resources for inventory collection. An LCA based on input-output modelling, however, has the whole economy as its system boundary.

2.3.2 The well-to-wheel LCA

The well-to-wheel LCA is a non-standardised approach for calculating the effect of transportation fuels and vehicles concerning energy and climate change. This is frequently measured by CO_2 emissions (Wulf & Kaltschmitt, 2016). A well-to-wheel analysis is divided into the following two stages (Mazuchi, 2018):

1. Well-to-station; this stage is related to the extraction or production of fuel, and the 'upstream' section
2. Station-to-wheel or the 'downstream' part relates to how this fuel is consumed and burned during transportation.

Chapter 3 includes a station-to-wheel analysis to investigate the impact of transportation fuels on the life cycle of one of these disposables. For this research, the station-to-wheel LCA was selected because it is the most feasible LCA to perform with the available data. Chapter 5 provides this research with a station-to-wheel LCA of the old supply chain and the new circular version.

2.3.3 Earlier application of LCA in healthcare

An article published last year in the Journal of Hand Surgery (Baxter, Yoon, & Chung, 2021), used IO-based LCAs to estimate the amount of CO_2 emitted during the life cycle of medical supplies, from raw material extraction to production and disposal. Additionally, they surveyed surgeons to investigate the differences in supply use and practice characteristics.

The results of this research were that by leaner use of ten critical items from the operating room, costs and CO_2 emissions could decrease by $22.47 and 10.9 kg per procedure. The primary outcome of this research was that to reduce the costs and environmental impact of hand surgery, the optimal use of disposable supplies is necessary. This research outcome coheres and is also the hypothesis for this research in Isala's operating room. This article uses quantitative (IO-based LCA) and qualitative (surveys amongst surgeons) data, which both contribute to the findings. This American research shows that Isala could potentially also reduce its costs and CO_2 emissions from medical procedures in the OR. Furthermore, it uses a similar methodology to this research. The question is now whether a material reduction is here possible as well.

2.4 INDUSTRIAL SYMBIOSIS

Industrial symbiosis (IS) is a concept that could help Isala to work more circularly in its use of medical disposables in the operating room. Industrial symbiosis is a subfield of industrial ecology that connects conventionally isolated industries and organizations in a cooperative attitude to resource sharing, which benefits both the economy and the environment (Chertow & Park, 2016).

In an industrial symbiosis, the output of organization A is used as input for organization B. This activity promotes working more circularly as waste from organization A is eliminated, and fewer added resources are extracted to produce goods for organization B. Chertow and his colleagues have constructed a '3-2 heuristic' as a minimum to define a network of resource exchanges between organizations as an industrial symbiosis network (Chertow M. R., 2007). This means that at least three organizations must be involved in exchanging at least two different resources to be defined as the most basic form of an industrial symbiosis network.

Industrial symbiosis uses theories from the 10R-model of circularity. By applying IS, the lifespan of products is extended as used products are given a second life. This principle covers the reuse strategies R3 (re-use) up and until R7 (repurpose), but R8 (recycle) and R9 (recover) are also activities that could be performed in industrial symbiosis. The latter two strategies are still useful applications of materials and are better than disposing of the materials in a landfill. Though, more circular strategies in which the lifespan of the product is expanded are preferred.

An IS relationship between two companies can only be established successfully if both parties gain economic benefits from the collaboration (Yazan & Fraccascia, 2020). If this is not the case naturally, then governments can provide incentives in subsidies or construct contracts related to waste exchange which should distribute the costs and benefits fairly. Frequently, there is a mismatch in supply and demand, as the collection of materials is based on the waste production of another company and not on the main activities of the company.

Companies need practical tools which support them in dealing with this quantity mismatch of materials. Therefore, Yazan and Fraccascia have provided a helpful tool for companies by integrating the Enterprise Input-Output (EIO) approach with agent-based simulation. This practical tool starts with creating a cost-benefit analysis for the involved parties of the IS, based on an EIO model. Section 2.3.1 mentioned the input-output approach briefly. Then, the cost-benefit model is integrated into an agent-based model that mimics how the involved companies negotiate the contracts for sharing the added costs to set up an IS partnership. In short, an agent-based model consists of various autonomous decision-makers (agents), each assessing its situation and making these decisions based on a set of rules (Bonabeau, 2002). The proposed model explores the 'space of cooperation', which represents the best conditions to set up an IS in which everyone benefits (Yazan & Fraccascia, 2020).

3 CURRENT LINEAR SUPPLY CHAIN

Chapter 3 investigates how Isala's operating rooms currently dispose of its materials. This chapter uses data from the purchasing department to examine how much waste the selected group of disposables emits in the OR. Secondly, the supply chain of one of these products entering the OR, i.e., the life cycle before use, is studied. Furthermore, a visualisation of the product life after use in the OR is provided. This is performed by modelling the current linear supply chain. Finally, this chapter ends with a station-to-wheel LCA of one of the selected products.

3.1 HOW MUCH MATERIAL WASTE DOES THE OR CURRENTLY EMIT

The purchasing department has provided this research with the order and usage data of the selected disposables over the past four years (2019, 2020, 2021, 2022). This department orders these ten items hospital-wide, however, this research is only interested in the orders meant for the OR. It is assumed that for 2019, 2020 and 2021, the order quantity is equal to the usage quantity. This assumption makes sense as the hospital cannot use more than is ordered, and purchasing will not order more than is needed especially since Isala has a limited inventory capacity because the newly built hospital in 2013 is based on the 'just-in-time'-principle. A Just-in-time (JIT) inventory system is a management strategy in which organisations will only receive goods from their suppliers when they need the goods, to minimize inventory costs (Banton, 2022). Well-performed demand forecasting is necessary for this system to work well.

For 2022, there is naturally a slight increase in order quantity to the usage quantity, which one can find in the inventory room. As 2022 has not ended yet, this research will only consider the usage data for 2019, 2020, and 2021. This is to ensure that all data is reliable and consistent.

Table 2 shows a clear overview of the usage quantity data of these ten disposables for the past three full years. Figure 6 presents this data in the shape of a bar chart. The COVID-19 pandemic did not significantly impact the usage of these items as there were only slight fluctuations in the order quantity between 2019 and 2020-2021. Over the past three years, fewer than a quarter of these ten disposables have been ordered for the OR. This order size is the most significant share of any department in Isala. Based on the assumption that the quantity used is equal to the amount disposed of in a year, this research assumes that also for Isala; the operating room is the biggest polluter in the hospital.

Usage quantity	Product number	Product Description	2019	2020	2021	Average
OR	114680	Narcosis system component #1	34	87	85	69
	115798	Narcosis system component #2	13876	13895	14624	14132
	132664	Narcosis system component #3	13899	13315	14392	13869
	111623	Infusion system component #1	18035	16064	16729	16943
	111624	Infusion system component #2	16436	14536	14798	15257
	141785	Infusion system component #3	27560	23834	24910	25435
	174591	Infusion system component #4	25112	22475	23950	23846
	180711	Infusion system component #5	3644	2960	1841	2815
	322292	Infusion system component #6	25509	23783	25184	24825
	331656	Anaesthesia mask	7519	7732	5830	7027
Total OR			151624	138681	142343	144216
Total Hospital-wide			658866	623455	644399	642240
OR usage percentage total hospital			23.01%	22.24%	22.09%	22.46%

Table 2: Usage data disposables 2019-2021

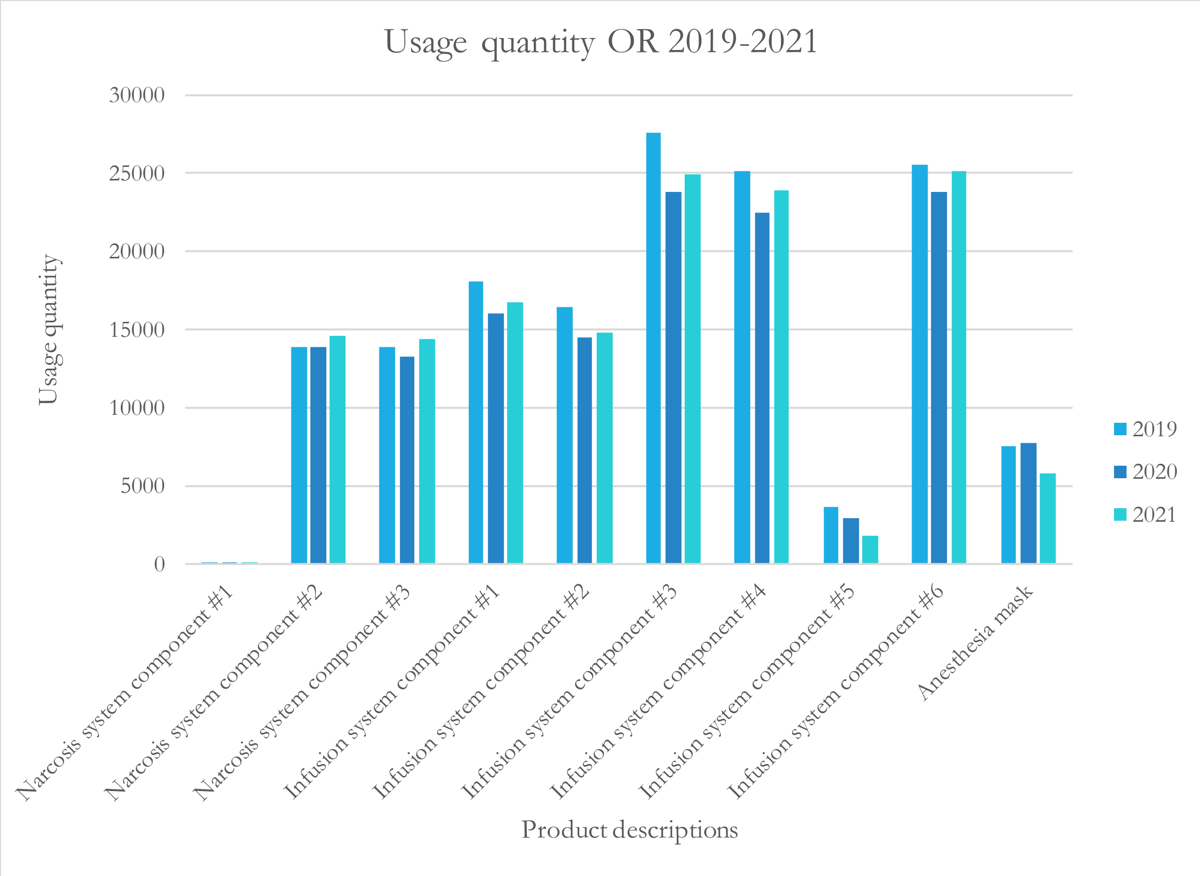

Figure 6: Bar chart usage data medical components

Table 3 provides the weight in grams of each disposable. A simple multiplication of this weight and the usage quantity, supplied by the purchasing department, gives the average yearly material waste emitted from these products in kilograms. This research shows that currently, Isala emits 17375.12 kg of waste from solely these ten products and 22.46% of this amount originates from the operating rooms. These numbers show that Isala's operating rooms emit 3901.61 kg of waste yearly from these 10 disposables. Isala's new waste collector, Milieu Service Nederland (MSN), has estimated the total amount of waste emitted from the hospital. In 2019, this amounted to a total of 396,580 kg of waste (Milieu Service Nederland, 2021). This number only includes waste from products used during medical procedures, e.g., objects such as plastic coffee cups are excluded from this number. Table 4 shows that in 2019, the OR emitted 4058.64 kg of waste from this selected group of disposables; in total, the hospital emitted 17636.41 kg of waste that year. Thus, this small group of disposables that this research considers forms 4.45% of the total waste that Isala emits annually. Table 4 also provides the amount of waste emitted in 2020 and 2021. Figure 7 shows this data visually in the shape of a bar chart.

Usage	Product number	Product Description	Weight product (g)	The average weight of waste per year (kg)
OR	114680	Narcosis system component #1	19	1.30
	115798	Narcosis system component #2	36	508.74
	132664	Narcosis system component #3	19	263.50
	111623	Infusion system component #1	47	796.31
	111624	Infusion system component #2	13	198.34
	141785	Infusion system component #3	5	127.17
	174591	Infusion system component #4	1	23.85
	180711	Infusion system component #5	6	16.89
	322292	Infusion system component #6	52	1290.92
	331656	Anaesthesia mask	96	674.59
Total OR				3901.61
Total Hospital-wide				**17375.12**
OR usage percentage total hospital				22.46%

Table 3: Average yearly waste emitted from these disposables (2019-2021)

Product Description	Waste output (kg) 2019	Waste output (kg) 2020	Waste output (kg) 2021
Narcosis system component #1	0.65	1.65	1.62
Narcosis system component #2	499.54	500.22	526.46
Narcosis system component #3	264.08	252.99	273.45
Infusion system component #1	847.65	755.01	786.26
Infusion system component #2	213.67	188.97	192.37
Infusion system component #3	137.80	119.17	124.55
Infusion system component #4	25.11	22.48	23.95
Infusion system component #5	21.86	17.76	11.05
Infusion system component #6	1326.47	1236.72	1309.57
Anaesthesia mask	721.82	742.27	559.68
Sum OR	**4058.64**	3837.23	3808.96
Total sum hospital	17636.41	17250.66	17243.48

Table 4: Yearly waste output from the 10 disposables

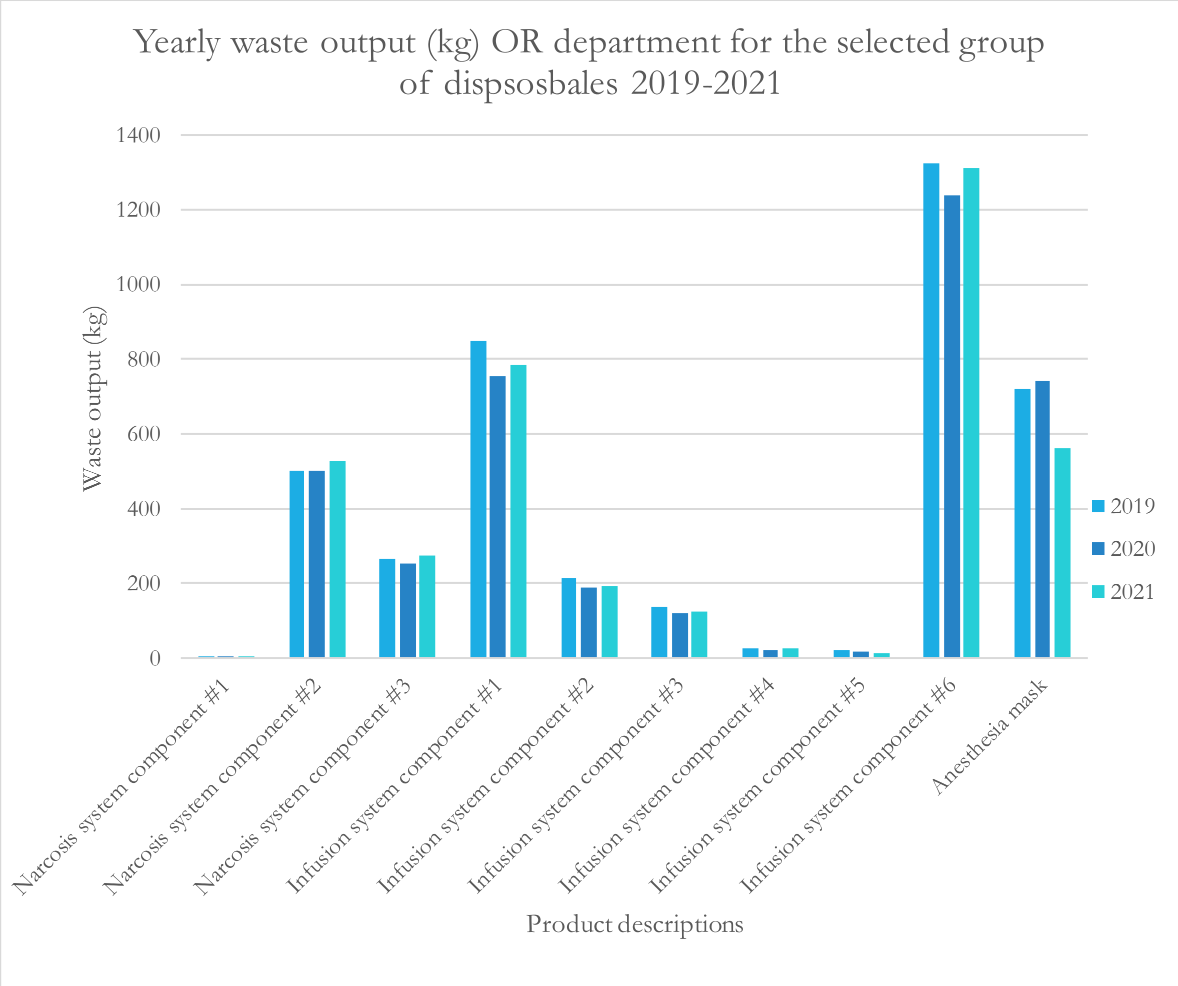

Figure 7: Bar chart of the yearly waste output of selected disposables (2019-2021)

3.2 The current supply chain of materials flowing into the OR

This research focuses on the supply chain of materials flowing out of the OR. Nevertheless, it is also essential to give a perspective of the supply chain of materials flowing into the OR. The life cycles of these products are evaluated from cradle-to-grave. Therefore, suppliers of these disposables have been contacted to learn more about the life cycles of these products. The next sub-section provides the production chain of one of the infusion system components. This disposable has been selected because here the data is available on the product itself and the packaging before use. For the other disposables, no data from this stage is available and only the packaging after use is considered in this thesis. The suppliers have been anonymised for this research. Table 5 shows which supplier delivers which disposable.

Product number	Product Description	Supplier
114680	Narcosis system component #1	Supplier A
115798	Narcosis system component #2	Supplier B
132664	Narcosis system component #3	Supplier B
111623	Infusion system component #1	Supplier C
111624	Infusion system component #2	Supplier C
141785	Infusion system component #3	Supplier D
174591	Infusion system component #4	Supplier E
180711	Infusion system component #5	Supplier E
322292	Infusion system component #6	Supplier F
331656	Anaesthesia mask	Supplier G

Table 5: List of suppliers

3.2.1 Infusion system component #2

The infusion system that is considered for this research, consists of six components. These six components come from four different suppliers. Supplier C provides Isala with the product known in this report as 'infusion system component #2' with product number 111624. For the remainder of this report, infusion system component #2 will be abbreviated to IS2.

According to supplier C, the various parts of the IS2 are produced at the production facility of a third party in Bad Hersfeld (Germany). This third party is a manufacturer of medical devices, specialising in, among others, infusion therapy (Fresenius Kabi AG, n.d.). Supplier C has designed the part, and the third party produces and packages it at the request of supplier C. When the features of the IS2 have been created, they are transported by truck to the assembly facility in Błonie (Poland). After assembly in Poland, supplier C collects the final product and transports it to its warehouse in Oss (the Netherlands). Before it finally arrives in Isala's inventory room, the part is delivered to a carrier called Hospital Logistics (HL) in Apeldoorn. HL provides Isala with all the products (medical and non-medical) that they need for daily operations. According to an Isala logistical employee, HL arrives at the hospital thrice a day. This is necessary due to the limited inventory capacity (just-in-time principle). Figure 8 depicts the supply chain of IS2.

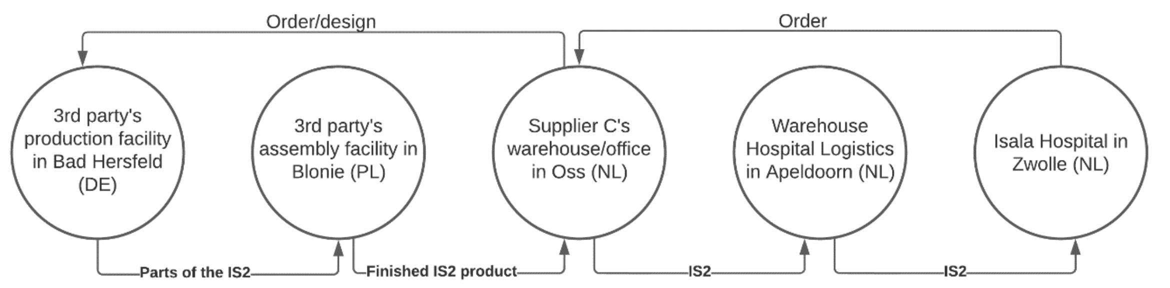

Figure 8: Supply chain of the IS2

3.3 THE CURRENT SUPPLY CHAIN OF MATERIALS FLOWING OUT OF THE OR

Supplier F is a supplier of one of the infusion system components, this part is manufactured in their production facility in Sabiñánigo (Spain). They deliver the bag containing the fluids. After manufacturing, it gets transported to supplier F's warehouse in Utrecht. Hospital Logistics is the third party that receives the product from supplier F and delivers it just in time for Isala to use it. Tables 2,3, and 4 refer to this product as 'infusion system component #6'.

Supplier F's fluid bags are an example of a product treated during its disposal as 'specified hospital waste'. Specified hospital waste (SHW) is waste that patients have contaminated. According to the law, SHW must be incinerated completely with waste packaging for hygiene reasons and the risk of contamination (Renewi, n.d.). The incineration of waste leads to high CO_2 emissions. Milieu Service Nederland (MSN) transports specified hospital waste to the incinerator in Antwerp (Belgium) (Milieu Service Nederland, 2021). Not only is CO_2 emitted from burning this waste but also from transporting it for such a long distance.

The current supply chain of infusion systems flowing out of the OR is elemental. These materials are plastic medical disposables packaged in mostly plastic. After the medical products have been used in the OR, the OR staff dispose of the materials in yellow bins. These bins indicate that they are specified hospital waste. MSN collects and transports this waste stream to a special incinerator in Antwerp. This is a basic linear process in which the product's life ends not long after it has been used once in the OR. This supply chain is modelled using Business Process Modelling Notation 2.0 in figure 9. The narcosis system components and anaesthesia masks, however, are disposed of in a 'regular' residual waste stream. This means these materials become incinerated after one use in the operating room. For the regular residual waste stream, MSN transports this waste to the closest incinerator when the maximum capacity has been reached. The only difference is that the incineration distance is shorter, and its costs are lower. The same principle is applied to the packaging of all ten disposables.

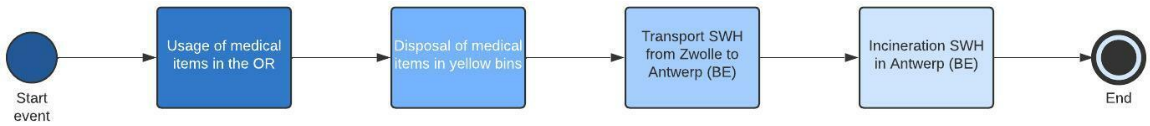

Figure 9: Linear supply chain of specified hospital waste

During a semi-structured interview conducted with a doctor who uses the medical disposables daily, it was revealed that supplier F's fluid bags are not contaminated by patients in reality. This discovery is also the case for most other selected disposables. Only the needle end of the infusion system is infected with blood and should, therefore, still be treated as SHW. This report refers to that part as 'infusion system component #5'. Thus, most plastic medical disposables are incinerated in Antwerp for no reason. There is exciting potential for applying circular principles to these bags and the other products.

The OR staff currently dispose of the materials in either the SHW or residual waste stream. The interviews have shown that the OR staff is willing to work more sustainably. The problem is that they do not know how, as the OR staff lacks the knowledge of which materials can be disposed of in which waste stream. Also, there is currently no supply chain for these waste streams, hence that needs to be created before the doctors and nurses can separate the waste. Chapter 4 looks at the design of a new circular supply chain for materials flowing out of the operating room. Here, using the 10R-model for circularity, it is investigated which circular principles could be implemented to reduce Isala's OR waste.

3.4 Station-to-wheel LCA

Since the locations of the different facilities involved in this supply chain are known, the distances between these locations are straightforward to determine. This knowledge allows this research to estimate the amount of transport-related CO_2 emissions in this supply chain. Using this data, it is possible to create a station-to-wheel LCA of infusion system component #2.

According to the European Federation for Transport and Environment, the average truck in the EU emits 52.7 grams of CO_2 per tonne-km (Transport & Environment, 2021). This LCA makes two assumptions to calculate the CO_2 emissions from the transport of the IS2. The first assumption is that the trucks used during this life cycle emit the same CO_2 per tonne-km as the EU average. Secondly, it is assumed that the most popular type of truck is used for transportation, namely the semi-trailer truck. The semi-trailer truck weighs around 4.6 tons with a load capacity of about 26.4 tons (Lampi, 2020). This adds up to a total weight of 31 tons. Table 6 shows the distances between the various locations and uses the average weight of the truck and the EU average CO_2 emissions per tonne-km to estimate the carbon emissions in this supply chain during transport. This research estimates that almost 3000 kg of CO_2 is emitted during transport in the life cycle of a truckload of IS2.

City A	City B	Distance (km)	A rough estimation of transportation-related CO_2 emissions (kg)
Bad Hersfeld	Błonie	568	927.9416
Blonie	Oss	922	1506.2714
Oss	Apeldoorn	82	133.9634
Apeldoorn	Zwolle	39	63.7143
Zwolle	Antwerp	221	361.0477
Sum		1832	**2992.9384**

Table 6: Distance between locations and CO_2 emitted

4 DESIGN OF THE NEW CIRCULAR SUPPLY CHAIN

The previous chapter described the current way of working, here it was concluded that currently, the life cycle of these materials is linear. A circular supply chain is introduced in this chapter to reduce the waste that the operating room is releasing. Section 4.1 discusses the different circular strategies in general. Then, in section 4.2, the most suitable circular strategy is selected to solve Isala's problem and explained for what reason it has been chosen. Finally, in section 4.3, a design of the new circular supply chain is provided based on the most sensible circular strategy for Isala.

4.1 THE CIRCULARITY STRATEGIES

The 10R-model for circularity – depicted in figure 3 – is used as a framework to model the new circular supply chain for materials. The 10R-model is a ladder with different circular strategies. The higher the strategy is placed on the ladder, the more circular the strategy is. That is why this research gradually goes over the methods to see which one suits this problem best, starting with R0 and ending when a feasible solution has been found. This section is divided into three subsections. Firstly, the reduce strategies (R0 up and until R2) are discussed. Next, the reuse strategies (R3 up and until R7) will be investigated and finally, this sub-chapter ends with the recycling strategies (R8 and R9).

4.1.1 Reduce strategies

The three most circular strategies in the 10R-model are concerned with smarter product use and manufacture. These are the following strategies: refuse (R0), rethink (R1) and reduce (R2). In these strategies, fewer natural resources are used, which makes these strategies more circular. Here, an emphasis is placed on lowering the input of the process. Reducing the input of a process will naturally also lower the output of the process. This concept is also related to the linearity property of EIO-LCA. In this case, the process is the medical surgeries occurring in the OR. The input is the medical disposables before use, and the output is the material waste. Thus, in theory, reducing the number of disposables used for surgeries in the operating room would be the most circular and ideal option for the new circular supply chain.

However, this theory does not coincide with reality. In practice, Isala cannot reduce the number of disposables used during surgeries. Daily, there are a varying number of surgeries taking place in the OR. For the surgeries in the OR, the medical specialists use an X number of disposables. In theory, there are only two ways to lower the number of disposables used. Either the number of surgeries decreases or the number of medical products used during surgery is reduced. Neither of these options is feasible. In the hospital, the health of its patients is the top priority. If a patient needs surgery, then this must be performed, even if the surgery requires many plastic disposables.

The most feasible way for which to use these types of strategies is to promote living a healthier lifestyle. Several studies have shown how healthy habits can prevent diseases, treatment, and surgeries (Rippe, 2018). This concept of promoting healthy lifestyles to treat patients is called lifestyle medicine. The six pillars of lifestyle medicine include: eating healthy, increasing physical activity, stress management, forming and maintaining relationships, adequate sleep, and reframing from smoking (American College of Lifestyle Medicine). The WHO and several national governments have set up multiple programmes to promote living a healthy lifestyle already (New Delhi: World Health Organization, Regional Office for South-East Asia, 2017). The Dutch government, for example, launched a campaign last year to help its citizens live healthier (NOS Nieuws, 2021). The campaign was called 'fit op jouw manier' (translated: fit in your way). In this campaign, the government would provide its citizens with tips on how to live a healthier lifestyle. Yet, the people could decide which lifestyle tips suited them best personally.

In conclusion, from a demand-side perspective, the most rational way to reduce the number of disposables used would be to promote a healthier lifestyle. Because when a population lives healthier, this leads to less treatment of diseases and thus fewer surgeries. Fewer surgeries would also mean less waste, however, this task seems more appropriate for the government rather than Isala. Therefore, this is not a feasible circular solution to Isala's problem.

4.1.2 Reuse strategies

The second group of circular strategies that could be applied to the OR supply chain are concerned with expanding the lifespan of products used during surgeries. Initially, this meant reusing (R3) products to extend their lifespan. Later, however, as the mantra 'reduce, re-use, recycle' has evolved into the 10R-model for circularity, the following strategies related to expanding the lifespan have been added, in descending order of circularity: repairing (R4), refurbishing (R5), remanufacturing (R6), and repurposing (R7).

As mentioned in the third chapter, the whole infusion system is currently disposed of in a waste stream called 'specified hospital waste' (SHW). MSN transports SHW to an incinerator in Antwerp. The law has made this separate waste stream in hospitals obligatory for materials contaminated with patients' blood. These products used in the OR are disposables, meaning they are intended only to be used once. Medical disposables used in the OR are sterile and thus cannot be used when they are not completely clean anymore. This makes the products exceedingly difficult to reuse. According to health and safety guidelines obtained from the interviews, it is impossible to decontaminate SHW and reuse the products.

The hospital also uses reusable products, such as the tools used for surgeries to operate on the human body. The main difference between disposables and reusables is that the disposables are made from plastic and are of low value. The reusable products, however, are made from metal, are of higher value and can be easily sterilised. Sterilisation happens regularly in the hospital, and a group of logistical employees, within the hospital, transport equipment from and to the OR to the sterilisation department, where reusables are decontaminated and can be used for further practice.

One could argue that using reusable infusion systems instead of disposable ones might solve this problem. PremierPro produces reusable pressure infusion bags, for example (S2S Global, n.d.). These bags are tear resistant and made from solid denier nylon. According to the manufacturer, this product can be reused in the operating room after cleaning it with a solution of mild detergent and water. Looking at the 10R-model for circularity, this is a more sustainable alternative to the plastic disposable infusion bags that Isala currently uses. The problem is, however, that Isala cannot sterilise these bags due to a capacity problem in their facility. After use, these bags would have to be transported back to the manufacturer, and the manufacturer would then properly sterilise the bags. Implementing this alternative would require the design of a whole new supply chain. Even more important is that health and safety regulations make it impossible for Isala to use these bags again. Moreover, the liquid in the infusion bags must also be sterile, which is another obstacle.

4.1.3 Recycle strategies

The last set of circular strategies from the 10R-model that Isala could apply is concerned with the useful application of materials, either recycling (R8) or recovering (R9) is meant here. Currently, Isala is recovering the materials by incinerating them for energy. This method is the least circular strategy in the 10R-model, as this is the traditional linear way of disposing of materials. A more circular approach instead of recovering is recycling the materials. When the materials are recycled, the same or lower quality can be obtained through manufacturing. This method is, after recovery, the least circular strategy. As more natural resources are necessary, more environmental pressure occurs than when the product life is expanded or if the amount of input could be reduced. Due to the health and safety guidelines, recycling specified hospital waste is not possible, but for the residual waste stream, it is.

4.2 Rethink and recycle

The previous sub-chapter discussed all available circular strategies. This section selects the most suitable strategy to solve Isala's problem, which is a combination of first rethinking and then recycling its materials. This sub-chapter explains why this strategy has been selected.

4.2.1 Rethink

Firstly, Isala must rethink its materials. The third sub-question of this research is: "*What share of the selected group of disposables can be recycled?*" The material specifications were essential to determine what (parts) could be recycled. For this research, various suppliers were contacted to acquire the material specifications of their products. Together with Isala's waste collector, Milieu Service Nederland (MSN), it was investigated which parts of the products MSN could recycle. The results were that due to the complex material specifications of these products, it was impossible to recycle most of them.

The infusion system, narcosis system and anaesthesia masks are all made from plastic; however, they are produced with the help of a high number of diverse kinds of plastic. MSN can only provide a circular solution for a few types of plastics. The types of plastic include polyethene terephthalate (PET), high-density polyethene (HDPE), low-density polyethene (LDPE), polypropylene (PP) and polystyrene (PS). For other types of materials, a third party could be consulted that can recycle these materials and could set up a circular supply chain or industrial symbiosis.

Supplier C's infusion delivery system is used as an example to illustrate this issue. Appendix C shows figure 14 and table 11, in which a technical drawing and the material specifications of this product are portrayed, respectively. In this report, this part of the infusion system is known as 'infusion system component #1' or IS1. This delivery system consists of seventeen parts. Only a few of those parts are made from recyclable plastics and MSN can provide a circular solution for them; the other parts would still be incinerated because they are too complex to recycle. For the IS1, this would mean that only the protective cap, air ventilation cap (both made from PP) and the closure-piercing device (made from PS) would be recyclable. The latter is also challenging to dissect from the delivery system if one would like to recycle it. The other disposables have this problem as well. MSN cannot recycle these disposables due to their complex material specifications or only a fraction of these materials. For this small portion of materials, it is not worth the effort to create a new circular supply chain, as the operating room would produce too little waste from these processes. Furthermore, dissecting the disposables after use to separate the materials into different waste streams would take too much time for the medical staff working in the operating room. Their main task is treating patients and not dissecting and separating materials.

The complexity of recycling the materials also applies to the packaging. The disposables are packaged in two parts. Firstly, there is the bottom part. This is made from a material similar to paper; however, it cannot be categorised as paper due to the coating layer. This coating layer makes it impossible to treat it as paper and dispose of it in the paper waste streams. This paper also has chemical substances added to it during the manufacturing process. When opening the packaging of the disposables, the plastic and paper part can be separated effortlessly. As concluded in the previous paragraph, the paper part cannot be recycled due to its composition. The other part of the packaging is made from see-through plastic foils. A similar story can be told for the plastic part, as for most plastic packaging, glue or another substance has been added, making it impossible to recycle and must still be disposed of in the residual waste stream.

This research concludes that for this selected group of disposables, Isala could only recycle the plastic packaging of the infusion bags and the anaesthesia masks. This finding was determined by an expert from Milieu Service Nederland. These are the only packaging types that do not contain additives that make recycling more difficult. For those reasons, it is paramount for Isala to first rethink its materials because right now the material specifications are too complex to recycle.

4.2.2 Recycle

This research has discovered, for the selected group of disposables, which share of materials Isala could recycle. Since the share of recyclable materials from this group of disposables is minuscule, it would be unsound to design a new circular supply chain. Isala's operating room would produce too little waste for MSN to collect and create new products. According to MSN, to set up a circular supply chain, the waste stream must generate at least 1000 kg annually. As of now, Isala is far away from this threshold. The specific numbers are provided in chapter 5 during the analysis of the circular supply chain. Because the recyclability of these materials is inadequate, Isala must first rethink. When Isala has rethought its materials, then the hospital can recycle them. To illustrate this, this research creates a hypothetical scenario where the packaging is recyclable after Isala has rethought its materials. A hypothetical situation in which the suppliers of these disposables package their products in a way that Isala could quickly dispose of in a separate plastic container and MSN could transform into new products. The packaging would be made from low-density polyethene (LDPE) in this hypothetical situation, which is a material easier to recycle than the ones currently used. This approach is a combination of two circular strategies, rethinking and recycling. First, the materials and their use are rethought by thinking of using more sustainable alternatives to the current materials. Later, the new, more sustainable materials are recycled which allows them to be used in the manufacturing process for different purposes

4.3 THE NEW HYPOTHETICAL CIRCULAR SUPPLY CHAIN

The final sub-section of this chapter is devoted to showing how Isala's new circular supply chain would look in the hypothetical scenario. In this hypothetical situation, Isala has rethought its materials and is now able to recycle. This chapter ends with a visual representation of the new supply chain.

This hypothetical scenario needs one assumption, which is that the foil packaging is made from 100% LDPE and thus no glue or other substances were added. In this case, the OR doctors and nurses could separate the packaging into a distinct waste stream. Milieu Service Nederland would then collect the plastic foils and transport these foils to their facility unit in Diemen, called Recycling Diemen. Here, the plastic foils are compressed into bales that would be sold and transported to a third party. This third party could be Kras Volendam, who is a manufacturer of foils and could use Isala's old foils to produce new foils. The input for Kras' manufacturing process would be a combination of Isala's packaging waste and additional raw materials, to make new LDPE materials with similar quality. These foils could be used to create new packaging. There even is a possibility that Isala's suppliers of medical disposables use plastic foils produced by Kras for packaging their disposables. Figure 10 portrays this hypothetical circular supply chain. The distinct colours represent the stakeholders involved in this supply chain: Isala, MSN, Kras Volendam and Isala's suppliers, respectively. This circular supply chain is also an industrial symbiosis because waste generated from Isala's processes is now used as input for Kras' manufacturing processes. Chapter 5 analyses the new hypothetical circular supply chain and provides the necessary computations.

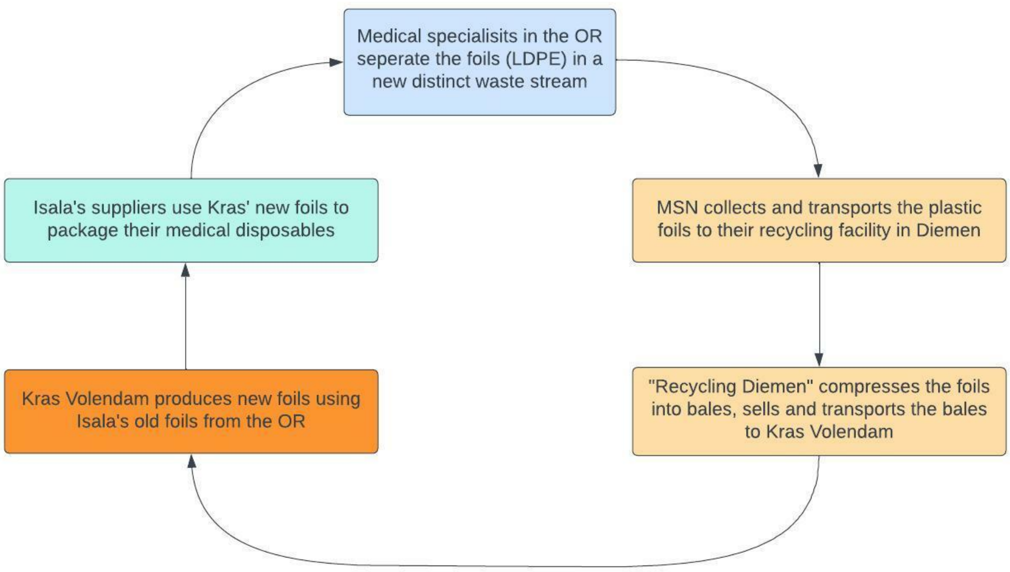

Figure 10: New hypothetical circular supply chain

5 ANALYSIS OF THE CIRCULAR SUPPLY CHAIN

This chapter analyses the new circular supply chain. This activity is performed by calculating how much kg of waste Isala could save by functioning in a circular supply chain instead of a linear supply chain. According to the research design (section 1.3), the circular supply chain can be labelled as successful if the circular supply chain shows any positive reduction in waste. Finally, this chapter provides a station-to-wheel LCA of the current and new supply chain.

5.1 THE LOW SHARE OF RECYCLABILITY

Chapter 4 has concluded that designing a circular supply chain for the OR is currently unfeasible since only a fraction of the materials can be recycled. The protection cap of the delivery system is an example of this fraction, this part is made from PP and could be recycled if there was a plastic waste stream in the OR. However, there is none and establishing this plastic waste stream and circular supply chain for only this piece of material is unrewarding. In total, without packaging, these ten medical disposables sum up to a weight of 185 grams. The total sum of recyclable materials adds up to 8 grams. This means that only 4.32% (=8/185) of these materials are recyclable, excluding the packaging. This point, combined with the fact that Isala would have to instruct the doctors and nurses in the OR on which parts of the medical devices they can recycle and which parts not, makes establishing a circular supply chain for the OR impossible for now.

Tables 7 and 8 provide the findings of this research in numbers. Table 7 shows the weight in grams of each disposable, which has been weight with and without the packaging. This activity is performed to discover what share of the weight is from the disposable itself and which percentage comes from the packaging. The packaging weight has been obtained by subtracting the weight of the disposable, including the packaging minus the weight of the disposable without the packaging. The rightmost column is copied from table 2, which shows the average yearly usage quantity between 2019 and 2021 for each disposable.

Product number	Product Description	Weight product (g)	Weight without packaging (g)	Weight of packaging (g)	Average usage quantity 2019-2021
114680	Narcosis system component #1	19	9	10	69
115798	Narcosis system component #2	36	32	4	14132
132664	Narcosis system component #3	19	13	6	13869
111623	Infusion system component #1	47	44	3	16943
111624	Infusion system component #2	13	9	4	15257
141785	Infusion system component #3	5	4	1	25435
174591	Infusion system component #4	1	0	1	23846
180711	Infusion system component #5	6	0	6	2815
322292	Infusion system component #6	52	42	10	24825
331656	Anaesthesia mask	96	32	64	7027
Sum		294	185	109	

Table 7: The weight and usage quantity of each disposable

Table 8 reveals the following for each disposable:

- The average annual weight of packaging waste (kg)
- The weight of paper packaging (g)
- The weight of plastic packaging (g)
- The yearly average weight of plastic packaging waste that could be saved by functioning the new circular supply chain (kg)

The average annual weight of the packaging waste is calculated by multiplying the packaging weight by the average usage quantity. Both these types of values were retrieved from table 7. For each disposable, the (non-recyclable) paper part has been weight. This number was then subtracted from the total packaging weight to obtain the weight of the plastic part. The paper part was weighed rather than the plastic part, because the paper part had a description of the disposable on it, making it easier to allocate the right packaging with the correct disposable. Finally, by multiplying the plastic packaging weight by the average usage quantity from table 7, the average annual weight of plastic waste from each disposable was achieved. By summing these values, this research claims that the operating room currently emits around 925 kilos of plastic packaging waste solely from these ten disposables.

Product number	Product Description	Average annual weight packaging waste (kg)	Weight of paper packaging (g)	Weight of plastic packaging (g)	Average annual weight of plastic packaging waste (kg)
114680	Narcosis system component #1	0.69	3	7	0.48
115798	Narcosis system component #2	56.53	2	2	28.26
132664	Narcosis system component #3	83.21	1	5	69.34
111623	Infusion system component #1	50.83	2	1	16.94
111624	Infusion system component #2	61.03	1	3	45.77
141785	Infusion system component #3	25.43	0	1	25.43
174591	Infusion system component #4	23.85	0	1	23.85
180711	Infusion system component #5	16.89	0	6	16.89
322292	Infusion system component #6	248.25	0	10	248.25
331656	Anaesthesia mask	449.73	0	64	449.73
Sum		**1016.43**		109	**924.95**

Table 8: Packaging waste

5.2 The evaluation of the hypothetical circular supply chain

It is impossible to design a circular supply chain currently when looking at this set of medical disposables. Therefore, section 4.3 illustrates a hypothetical situation in which the packaging of the disposables is made from 100% LDPE material. Furthermore, a circular supply chain is introduced for this hypothetical situation.

For this research, during chapter 3, the medical disposables were weight to know how much kg of waste materials flows out of the OR yearly. For 2019-2021, this came to around 3901 kilograms of waste annually on average. The disposables have been dissected to find out what share is recyclable. The disposables were weight again, this time without packaging. This weight has been subtracted from the original weight measured in chapter 3 to determine the packaging weight.

The results of this process were that the packaging of this set of medical disposables sums up to 1016 kg of material waste. When the paper is subtracted from this number, this results in 925 kg of plastic foil waste. This finding means that around a quarter of material waste from this set of disposables currently consists of plastic foils. Thus, if the packaging of these disposables were made from 100% LDPE, Isala's operating rooms could reduce residual waste by 925 kg annually by working more circularly. A vital assumption here is that the weight of the plastic packaging part remains the same after it has been replaced by 100% LDPE material. This number excludes the packaging that stays behind at HL for sterile delivery of the disposables. Again, this is only the case for the selected group of disposables. If more disposables were packaged with recyclable materials, then even more material waste could be saved and given a second life. MSN has stated that they could turn this into a real case if Isala produces more than 1000 kg of material waste from this waste stream. This research concludes that solely from ten types of disposables, 925 kilograms of plastic foils are generated annually on average. Therefore, it is possible to confidently assume that Isala's OR department generates more than 1000 kg of plastic foils annually in total. This assumption is undoubtedly the case hospital-wide, as MSN could also collect the plastic foils if the entire hospital separated these materials into a distinct stream.

In conclusion, the new hypothetical circular supply chain can be evaluated as successful as Isala would work more circularly and produce and incinerate less unused waste.

5.3 The station-to-wheel LCA of the circular supply chain

This chapter ends with a station-to-wheel LCA of the new hypothetical circular supply chain. The locations of the distinct facilities in this industrial symbiosis are known. This data is necessary to conduct a station-to-wheel LCA. The assumptions on the weight, size and CO_2 emissions for the trucks from chapter 3 are also applied here, to determine the total CO_2 output of this supply chain. Chapter 3 assumes that the used vehicle weighs 4.6 tons. If around 0.925 tons of plastic foil waste is summed with that number, then a total weight of 5.525 tons is obtained for a truck filled with OR plastic foil waste. This would mean that this load is only transported once a year therefore the CO_2 emissions from this LCA are for one year. In reality, however, it would be unpractical to keep this waste in for such a long time in inventory, therefore MSN should use smaller trucks to transport the LDPE waste and collect it multiple times a year.

Table 9 shows that this new supply chain would generate roughly 6.1 kg of CO_2 yearly. Table 10 shows the amount of CO_2 emitted in the current situation for the plastic foils, MSN transports the packaging waste from Isala's operating room together will all the other residual waste from the hospital to the closest incinerator. Therefore, it is difficult to estimate the CO_2 emissions from this transportation. Nevertheless, it is still possible to estimate this number if the assumption is made that the packaging waste is transported separately once a year. The closest incinerator is on average 35 km away. This means that around 1.7 kg of CO_2 is yearly emitted from transporting the packaging waste for this selected group of disposables. These carbon emissions might seem low, but that is because transportation happens in this scenario only once a year and MSN only collects the plastic foil waste from the selected group of disposables.

City A	City B	Distance (km)	CO2 emitted per distance (kg)
Zwolle (Isala)	Diemen (MSN)	98	4.777255
Diemen (MSN)	Volendam (Kras)	28	1.36493
Sum		126	6.142185

Table 9: Station-to-wheel LCA of the circular supply chain

City A	City B	Distance (km)	CO_2 emitted per distance (kg)
Zwolle (Isala)	Closest incinerator (MSN)	35	1.7061625

Table 10: Station-to-wheel LCA of the linear supply chain

Based on this LCA, this research concludes that during the transportation of the circular supply chain, 3.6 times more CO_2 is emitted yearly than in the linear supply chain. If only carbon emissions from transportation are taken into account, then this finding also supports the claim that more circular does not always mean more sustainable. However, if a look is taken at the bigger picture, then the circular supply chain is most likely to be more sustainable as well as the materials are no longer incinerated, which also prevents a high quantity of carbon emissions.

6 CONCLUSION, RECOMMENDATIONS, AND FUTURE RESEARCH

The last chapter of this thesis provides the conclusion of this research and based on these findings, recommendations for Isala are constructed. These recommendations are mainly focused on what the purchasing department should do. However, advice will also be provided on; the possibilities of the supply chain, the role of sustainable product and packaging development, cooperation of the medical specialists and finally, a note is given on the restrictions of health and safety guidelines. This chapter ends with a section on what Isala could research in the future regarding this topic.

6.1 CONCLUSION

This thesis aimed to reduce Isala's operating room waste using a circular approach. It researched how to redesign Isala's operating rooms' current linear supply chain into a new circular supply chain. This thesis concludes that for the selected group of disposables, only a slight fraction of the materials are recyclable due to the complex material specifications. The amount of material waste produced that Isala could recycle, is too little to design a new supply chain. The packaging of these disposables is currently also not recyclable. The paper part and plastic foils are a mix of multiple additives, this fact prevents Isala from recycling the materials. That is why it is paramount for Isala to first rethink its materials before the hospital can recycle them.

Based on these findings, a hypothetical scenario is created in which the plastic part of the packaging is made from 100% LDPE and could be recycled. In this hypothetical situation, MSN would collect and transport the foils to their recycling facility in Diemen. There, the old plastic foils would be compressed and transported to Kras in Volendam. Kras could use the old foils as input to produce new foils, which they could then sell to Isala's suppliers, who can use the foils for packaging the disposables again. Operating this new circular supply chain would save Isala, on average, around 925 kg of material waste yearly. Usually, packaging waste would be disposed of in the residual waste stream and be recovered for energy at the closest incinerator. Therefore, this circular supply chain is evaluated as successful.

The only problem, however, is that this is a hypothetical situation in which the packaging of the materials would be easier to recycle than they currently are. In the next sub-chapter, the recommendations, this topic is investigated further.

6.2 RECOMMENDATIONS

The recommendations for Isala are divided into five sections. These sections provide a recommendation for the purchasing department and notes on sustainable product/packaging development, the possibilities of the new supply chain, cooperation of the medical specialist and finally the health and safety guidelines.

6.2.1 Recommendation for the purchasing department

The main recommendation from this research is that Isala's procurers should go into discussion with their suppliers on the topic of sustainability. This research focused on the output side of the OR; however, Isala must change the input side. When the procurers order new medical items for the OR or any other hospital department, sustainability should be a critical factor in their decision-making process. Right now, sustainability is still neglected when compared to a factor such as costs. The material specifications of the disposables are too complex. Isala procurers could ask their suppliers why their material specifications are this complicated and if they could not be made more suitable for recycling.

6.2.2 The role of sustainable product and packaging development

It is difficult to change the material specifications of the product itself, it is nonetheless more feasible to change the packaging. This research has shown that the OR annually produces more than 1000 kg of material waste solely from the packaging of this selected group of disposables. Procurers could ask suppliers if it would be possible to change their current packaging materials for more sustainable alternatives such as LDPE. If the packaging were made from 100% LDPE, Isala could implement the circular supply chain introduced in chapter 4.

A different suggestion would be to group disposables together in one packaging to reduce the amount of material waste packaging. However, this idea is more challenging as most products come from different suppliers. Furthermore, the products from the suppliers are not needed the same number of times, which will create problems in Isala's limited inventory capacity.

A more exciting alternative to this problem is the usage of paper packaging because recycling paper is unchallenging. Isala already has a paper waste stream established and medical specialists could quickly then dispose of the paper packaging in the paper waste stream. MSN could turn old paper into new products. Moreover, producing residual waste, especially specified hospital waste, is very costly for Isala, whilst having paper waste generates income for Isala. In this solution, everyone benefits, as less waste is produced and more revenue is generated. For Isala's suppliers, however, it may be less practical to package the disposables in paper.

6.2.3 Possibilities of the new supply chain

The new circular supply chain, introduced in chapter 4, is an example of a circular way of working that this research recommends Isala adopts. Adopting this supply chain, however, is only possible if the materials disposed of in the operating room are made from 100% LDPE. The possibilities that this circular supply chain provides are almost endless. As for any type of material, the partner in the supply chain that converts the materials into new products can be replaced. For example, this research uses Kras in the circular supply chain because they can transform old foils into new foils. These materials seem the most suitable replacement for the current way of packaging disposables. Nevertheless, for any other type of (plastic) material, Kras can be replaced by another company that can transform a specific variety of materials into new products. The circular supply chain introduced in chapter 4 is a framework for other circular supply chains that this research recommends Isala adopt.

6.2.4 Cooperation of the medical specialists

During the interviews, the medical specialists in the OR have shown that they are willing to cooperate in separating the materials and working more circularly. Their cooperation however has two requirements. Firstly, their work must matter, which means that when they have disposed of the materials in a separate waste stream, then MSN must differently treat this waste stream. The medical specialists would like to be ensured that their work matters and that the separated materials will not result in the same incinerator as the other residual waste. Effective communication with the medical staff is of the utmost importance for the staff to keep being motivated. Secondly, dissecting and separating must not seize too much time, it should be a simple task that can be performed rapidly. The main focus for the OR staff should be treating patients and not separating materials.

6.2.5 Health and safety guidelines

A final note must be made on the health and safety guidelines. Due to legal reasons, any materials that internal fluids from patients have contaminated must be disposed of in the specified hospital waste stream. This law means that recycling these materials is impossible. Therefore, this research recommends that future circular supply chains shall only be introduced for materials that have not been contaminated by patient blood or other internal fluids. What these materials exactly are is something that the medical specialists can help with.

6.3 Future research

Isala's operating rooms produce a high quantity of material waste. This fact and the declaration that the hospital should work more circularly to reduce the amount of material waste and reach the Green Deal targets have been established before. The most relevant information that this research adds is that hardly any materials used are recyclable, or at least from the selected group of disposables. With this added information, Isala can take further steps in its research on how to work more circularly.

Isala must investigate how to increase the share of recyclable materials. From the research set, only a slight fraction is recyclable. It would be interesting to see if this fraction could be expanded to produce enough material waste to establish a new circular supply chain. This applies to the materials of the disposables but especially to the packaging. Redesigning the disposables to make the materials more convenient to recycle may be an interesting research topic, or what is more feasible is redesigning the packaging. There should be a more innovative idea to change how disposables are packaged to make the packaging easier to recycle. Yet still also practical to transport and keep sterile during the process. What this innovative idea exactly is, should be researched further. Reducing or reusing materials are more circular options, however, chapter 4 has already concluded that that is unfeasible. Therefore, recycling was deemed as the most suitable option, but how Isala can make more materials recyclable could be the perfect research topic for the future.

One could argue to examine if other medical disposables or their packaging are recyclable, as this research has only performed this for a small set of products. However, this approach tackles the symptoms of the problem and not the cause itself. Most likely, this is a structural problem that is also the case for many other disposables. The most important topic for future research is whether the materials can be redesigned for recycling.

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APPENDIX A: SYSTEMATIC LITERATURE REVIEW

This section provides the Systematic Literature Review (SLR) of this research. During the SLR, a knowledge problem or research question is tried to be answered. For my research, I will design a new circular supply chain for the disposal of used items in the Isala Hospital's operating room. As an improvement regarding the current linear supply chain. For my research, I intend to show that the newly designed circular supply chain is better to use for Isala than its current linear supply chain concerning waste reduction. To show that this is the case, I am planning to use life-cycle analyses (LCA) and input-output modelling to determine the quality of the new circular supply chain and it is backed by quantitative results. The problem here, however, is that currently, I lack knowledge as to how to use LCA's for my research. As I am not familiar with this topic yet. This SLR follows seven steps.

1.

The first step is to define the research question. Based on the background information provided above, the following research question has been constructed to answer during the SLR:

How to use the life cycle approach to model the life cycle of the selected group of disposables?

2.

Secondly, we must define the inclusion and exclusion criteria. The table below provides the inclusion and exclusion criteria for this research

Inclusion criteria	Exclusion criteria
Only academic information will be used for my research These academic sources are extracted from scientific databases such as Scopus and Web of Science. Search engines such as Google Scholar will be used as well but more for orientation.	Non-academic sources are excluded from this literature search. Information from blogs such as Wikipedia or YouTube videos from unverified channels might provide unreliable info that does not meet the validity requirement of this study/
The theme of my research question is LCA, and I would like to gain more knowledge on this topic, therefore this term must be included in the criteria. If this is too broad, then the term 'input-output modelling' is included. My UT supervisor mentioned this term and that it could be useful for my literature search.	Academic sources in foreign languages (any language besides Dutch or English) are excluded as well. The information that is provided here might be valid, reliable, and particularly useful for my research. However, the process of translating these documents would be too time-consuming. Luckily, the lingua franca of academic articles nowadays is English.

3.

The third step is to define the databases used. Information specialists from the Faculty of BMS at the University of Twente recommend using 2-4 databases for the SLR (BMS Faculty, 2020). This number has been chosen to provide enough options for academic articles, but not too many so that not too much time is wasted on the literature search. I study Industrial Engineering and Management (IEM) and therefore this research is related to that field of study. In the subject guide for Industrial Engineering and Management on the UT (University of Twente) service portal, they state that the most important databases for the field of IEM include Scopus, Web of Science and arXiv.org (UT Service Portal, 2022). Therefore, these are the three databases used for this SLR.

4.

The fourth step is to describe the search terms and the used strategy. I would like to gain more knowledge in general on a topic that is unfamiliar to me. The information I desire is an overview of a certain topic. According to the information specialists, I need to look for study books, handbooks, and systematic reviews (BMS Faculty, 2020). Therefore, my strategy is to focus on these kinds of academic sources. But I also do not want to exclude any other relevant types of information right from the start, so it is not a hard criterion. The search terms that are used include "LCA" "life-cycle assessment" "life-cycle analysis" "input-output modelling" "health care" and "operating room." The last two search terms are more specific to my research. They are included to potentially limit the number of search results and see if the research that looks like mine has been done elsewhere. These terms are presented in the search matrix that is used as a strategy to find suitable literature.

Concepts	Related terms	Narrower terms	Broader terms
Life cycle assessment	LCA, life-cycle analysis,	Ecological impact,	Environmental science, sustainability
Input-output modelling	LCA, waste reduction	Hybrid input-output modelling	LCA, circular economy
Operating room	Surgeries	Medical devices	Health care

Truncation is used with the term 'LCA' for the queries, to also include related terms such as life-cycle assessment and life-cycle analysis. The terms that consist of multiple words such as 'operating room' and 'input-output modelling' need additional quotation marks to make sure that they are registered as one search term as I am not interested in rooms but specifically operating rooms. Parentheses and Boolean operators such as 'AND' and 'OR' are used to group search terms, either to create a more narrow or broader search result.

5.

During the fifth step, this strategy from step 4 is used to find suitable literature to eventually answer the research question.

Date	Database	Query	Number of entries + comments
19-05-2022	Scopus	LCA* AND "input-output modelling"	0, surprisingly small number of results, remove the modelling part
19-05-2022	Scopus	LCA* AND "input-output"	4, still incredibly low, try another database
19-05-2022	Web of Science	LCA* AND "input-output"	8, a new database is used but still a small number of entries
19-05-2022	arXiv.org	LCA AND "input-output"	107, another database, which should be more related to my field of study is used, now there are a lot more entries
20-05-2022	Scopus	"Input-output" AND "life-cycle assessment"	927 I should have used 'life-cycle assessment' instead of the term 'LCA'
20-05-2022	Scopus	"input-output" AND "life-cycle assessment" AND (LIMIT-TO (DOCTYPE, "ch"))	42, to limit the number of entries, I confined myself to only sources that are defined as 'book chapters '. Because according to the information specialists, this is the type of source that I need if I am interested in getting an overview of a certain topic.
20-05-2022	Scopus	"input-output" AND "life-cycle assessment" AND ("health care" OR "operating room")	201, after being satisfied with the general results of input-output modelling and LCA, I wanted to find more specific info about my research to see if similar studies have been done before

When I first used the term "LCA," I received an exceptionally small number of entries. But when I typed out the words 'life-cycle assessment,' I got a lot more hits. I initially thought that adding a truncation to LCA would mean that the full form of the term, 'life-cycle assessment,' would be included in the search term. I was wrong.

6.

The table below which articles have been used for the literature review, the authors of the sources, what they provide and how they are useful for my research.

Title	Author(s)	Findings
"Use of input-output analysis in LCA"	Tuomas J Mattila	This is a chapter of a textbook called "Life Cycle Assessment: Theory and Practice." This chapter explains to the reader how to use input-output analysis in LCA and how it improves the quality of LCAs. This book chapter gives many practical examples of how input-output modelling can be used to assess life cycles. The author of this chapter has been working on LCA development for more than 10 years now and has a background in among others mathematical modelling (Mattila, 2017). In addition to the author being an authority figure, this is also an academic peer-reviewed source. Therefore, this is reliable information, and the content is particularly useful for my research.
"Variability in the Use of Disposable Surgical Supplies: A Surgeon Survey and Life Cycle Analysis"	Natalie B Baxter, Alfred P Yoon, Kevin C Chung	This is an article from the Journal of Hand Surgery. The researchers conducted a "multicentred survey to investigate how the variation in use of disposable supplies contributes to the environmental and financial burdens of health care" (Baxter, Yoon, & Chung, 2021). This recently published research seems especially useful to me as it also applies LCAs to disposable items in the operating room, which is something I am planning to do.

7.

The book chapter "Use of input-output analysis in LCA" (Mattila, 2017), states that, initially, input-output modelling (IO) was developed for macroeconomic systems analysis and planning. However, since the late nineties, it has increased in popularity to be used with process-based LCA, because it shares many approaches and methods with it. Conventional process-based LCA has an important problem which is the exclusion of some parts of the product system, also known as the cut-off. The product system of an LCA resembles that of a branching tree, with multiple tiers until all the identified inputs and outputs are either emissions emitted to the environment or resources extracted. Input-output modelling does not start from a product, however, but data collected, often from inventory, at the whole economy level. That is why it was initially developed as a macroeconomic systems analysis. The total economic, social, and environmental results are allocated to specific industries. This then shows how much direct impact each sector causes during a year of production. That the relationship between production and impacts is linear is a key assumption in IO. The two main benefits of this IO approach to use for LCAs are that is fast and comprehensive. The 'regular' process-based LCA includes choices about system boundaries and is limited by the resources for inventory collection. An LCA based on input-output modelling however has the whole economy as its system boundary, according to Mattila. This book chapter has provided some background information on what input modelling in LCA's exactly is for the literature review. There are also multiple practical examples that can help me conduct my own IO-based LCA for my research.

An article published last year in the Journal of Hand Surgery (Baxter, Yoon, & Chung, 2021), used IO-based LCAs to estimate the amount of Co_2 emitted during the life cycle of medical supplies, from raw material extraction to production and disposal. In addition to that, they surveyed surgeons to investigate what are the differences in supply use and practice characteristics. The results of this research were that by leaner use of ten key items from the operating room, costs and Co_2-emissions could decrease by $22.47 and 10.9 kg per procedure. This research's main outcome was that to reduce the costs and environmental impact of in this case hand surgery, optimal use of disposable supplies is necessary. This research outcome makes a lot of sense and is also the hypothesis for my research in Isala's operating room. This article gives quantitative (IO-based LCA) and qualitative (surveys amongst surgeons) data, which both contribute to the findings. My research will resemble a like approach and therefore this piece of literature is particularly useful for my report.

These two articles have provided me with more knowledge on how I can use input-output modelling to assess the life cycle of the most used items, which are all disposables, in Isala's operating room. Therefore, this has been a successful literature search.

APPENDIX B: THE SET OF MEDICAL DISPOSABLES THIS RESEARCH FOCUSES ON

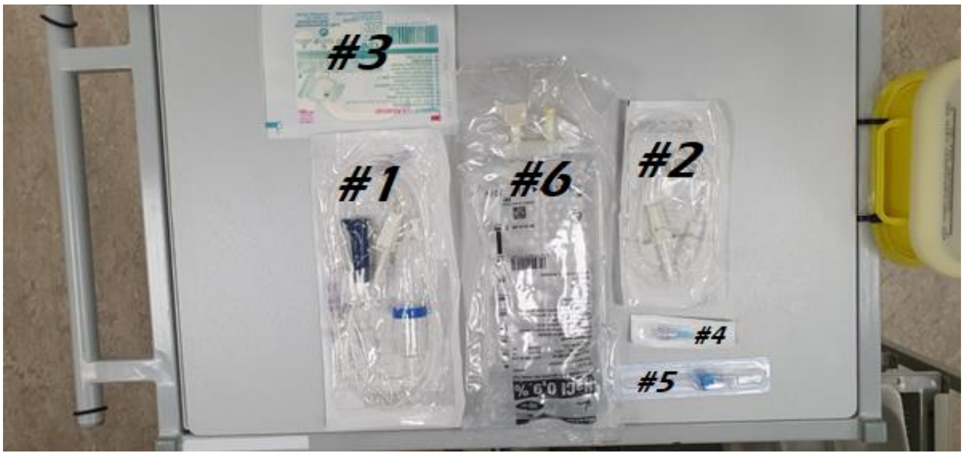

Figure 11: Components infusion system (IS1 up and until IS6)

Figure 12: Components of narcosis system (NS1 up and until NS3)

Figure 13: Anaesthesia mask

APPENDIX C: DRAWING AND MATERIAL SPECIFICATIONS OF SUPPLIER C'S INFUSION DELIVERY SYSTEM

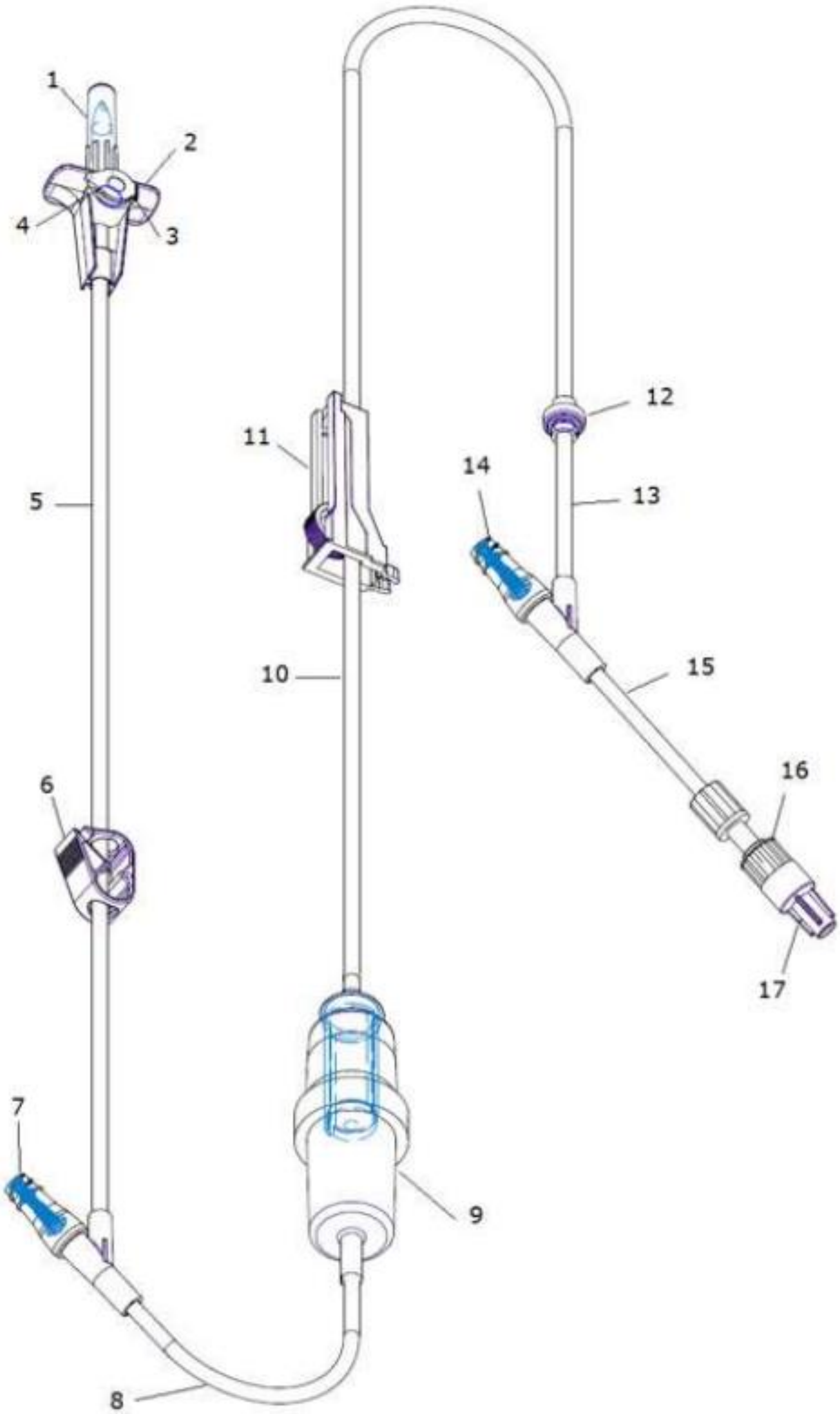

Figure 14: Drawing delivery system

Pos.	Description	Material
1	Protective cap	PP (Polypropylene)
2	Closure-piercing device (Spike body)	PS (Polystyrol), Colourant
3	Air ventilation flap	PP (Polypropylene)
4	Bacteria filter:	PTFE (Polytetrafluoroethylene) on non-woven Polyester
5	Tubing 3.0 x 4.1 x 200 ± 20 mm	PVC (Polyvinylchloride) with plasticizer TEHTM
6	Robert clamp white	ABS (Acrylonitrile-Butadiene-Styrene)
7	Injection site (Y-Clave SA 3,86 mm)	Body: PC (Polycarbonate) compressible seal: silicone Internal Pipe: ABS (Acrylnitril-Butadien-Styrol)
8	Tubing 3.0 x 4.1 x 150 ± 20 mm	PVC (Polyvinylchloride) with plasticizer DINCH
9	Drip chamber with filter for blood and blood components (inline with filter 200 µm)	Upper part: MABS (Methacrylate-Acrylonitrile-Butadiene-Styrene) Ring: PA (Polyamid), Colourant Lower part: LLDPE (Linear Low Density Polyethylene) Filter: PA (Polyamid)
10	Tubing 3.0 x 4.1 x 2000 ± 50 mm	PVC (Polyvinylchloride) with plasticizer DINCH
11	Flow regulator (Roller clamp)	ABS (Acrylonitrile-Butadiene-Styrene), Colourant
12	Back check valve inline	MABS (Methacrylate-Acrylonitrile-Butadiene-Styrene) Valve: silicone rubber
13	Tubing 3.0 x 4.1 x 50 ± 5 mm	PVC (Polyvinylchloride) with plasticizer DINCH
14	Injection site (Y-Clave SA 3,86 mm)	Body: PC (Polycarbonate) compressible seal: silicone Internal Pipe: ABS (Acrylnitril-Butadien-Styrol)
15	Tubing 3.0 x 4.1 x 150 ± 20 mm	PVC (Polyvinylchloride) with plasticizer DINCH
16	Male conical fitting (Rotating Luer Lock connector)	ABS (Acrylonitrile-Butadiene-Styrene)
17	Protective cap of the male conical fitting (Luer cap with filter)	Luer cap: LDPE (Polyethylene, low density), Filter: acrylic copolymer on non-woven nylon

Table 11: The materials list of the delivery system