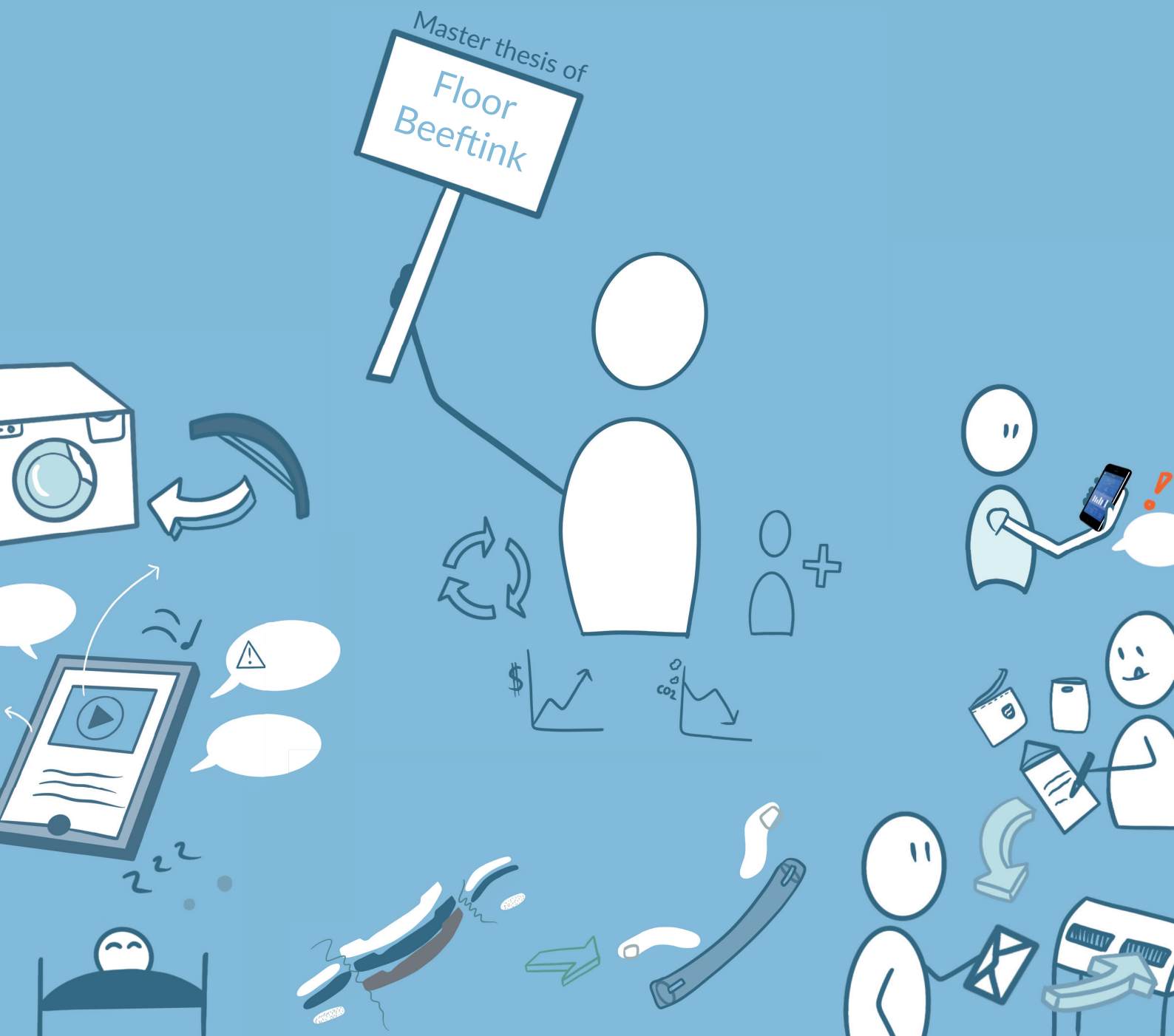
The redesign of CPAP supplies for the Circular Economy

A product service system as a modular solution



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The redesign of CPAP supplies for the Circular Economy

A product service system as a modular solution

Dear reader,

During this project, I had the pleasure of working with inspiring people that are truly passionate about sustainability and making the world a better place. I loved the large playing field and the freedom that was given by my colleagues at Philips in Group Sustainability and Sleep & Respiratory Care. This and all the valuable conversations gave me the chance to learn a lot and inspire others at the same time.

I would like to thank all of you who helped me along the way. With special thanks to;
Sophie, for your enthusiasm, effort, critical questions and continuous support. Next to circular propositions, you learned me a lot about effective communication and pitching.
Mark, Claire and Raquel, thank you for the collaboration and all the insights you gave me along the way.
Bas, thank you for the interesting discussions and always pushing me to bring my work to a higher level. The question "Why?" will stay in my mind forever.
Caroline, for helping with structuring my thoughts, going along with my enthusiasm and coaching in such a personal way.
Gigi, for all your positivity and laughter, which helped me through this challenging and inspiring year.
And last but not least, my parents Wim & Cora, who have always supported me and made finishing this master study a reality.

Enjoy the read and allow yourself to get inspired too!

Glossary

Definitions

Linear Economy
The Take-Make-Waste economy that is focused on consuming.

Circular Economy
The economy that aims to decouple economic activity from the consumption of finite resources and to design out waste.

Eco design
Eco design principles focus on the environmental performance of the product throughout its whole life cycle and is mainly based on the linear economy. This if often done with a life cycle analysis and CO2 calculations.

Circular design
The mindset is to design products that are optimized for a cycle of reuse. The design principles for the circular economy are more holistic approaches and therefore suitable to design truly sustainable and circular innovations. The three strategies are: slowing resource loops, closing resource loops and material efficiency.

Circular Revenue
The circular targets from Philips mentioned earlier, are expressed and measured in circular revenue as a percentage of the total Philips revenue. A product or service contributes to this circular revenue when it fits in at least one of the eight circular revenue categories.

Circular ready requirements
Circular design principles need to be applied to support the generation of circular revenues. These state which requirements a product or service has to fulfil, to be able to implement a circular business model with that product or service.

Patient/User
These terms are both used in this report and refer to the OSAS patients that use the CPAP supplies for therapy at home.

Circular Barriers
These barriers are things that could hold back or prevent the product system and business model from becoming circular. The four circular barrier categories are Cultural, Regulatory, Market and Technological,

Dreamwear
A product line of CPAP masks and headgear from Philips SRC. Referred to as the product system.

Dreamstation
A CPAP sleep therapy device from Philips SRC.

DreamMapper
This is an app from Philips which is a self-management tool for patients that connects to the CPAP device with Bluetooth. This app provides goal-setting tools, video instructions and feedback about the therapy quality.

Abbreviations

DME	Durable Medical Equipment supplier
SRC	Philips Sleep & Respiratory Care
UBL	UnBrokenLoop fabric
TPE	Thermoplastic Elastomere
LCA	Life Cycle Assessment
CE	Circular Economy
OSAS	Obstructive Sleep Apnea Syndrome
CPAP	Continuous Positive Airway Pressure
APAP	Automatic Positive Airway Pressure

Executive Summary

The linear economy is focused on consumption: Take- make- waste. This results in global challenges like overconsumption of resources, generation of significant quantities of waste and acceleration of the climate change. The transition from a linear to a circular economy has the goal to decouple economic activity from the consumption of finite resources and to design out waste. Therefore, designers need to include sustainable design approaches in their design process. The combination of **Eco design and Circular design** principles results in truly sustainable and circular innovations. There are three fundamental circular strategies:
- Closing resource loops
- Slowing resource loops
- Resource efficiency

The circular solutions cannot be created in isolation and therefore the entire system, product life cycle and all stakeholders should be considered.

The business wide objectives of Philips regarding the transition to the circular economy is among others, that 15% of the total revenue should be from **circular revenue** from products and services by 2020. The Group Sustainability department guides this transition of Philips by supporting the different businesses and creating standards and structures in collaboration with Philips Design. They have defined **circular ready requirements** and **circular ready categories** to help designers and other colleagues to implement circular propositions.

The **Obstructive Sleep Apnea Syndrome** is treated with a CPAP machine which keeps the airways open by applying air pressure. The air pressure is guided from the machine to the airways of the patient through a tube and a mask that is hold on the head by the headgear. OSAS causes patients to have breathing stops during the night, which can cause sleepiness during the day and increases the risks on other diseases.

The **Sleep & Respiratory Care** business of Philips creates these products and needs to reach the same general sustainability targets as mentioned **related to circular revenue. The Dreamwear CPAP** masks and headgear in the portfolio of Sleep & Respiratory Care are medical consumables which are disposed after a short life span. The goal of this project is to answer the following research question:

How can circular design principles help prevent the headgear from ending up in landfill whilst creating value for user and business?

Furthermore, the underlying objective is to **inspire** SRC to make the transition towards a Circular Economy.

A **Life Cycle Assessment tool** is created to assess the life cycle of the current product system and compare this to new designs and scenarios in an iterative way. The highest impact of the product life cycle is caused by the washing of the products and especially the used energy to warm up the water.

Circular barriers are things that could hold back or prevent the product system and business model from becoming circular. The four circular barrier categories are Cultural, Regulatory, Market and Technological. The insights of the research are divided over these 4 categories. The main conclusions from the research are:

1. Risk aversion and lack of knowledge for and about circular propositions, results in less sustainable or non circular designs.

2. SRC Philips does not have direct interaction with patients or control over the mask decision and procurement process, which results in no responsibility and control over the material flow.

3. The product design is not optimized for an easy cleaning ritual which results in a high CO2 impact and the headgear breaking down earlier.

4. The current headgear design is not suitable to be recycled, refurbished or remanufactured.

To stimulate SRC to make the transition to the circular economy it is needed to show the possibilities and advantages of new circular propositions for the CPAP supplies. Furthermore, the results and holistic design solution are communicated in a structured overview because feasibility and relativity is key to inspire SRC and make the proposition a success, in this already complex system. Therefore, the circular proposition needs to focus on already existing solutions and logistics as much as possible.

The design vision is
"..improve the motivation to work towards a circular solution with an holistic design approach and showing that such a circular proposition is of advantage for SRC; by increasing contact with patients and gaining control over mask decision process, while increasing the control over material flow.."

The 4 **key ingredients** of the design phase are **Circularity, CO2 reduction, Advantage for Philips SRC and a user advantage**. The main opportunities for user advantage are:
1. Make the patient feel more in control over the mask decision process and resupply.
2. Make it easier and logic to solve common comfort problems
3. Create an easier and faster cleaning ritual

The design solution consists out of four parts, which can be integrated in the current system over time. The advantage of this is that positive sustainable changes can be achieved on the short term, while a larger sustainable goal is achieved on the long term.

1. The headgear and attachment to the mask have been redesigned to become circular ready and to support the next three proposition parts. This design has been optimized for a longer lifetime and easier cleaning ritual, as a first short term strategy. The new headgear will be made with a knitting production technique and two arms that slide in this fabric piece. This design is based on the just released headgear with arms design of Philips. This design ensures comfort and more stability for the user and material efficient production.

2. The business model is redesigned in combination with a new procurement scenario that can be included in the already existing DreamMapper app. This is done to link the replacement to the performance of the products and stimulate a longer product life. Next to this, several extra functions are integrated in the app. The mask select software is integrated to pick the right mask type and size and patients can buy comfort products from the DME directly through the app when they experience comfort problems.

3. A recycling and future reverse logistic scenario has been created. The silicone of the mask could be taken back and sold for recycling. The DME is the centre of the supply chain and therefore the products should be collected at their warehouse. The user can sent the products through the normal mail with the help of information from the app. The headgear can be recycled through the municipal textile recycling stream that should be implemented in Europe by 2025.

4. All the proposition parts are designed with the eye on the future and technology trends, to make it feasible and viable on a long term. The future of CPAP supplies are custom made products, supported by digital production techniques and the 3d face scan software. The custom made products will result in a perfect comfortable fit for all users and this can extend their product life. Furthermore, the production techniques are material efficient and the digitization could enable super local production.

A **roadmap** has been created to communicate the strategy and implementation plan of the 4 proposition parts. The first next steps are to create knitted prototypes and injection moulded arm parts, to test with patients for comfort and easy assembling.

From the **final life cycle assessment** of the different proposition parts can be concluded that all phases lower the kg CO2 emissions. Changing the cleaning scenario will have the largest positive impact, but the reality is highly dependent on the user behaviour.

The project results are expected to be highly feasible as this was a key requirement through the whole project. Existing resources and infrastructures are used for the new proposition. Inspiring SRC was achieved by presenting the holistic design approach and solution, including the clear steps and advantages for the 4 key ingredients. The next steps are already taken.

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Section 4 Design brief & Ideation

Section 5 Final design

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SECTION 1

Project introduction

Chapter

01

CIRCULAR ECONOMY INTRODUCTION

1.1 Why CE?

The problem of the linear economy

In a linear economy, the focus is on consumption and discarding food, products and material: Take-make-waste (Ellen MacArthur Foundation, 2019b). This linear economy results in global challenges like overconsumption of resources, significant quantities of waste generated and acceleration of the climate change. A lot of waste is exported from Western countries to the other side of the world, like Indonesia and China. Not all this waste is recycled; the amount is piling up. This results in large waste mountains, like the one in figure 1. In 2018, Indonesia imported 25.000 ton of plastic waste from the Netherlands (Buitenlandredactie, 2019). China was the worlds largest importer of waste, but in 2018 they stopped the import of 24 types of waste including plastic.

"Our way of doing things is reaching its limits"

- Ellen MacArthur foundation, 2019b.

Exporting waste to other countries is not the solution. It only moves the problem away from our sight and thus other solutions are needed.
The Western countries are working towards a solution and waste management is a hot topic. Meanwhile, the largest part of plastic waste in the Netherlands is already processed inside the country, which in 2016 was 70% (Buitenlandredactie, 2019). The volumes of plastic waste that is collected for recycling in the EU increased by 79% over the past ten years (PlasticsEurope, 2018) and export to landfill is banned. All this waste is recycled or incinerated to fight the waste problem. Though, waste incineration is also bad for the climate as it releases kg CO2 emissions and destroys resources. The transition from a linear to a circular economy has the goal to decouple economic activity from

Waste does not exist.

the consumption of finite resources and to design out waste (Ellen MacArthur Foundation, 2019a). Decisions that are made during the design phase determine around 80% of the environmental impacts (Ellen MacArthur Foundation, 2019b). Waste and pollution are therefore a result of the way we design things, and this can be changed by adapting a different design mindset.

Figure 1. The problem of plastic waste mountains. Reprinted from Getty, 2018.

1.2 What is CE?

CE compared to Eco- design

Eco-design and circular product design are two fundamentally different approaches (Hollander, Bakker, and Hultink, 2017). Eco- design principles focus on the environmental performance of the product throughout its whole life cycle and is mainly based on the linear economy (Hollander et al, 2017). This if often done with a life cycle analysis and CO2 calculations. Eco-design can be described as a relative approach which identifies current problems and only optimizes what is already there (Hollander et al, 2017).
For this reason, the eco-design approach is criticized and a totally different and holistic design approach is needed to fight the environmental problems and upcoming resource deficiency (Hollander et al, 2017). The design principles for the circular economy are more holistic approaches and therefore suitable to design truly sustainable and circular innovations (Hollander et al, 2017).

The butterfly diagram

There are many different design principles to design for a circular economy. The mindset is to design products that are optimized for a cycle of reuse (Ellen MacArthur Foundation, 2013). The butterfly diagram is designed to demonstrate the principles of the circular economy and illustrates the way in which technological and biological nutrient-based products and materials circle through the economic system, see figure 2.
In the diagram, the distinction is made between consumers and users. In a circular economy, biological materials are defined as consumable while technical materials like metals, ceramics and, synthetics are only used (Ellen MacArthur Foundation, 2019b).

Though, reusing is not the only circular strategy. There are three fundamental circular strategies (Bocken et al, 2016). These are described on the next page.

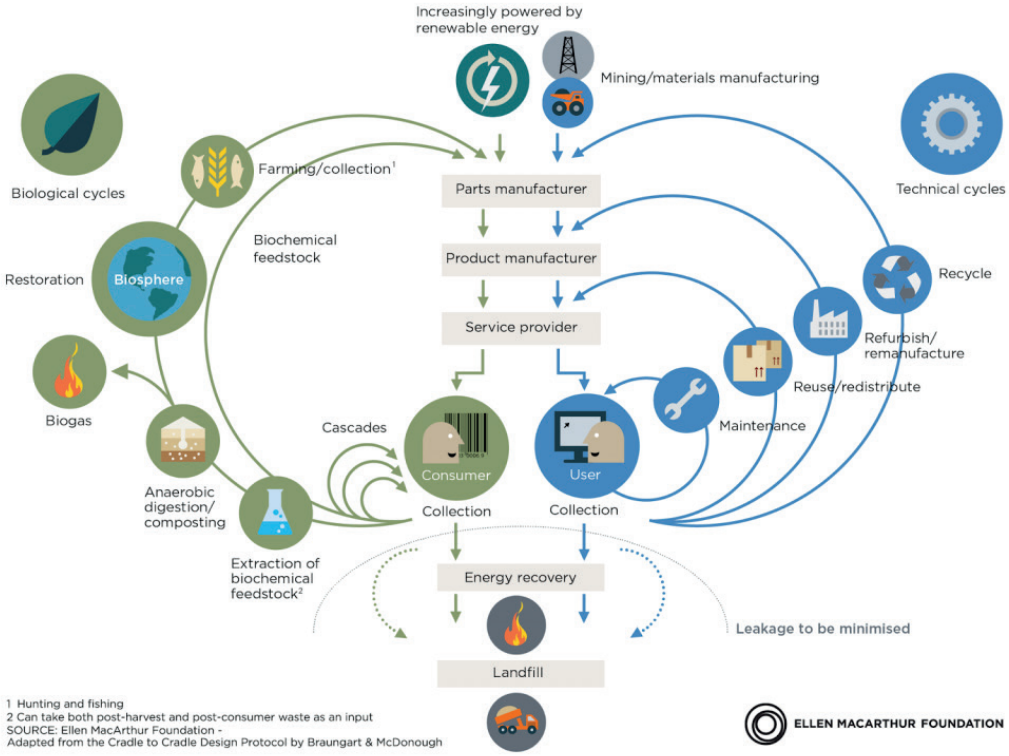
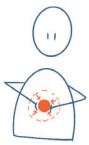


Figure 2. The butterfly diagram. Reprinted from the Ellen MacArthur Foundation, 2019.

Three circular strategies

The first strategy is to slow down resource loops, or "the flow" of the product and its material. To achieve this, the inertia principle of Walter Stahel should be taken into account (Bakker, Hollander, 2015). This means that a product should be kept at its highest possible value, for example by not recycling something that can be repaired. Designing the product as such, that it lasts a long time, is a circular design principle that contributes to this strategy.



The second strategy is resource efficiency. This does not necessary relate to the lifetime or flow of a product, but means to use as less material and energy as possible for the production of a product and service system.

The third strategy is to close the resource loops. This strategy is needed because making everything last forever is not necessarily the best solution. "Products that flow" are defined as not meant to last in contrast to "products that last" (Haffmans et al, 2018). These flowing products have a quick value drop after they have served its purpose. This value can not only be described in terms of money, but also in a sense of potential (Haffmans et al, 2018). Therefore, the flow of a product and its material needs to be controlled logistically and processed in an sustainable way (Haffmans et al, 2018). Circular design strategies, like design for disassembly, could enable the flow of a product. A new circular proposition includes business scenarios that are flow enhancing because just redesigning a product so the parts could be recovered is not the total solution. Next to this, the new product or service needs to have an added user and business value to make the proposition economically viable. To optimize these Circular Economics, companies need to gain control over both lasting and flowing products (Haffmans et al, 2018).

The Ellen MacArthur Foundation has identified four essential building blocks that together can make the transition towards a circular economy possible (Ellen MacArthur Foundation, 2019c).

Circular economy design to facilitate product reuse and recycling.

New business models which enable the shift from consuming to using products, to control the flow.

Reverse cycles which facilitates the return logistics and sorting of products and materials.

Enablers and favourable system conditions are needed to optimize the reuse of materials and productivity, like collaboration, regulations and financing.

Conclusion

To design truly sustainable products, we need to take an holistic approach whereby the hole system is taken into account. In this way, it is possible to optimize the flow of the product, reduce waste and reduce its environmental impact. Therefore, a critical assessment of the product and its context is needed to establish the best circular strategy.

In this project, eco- design and circular design principles are used in an integrated way to choose the right sustainable direction for a new proposition. The current product system and possible solution directions are assessed with LCA analyses and ideas were formed with circular design principles.

Chapter

02

PROJECT STAKEHOLDERS

2.1 Introduction

This graduation project is a collaboration between two parties: the TU Delft, faculty of Industrial Design Engineering and Koninklijke Philips N.V, in short: Philips. Philips is a multinational conglomerate corporation and has many different businesses and departments. For this reason, the departments that are involved in this project are described separately.

The faculty **Industrial Design Engineering** manages and executes this project; represented by Floor Beeftink, graduating from the Masters Integrated Product Design

Philips Sleep & Respiratory Care (**SRC**) in Pittsburgh, US is the product owner and target audience for the new circular proposition. They are the primary information source regarding the products and supply chain and the basis of many interviews.

Philips **Group Sustainability** department in Amsterdam and Eindhoven is the base of this project and has the role of client, supervisor and collaboration partner.

Philips Design in Eindhoven collaborates with Group Sustainability to develop a circular design framework and requirements. These will be used and reflected on during this project.

Chapter

03

PHILIPS

Client and collaborator

3.1 Guiding the transformation

Philips' goals

Philips sees that the transition from a linear to a circular economy is necessary to create a sustainable world (Koninklijke Philips N.V., 2019a). Next to this, all companies should move towards a circular economic model, because the availability of resources decreases by a lack of fossil fuels, the resource prices and the consumer demands increases (Vijlder, 2019).

> *"For a sustainable world, the transition from a linear to a circular economy is essential. A circular economy aims to decouple economic growth from the use of natural resources by using these resources more effectively."*
>
> Frans van Houten, CEO Philips

To make the transition to a circular economy, Philips adopts innovative business models and maximizes the lifetime value of their products and services (Philips Design, 2019). The business wide objectives regarding the transition to the circular economy is that in 2020, 15% of the revenue should be from circular products and services, 90% of the operational waste should be recycled and the loop should be closed for all large medical system equipment that becomes available to Philips (Koninklijke Philips N.V., 2019b). By 2025, all medical equipment should include circular practices.

Role of Group Sustainability

The Group Sustainability department guides this transition of Philips by supporting the different businesses and creating standards and structures. As an example, they colalborate with Philips Design to create Circular Design frameworks and requirements. Part of the goal is to educate the designers within Philips and search for ways to make Philips more sustainable, for example by campaigning to reduce the amount of flights by colleagues.

The department of Group Sustainability is a function of Philips. This means that they do not produce products or services and they operate on a high strategic level within the company. An overview of the Philips internal structure is displayed in figure 3. Some of the employees are business partners of a certain business section like Connected Care or Personal Health. The business branch Sleep & Respiratory Care is a part of the Connected Care division.

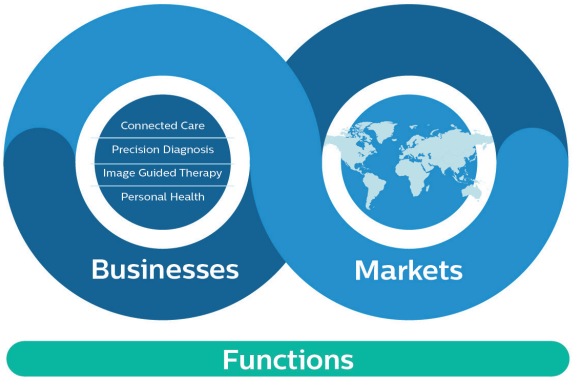


Figure 3 Overview of the company structure of Philips (courtesy of Philips, Philips, 2019).

3.2 Documentation and definitions

Circular revenue

The circular targets from Philips mentioned earlier, are expressed and measured in circular revenue as a percentage of the total Philips revenue (Philips Design, 2019). A product or service contributes to this circular revenue when it fits in at least one of the circular revenue categories, see figure 5.

Circular ready requirements

Circular design principles need to be applied to support the generation of circular revenues. Therefore, circular ready requirements where formulated and are linked to the specific circular revenue categories, as displayed in figure 4. These state which requirements a product or service has to fulfil, to be able to implement a circular business model with that product or service.

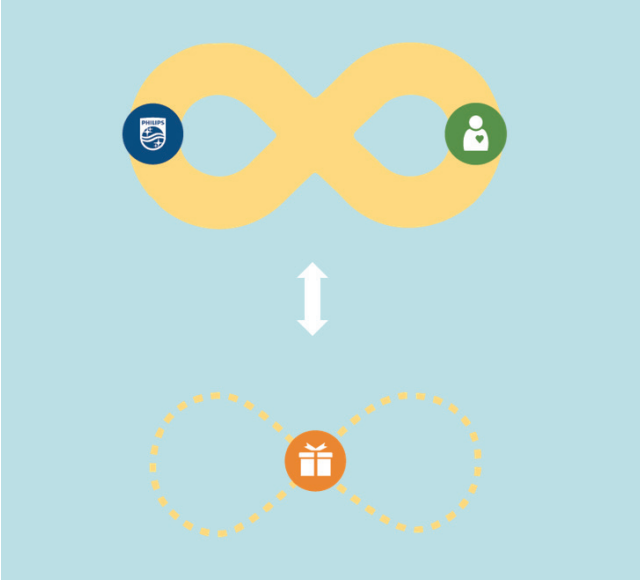


Figure 4 Circular revenue and circular ready requirements. Reprinted from the Circular Design Playbook (courtesy of Philips, Philips Design, 2019).

Circular design playbook

Philips Design created the circular design playbook in collaboration with Group Sustainability to support leaders and innovators by creating circular value propositions (Philips Design, 2019). This circular design playbook was developed by Philips in 2019 and was a key reference in this project. It can be seen in Confidential Appendix 1.

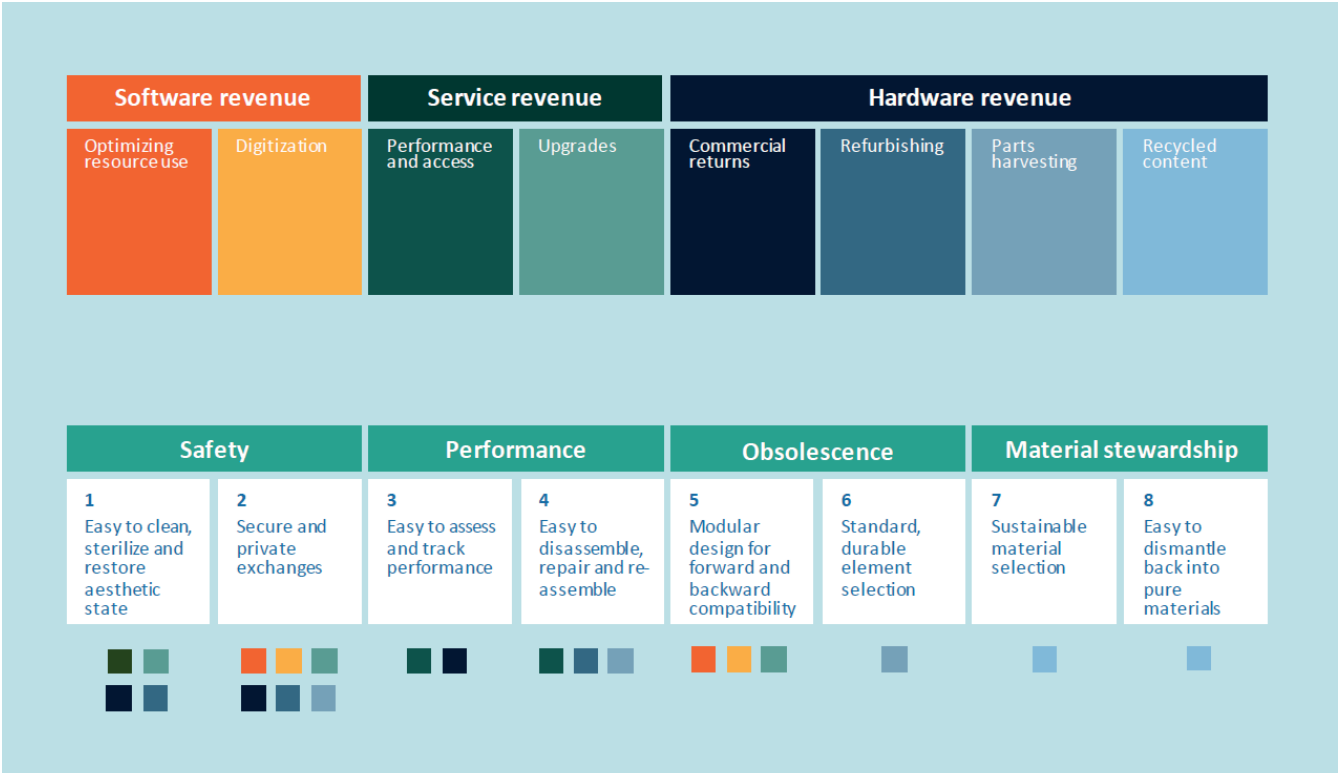


Figure 5 Quick reference card. Reprinted from the Circular Design Playbook (courtesy of Philips, Philips Design, 2019).

3.3 Philips Sleep and Respiratory Care (SRC)

Respironics

In 2007, Philips announced to buy U.S. sleep therapy products maker Respironics Inc (Chee, 2007). In 2008, the tender agreement was completed. This means that the Sleep & Respiratory Care department of Philips does not exists that long. The contact and relations with their business partner at Group Sustainability are starting up to implement Circular propositions. Therefore, this circular headgear project will also function as a way to inspire the business and increase the knowledge on circularity.

SRC and the circular economy

The Sleep & Respiratory Care business needs to reach the same general sustainability targets as mentioned before, like the 15% circular revenue in 2020. The CPAP masks and headgear in the portfolio of Sleep & Respiratory Care are medical consumables which are disposed after a short life span. The Philips circular targets and strategy do not yet relate to consumables, but a strategy is currently developed at the Group Sustainability department.

Department structure

The main contacts during this project are based in the SRC Engineering department, which designs headgear and masks. Next to this, Philips Design has a local group of Industrial designers in Pittsburgh which is working on different new headgear and mask solutions. The marketing department is spread over different countries and the engineering department does not have a clear view on the sales part of the products. The marketing division makes a vision and list of requirements for the designers and the engineers. The owner of a new design project is the product manager from marketing who also makes the final decisions.

The market

Philips SRC makes products for sleep and respiratory care in hospitals and for consumers at home; including sleep apnea management, oxygen therapy, non-invasive ventilation, and respiratory drug delivery. Therefore, they have different types of clients and consumers. The marketing department manages the sales through Durable Medical Equipment (DME) suppliers. The DME's have respiratory equipment from many brands and manages the delivering to the patients and the hospitals.

The largest competitor of Philips Respironics is Resmed. Some other competitors with respiratory masks and headgear are Fisher & Paykel and Weinmann.
The market is very competitive and the designs change rapidly. Every year, there are new masks on the market and Philips needs to innovate constantly to keep their market share.

"Take back your dreams"

- Philips Respironics

Chapter

04

PROJECT ASSIGNMENT

4.1 Research questions

Main research question

In the beginning of the project, it was chosen to focus on the business model, life-cycle and design of one of the Philips medical headgear products. The solution space consists of exploring circular opportunities for the current headgear and looking into other business models while redesigning the product accordingly.
Next to the circular design requirements of Philips, the comfort and performance of the headgear is very important to the user. This needs to be reflected in the new headgear design, just as the economic value for the SRC Business.

?

How can circular design principles help prevent the headgear from ending up in landfill whilst creating value for user and business?

Project focus

During the research phase of this project was found that to make the headgear circular, the whole product system needs to be taken into account to fit the holistic design approach described in chapter 1. In this way, the context, the barriers and the opportunities for other business models and reverse cycles can be defined. This also makes sense because the life cycle and procurement of the mask and headgear are linked. Furthermore, the environmental impact of the headgear is small compared to the whole package.

It is chosen to focus the research on the Dreamwear nasal mask and headgear displayed in figure 6, because the most new sleep apnea patients that choose for the Philips brand get this type of mask. This new innovative design is very well received due to it's small design (SR manager SRC, 2019). Next to this, nasal masks in general are the most used type of masks (ApneuVereniging, 2017). The product system is more described in the Dreamwear chapter.

Figure 6. Dreamwear nasal mask and headgear. Reprinted from Vivisol, 2019.

Sub questions

As described before, an holistic design approach is needed to make the Dreamwear headgear and mask circular. To reach this goal, several sub questions were defined to answer the main research question.

First, we need to understand the context and design requirements for the current and new design and business model;

1. How does the current business model, product system and context look like?
- Who are the key actors and what are their roles and values?
-How can the user experience be improved?
-Why is the product designed as it is and what influences does it come across during its lifetime?

Like described in the introduction, in this project eco- design and circular design principles are used to come to new sustainable proposition. The problem definition and design brief is written according to these research questions:

2. How can the environmental impact of the product be reduced?
- Which life cycle part has the highest impact?
- How can the product be redesigned to lower the impact?

3. Why is the product currently not circular?
- What barriers in the supply chain prevent the product and their materials from being reused?
- Why is the current product design not suitable for a circular business model?

4. How can the product system and supply chain become circular?
- Which circular business model is suitable for this product system and context?
- How could the new proposition contribute to the circular revenue targets of Philips?
- How can the product be redesigned to become circular ready?

5. What is further needed to make the proposed circular proposition a reality?

Objective

The goal of this project is to answer the research question. Furthermore, the underlying objective is to inspire SRC to make the transition towards a Circular Economy to enable them to contribute to the corporate target of circular revenues.
This will be done by executing this project, showing the design approach and give recommendations on how to proceed after proposing the new circular proposition.

Scope

The US is the largest market of Philips Respironics, so creates more waste in comparison to the EU Market. Though, the European Union is working actively to move towards a circular economy and the regulations are in favour of these propositions. In consultation with the stakeholders, the EU has been chosen as the main scope for the this project.

4.2 Approach

To answer the defined research questions, different approaches were taken to gather information about the supply chain, design and decision making process.

Interviews within Philips

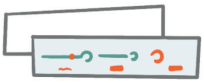
OSAS patient questionnaire

OSAS nurse interview

The interviewees inside Philips were from several departments and had different functions. Among others some of the functions:
- Sr Manager engineering SRC
- Mechanical Engineer SRC
- Senior Expierience Lead
- Materials and finishing Engineer
- Senior product designer
- Sustainability professional
- Senior design strategist

The results were among other things used for:

LCA analysis



Product life cycle map & Patient journey map

Material & recycling research

This resulted in the answering of the research questions and the definition of:

Main problems

Design requirements

Opportunities

The interim results and conclusions were presented and discussed in Philips with several employees of the Engineering department of SRC, the Innovation Lead of SRC, research director of Sleep and sustainability managers.

SECTION 2

Analysis: Context

In this section, the context of this circular design project will be described and reviewed. This is done to understand the system and identify opportunities for value creation for the patient, the different key actors and stakeholders in the system. Furthermore, it is important to understand the design requirements and the market of the Dreamwear products, to know what should be taken into account for the new designed proposition.

Therefore, the research questions for this section are:

1. How does the current business model, product system and context look like?

- Who are the key actors and what are their roles and values?

-How can the patient journey and user experience be improved?

-Why are the products designed as it is?

Chapter

05

OBSTRUCTIVE SLEEP APNEA SYNDROME

5.1 OSAS

The disease

Someone who has the obstructive sleep apnea syndrome (OSAS) has breathing stops during their sleep (National Sleep Foundation, 2019a). An apnea is a breathing pause of at least ten seconds, which occurs when the muscles in the back of the throat fail to keep the air path open during the attempt of breathing. This happens because the muscles relax during sleep causing the soft tissues in the throat, like the tongue and the palate, to collapse and obstruct the air path (National Sleep Foundation, 2019a). The body responds by giving an alarm signal to the brain. The reaction, called an 'arousal', causes a disruption of the sleep pattern, which can lead to several consequences. The patient can experience for example sleepiness, a lack of concentration, depression and memory difficulties (National Sleep Foundation, 2019a). This can lead to a decrease of life quality and an increase of risk at accidents, high blood pressure and heart and vascular diseases.

Figure 7. One of the main symptoms of obstructive sleep apnea is loud snoring. Reprinted from South China Morning Post, 2019.

5.2 The patient

The facts

In America, more than 18 million adults have sleep apnea (National Sleep Foundation, 2019a). It is estimated that in the Netherlands, 600 thousand people suffer from sleep apnea, while only 275 thousand people are treated for it (Taha, 2019). This is caused by that many people do not know the origin of their daily complaints (Taha,2019). Obstructive Sleep Apnea is the most common type of sleep apnea (National Sleep Foundation, 2019a). Another type is Central Sleep Apnea, whereby the apnea is caused by neurologic disfunctions.

Historically, OSAS is seen as a disease that mostly affects men. As a result, the most studies are done with largely male populations. It is estimated that the male - female ratio is between 3:1 and 5:1 in the general population, while the ratio in the clinical population is between 8:1 and 10:1 (Wimms et al, 2016). The hypothesis in recent studies is that this is due to women being frequently misdiagnosed because they show other symptoms than men (Wimms et al, 2016).

Profile

In a study with more than 5000 OSAS patients in the Netherlands, 54% experienced complaints due to being overweight (Meinema, 2017). These are only the ones that stated this by themselves, which means that the actual number of obese OSAS patients can be higher. The National Sleep Foundation confirms these primary risk factors of OSAS (National Sleep Foundation, 2019b):

- Being a man or post-menopausal woman
- Age of 40+
- Excess body weight
- Physical features like: a large tongue, small jaw, larger neck and a large overbite.
- Lifestyle: using alcohol or sedatives.

Figure 7. The stereotype OSAS patient.

5.3 Treatment

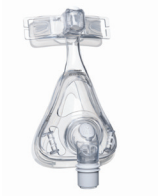
The products

The most used and successful treatment for OSAS is sleeping with a continuous positive airway pressure machine (American Sleep Apnea Association, 2019). This machine is attached with a flexible tube to the patient's nose and/or mouth via a mask and headgear combination.

The CPAP machine helps the patient to breathe more easily and regularly during the night. It increases the air pressure in your throat to prevent your airway from collapsing when you inhale (NATIONAL SLEEP FOUNDATION, 2019). A tube guides the air towards the mask, which is hold on the patients' head by the headgear.

The CPAP machine (1) often has a humidifier and registers data during use about the performance and amount of apneas.

The hose (2) has an universal in and outlet connection. This means that they can be used with any type of CPAP machine and mask, which do not have to be from the same brand.



The mask (3) is the part that is in contact with the face and has the most challenging requirements. It has to have a tight fit and needs to be suitable for long skin contact. Sometimes, it has a separate cushion or pillow part that has direct contact with the nose or mouth.

The headgear (4) makes sure that the mask stays in place during the night.

1) Dreamstation Cpap Pro. Reprinted from Sleep Restfully, 2019.
2) Philips Respironics 6 Foot Ultra-Light White Performance Tubing for Cpap. Reprinted from DirectHomeMedical, 2019.
3) Philips Respironics Amara Gel Mask Frame With Cushion - No Headgear. Reprinted from GoCPAP.com, 2019.
4) ResMed AirFit™ F20 Replacement Cpap Mask Headgear. Reprinted from Amazon, 2019.

Mask and headgear types

The masks and headgear exists in many different forms and sizes. The type of mask that fits with a patient depends on their facial characteristics; facial hair, sleep position, oral or nasal breather and skin sensitivity. It is very important that the patient has a mask that fits them well, otherwise the therapy can work inefficiently due to air leakage.

Figure 8. Most common types of CPAP masks. Reprinted from Vitality Medical, 2019.

New trends and developments

The advantages of 3d scanning and printing is finding its way into the world of respiratory care products. The company Metamason has created a face mask that is customely 3d modeled and printed for each patient (Freier, 2017). The advantages of this are that it ensures a perfect nasal air seal with a higher comfort level (Freier, 2017).

Figure 9. 3D printed mask from Metamason. Reprinted from Freier, 2017.

5.4 Patient journey

The insights are gathered during an interview with an OSAS nurse (1), see appendix B, and a user questionnaire with CPAP users in the Netherlands (2), appendix C. The total patient journey and user experience are combined into one poster for easy communication and discussion with the stakeholders, displayed in appendix D. A short description and the main insights are described in this paragraph.

Diagnosis

In the Netherlands, a medical specialist 30% or the sleep partner 29% mostly mention OSAS to the patient first (Meinema, 2017). The patients are examined and diagnosed by a specialist in the hospital, mostly by a lung doctor 61%, ENT doctor 23% or neurologist 8% (Meinema, 2017). After the diagnosis, the doctor refers the patient to a specialized external sleep facility or a sleep department within the hospital. In the first 3 months, these facilities are responsible for the guidance and care of the patients while they start a specific treatment.
In 91% of the facilities, a separate specialist takes care of the guidance and informing of the patient when they have been diagnosed. This is mostly the OSAS nurse (Meinema, 2017). In 23% of the facilities, this is done by the supplier of the CPAP products, who holds consultation hours in the facility (Meinema,2017).

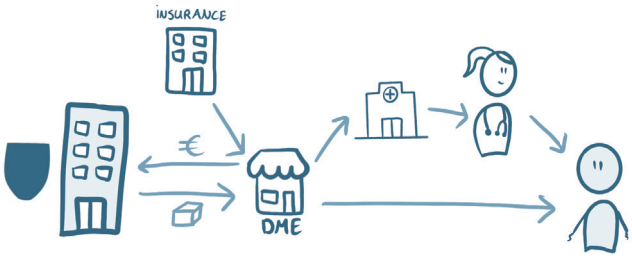


Figure 10, The main actors in the patient journey.

In the Netherlands, the CPAP machine and the masks are mostly fitted to a patient in the hospital by the supplier 63% (Meinema, 2018). Next to this, 80% of the sleep facilities have a standard supplier of which 29% mention Vivisol, 16% Mediq Tefa and 12% VitalAire. The most patients are happy with their professional help (2).

Reimbursement

In the Netherlands, the CPAP products are standard included in the base insurance package. Some complementary comfort products need to be bought by the patients themselves.
The most sales of SRC are in the US. Health care in the US is more expensive than in any other country, though many people do not have health insurance, see figure 11. Medicare and Medicaid are government insurance programs. Medicare funds health care for the elderly, disabled and people receiving long- term treatment with dialysis (Schreck, 2019). In Medicare, you pay 20% of the reimbursement costs of the CPAP supplies yourself. After 13 months, you even own the CPAP machine. Medicaid funds health care for certain people who are living below the poverty level. Most private insurers cover CPAP supplies. It varies per insurer if the CPAP machine is bought or rented from the supplier.
The data of the CPAP machine can be tracked by the nurse or the supplier. In the Netherlands, the patient needs to give permission for this. When the treatment is not working properly, the nurse could even change the settings from a distance. The treatment should be used for an average of at least 4 hours per night. If this time target is not reached, the patient could loose the reimbursement from the insurance company (1).

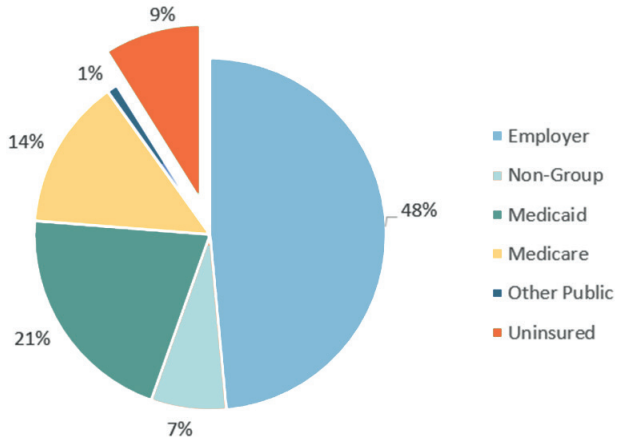


Figure 11, Health insurance coverage of the total population in the US in 2017. Data source: Kaiser Family Foundation, 2019)

Choosing the right mask

Like mentioned in paragraph 5.3, the masks have different fittings and forms to match all kind of facial geometries. The OSAS nurse has a lot of experience with matching a mask to a specific form of face and nose, so often picks one intuitively (1). There are many different types of masks and the patient can not try all the masks at the fitting appointment due to time and cost reasons. After every fitting, the mask should be disinfected before it can be tried on by another patient. For these reasons, the patient does not see all available options and the OSAS nurse plays a key role in the choice for specific brands and masks. This nurse can have personal favourites which have a higher change of being consumed (1). When people have an asymmetric

"I don't know when or how I should get a new mask, it still functions..?" - OSAS patient (2)

face (for example; because of an accident), it is very hard to find a mask that ensures a tight fit. There are custom fit masks available but they are very expensive and they are not always insured.
It can happen that the patient has tried the mask at home for a while and is not happy with it. In this case, he often starts searching on the internet for other types of masks and comes back at the nurse. Sometimes, the wished mask is not available at the linked supplier.
It can be a hurdle to find the right mask, testing it and adjusting it till it is right. For this reason, patients are reluctant to try out new masks when they are accustomed to a certain one where they are happy with (Personal communication SR Manager Engineering SRC).
Once in a while, the supplier or competitor ResMed comes by the hospital to show new masks and demonstrate them (1). This is a smart move, as the OSAS nurse plays a key role in "selling" their products.

- It is not clear for the patient what all the mask and headgear options are.
- The mask and headgear should be chosen in the same size. This does not always correspond with the facial characteristics of the patient.
- Not every nurse shows all the mask options to the patient.

Re- supply

After the first 3 months, the care for the patients and the supply of the products is done by the Durable Medical Equipment supplier (the DME). This is mostly done in combination with yearly check-ups, which the supplier schedules. Although, the products in the Netherlands are reimbursed by the basic medical insurance, only 6/12 of the Dutch patients mention that the supplier takes initiative to replace the products (2). The frequency of the check-ups and the way they are communicated, differs per supplier (2). These check-ups take place at their own location, at the patient's home or in the hospital (1). The DME manages the contact and the payment with the insurance company. It is more expensive to do the check up appointments in the hospital, so this is not preferred by the insurance companies (1). The CPAP machine is replaced after 5 years. It depends on the type of insurance if this machine is rented out by the supplier or becomes property of the patient.
In the Netherlands, the headgear and the masks are often replaced yearly in one package. In the US, the headgear is replaced every 6 months and the mask every 3 months. While the separate mask cushion or pillow is replaced every 2 weeks. The overview of the reimbursement schedule can be seen in Appendix E.

- It is unclear for patients how and when to get replacement products.

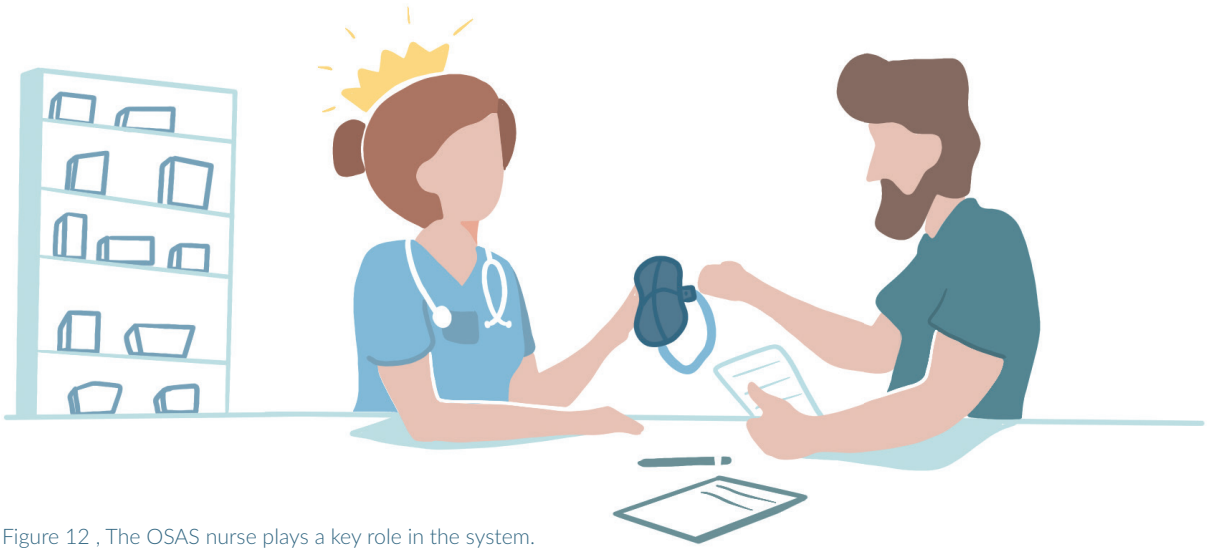


Figure 12 , The OSAS nurse plays a key role in the system.

5.5 User experience

Use

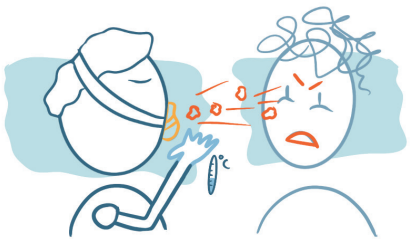
Before the patient goes to sleep, he puts on the mask and the headgear. It depends on the type of mask, where the tubing should be connected. The tube can get in the way during sleep or can get caught in the blankets or movement of the arms (1).
The CPAP machine is often placed on the nightstand or on the ground next to the bed (2).
The CPAP machines settings are set by the nurse and the machine will track apnea data during sleep. When an apnea occurs, the pressure of the CPAP machine is automatically increased if you have an automatic CPAP (APAP) (1).
When patients have to go to the toilet during the night, it is recommended that they keep on the mask and the headgear. Otherwise, they could forget to put it on when they are sleepy (1). The connection with the tube is often designed in a way that it can be quickly released.

There are many problems of discomfort that can occur when you use CPAP treatment during the night. Next to this, also the partner can experience inconvenience due to noise or air flow. The main problems are listed in the illustrations below.

Users dealing with their problems

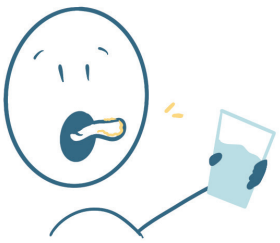
The experience of the OSAS nurse was that some patients can become very creative (1). They have to deal with the products every day and they try to make it as comfortable and easy for themselves as possible. Many try to create solutions for problems they come across by ordering additional products from the internet or making diy solutions that are shared and discussed across the internet.
Some of these solutions mentioned were; a plastic partition between the patient and partner in bed, something to guide the hose to the ceiling above the bed or a knitted cover for around the hose to prevent water condensation in the system. Some patients even try to fix cracks in their mask with scotch tape.
Like mentioned earlier, the headgear and the mask can often only be ordered in one size combination. When the headgear is too large or small, patients can start to cut in the headgear or add pieces. This can result in breaking the product.

Comfort problems can result in patients tempering with the products, which can result in defaults.



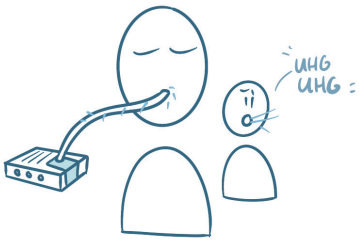
Overpressure air release

Frustrated partner



Dry mouth

Noise



Condensation of water in the system

"The less you feel like a pilot in a turbo jet, the better.."
-OSAS patient (2)

Cleaning

After a night sleep, the masks should be cleaned from skin grease. This is mainly to prevent slipping off the face during the night and for a healthy skin (1). According to the interviewed OSAS nurse, this should be done with a wet cloth and soap. Once a week, the mask and the headgear should be cleaned in a bowl with water and soap. It is recommended to do this in the morning, because it needs time to dry before it can be used again (1). Not all users know how to clean the products and clean it regularly as they should (2). By the 12 Dutch patients who filled in the questionnaire (2), the mask is mostly cleaned 1x week. Only 2 participants mentioned to do this daily. The headgear is cleaned 1x a week , 1x a month or even never. These patients knew how to clean the products from oral explanation or the product manual, but rarely follow these instructions (1).

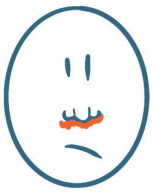
- Forgot to clean the mask= discomfort of dirt
- Headgear is not dry from cleaning
- Cleaning is a time and effort burden

End of life

The headgear's Velcro can break down over time and the fabric becomes dirty. The mask can loose it stretch and can start showing cracks. Both problems can cause air leakage and dysfunction of the mask.
When the headgear and the mask is replaced by the supplier, the old ones are not taken back. Only the CPAP machine is sometimes taken back by the supplier for professional cleaning and re-renting. The patients mostly throw the mask and the headgear in the residual waste bin after they have received a new one (2). Sometimes they throw the mask in the plastic recycling bin, although they can not be recycled through this infrastructure. Several patients keep their old mask as a reserve, which means that the products are not always broken when they are replaced.

- The headgear may not be cleaned in the wasmachine and dryer but should be hand washed.

Waking up with skin marks



Bad skin reaction or wounds

Bad night sleep due to problems

Displacement of mask

Claustrophobic feeling

Chapter

06

DREAMWEAR

6.1 An innovative design

Product introduction

The total product system that is taken into account in this project is the Dreamwear headgear and nasal mask combination of Philips, see figure 13.

Figure 13. Dreamwear Mask and headgear with nasal cushion. Reprinted from Vivisol, 2019.

The most new sleep apnea patients that choose for the Philips brand get this type of mask. This new innovative design is very well received due to it's small design and the other USP's mentioned on the right (SR manager SRC). Next to this, nasal masks in general are the most used type of masks (ApneuVereniging, 2017).

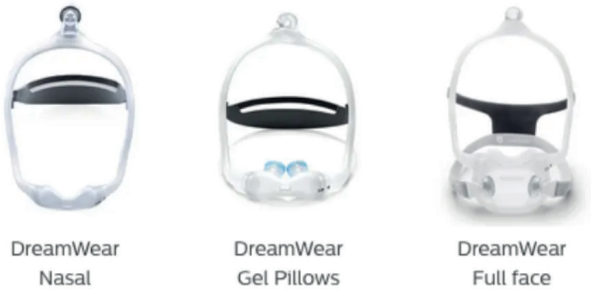


Figure 14. The Dreamwear family: a modular system. Reprinted from the CPAP shop, 2018.

Unique selling points

A: The tube is connected to the mask on the top of the head in stead of at the front of the face. The hose can now easily be guided over the end of the bed. The connection piece can also turn 360 degrees, which ensures that turning in your sleep is not a problem.
When the tube is connected at the front, laying on the pillow on the side of your face and turning in your sleep can cause the tube to pull on the mask. This can cause air leakage or displacement of the mask. The new on top tube connection prevents this problem.

B: Another advantage of the on top tube connection is that the over pressure air release holes are also on top. This prevents that the air is blown in the face of the bed partner or the hand of the patient while sleeping.

C: The cushion can be released easily from the mask frame and can be changed for other cushions, like a nasal pillow or a full face mask, see figure 14. Multiple cushion sizes are delivered in the package, where from the right one can be chosen, see figure 15.

Figure 15. Original package content from the Dreamwear Nasal mask of Philips.

6.2 Design

Headgear Design

There are different sizes available for the mask frame and the different type of cushions because a good fit is critical for the therapy. The headgear, see figure 16, can be adjusted with Velcro, to tighten the mask to the face. The headgear is designed with several layers of fabric and foam which are flame laminated together. The different types of fabrics have different functions. The outside Nylon fabric is chosen for aesthetic reasons and grip for the Velcro, the inside PUR layer is for grip on the head and the Nylon at end part is for easy gliding through the slots of the mask. The Velcro is ultrasonically welded on top of the layers. It is not chosen to use glue because this is often rigid and can cause discomfort. Only the layers that have direct contact with the skin, is tested on biocompatibility. The headgear is thick and it fits the slots of the mask perfectly, to ensure the place of the headgear on the back of the head without slipping during the night.

Figure 16. The original Dreamwear headgear. Reprinted from CPAP direct, 2019.

Recently, a new type of headgear for this mask came out, which has thermoplastic arms see figure 17. These arms cause better stability during the night on the lower back of the head, according to 88% of the DreamWear nasal users (Koninklijke Philips N.V., 2019c).

Figure 17. The new Dreamwear Headgear with Arms. Reprinted from Koninklijke Philips N.V. , 2019c)

Product life cycle

The total product life cycle, from design and manufacturing to disposal, all the influences on the products and the supply chain are displayed in a poster in Confidential Appendix 2. The stakeholders and contact points in the system are mapped in the same visual.
The materials and end products are transported through many different contact points before it reaches the user. It is stored by the DME before it is transported to the hospital or directly to the user's home. At the hospital, it is cleaned with alcohol if a patient has tried it on and does not take it home. This can happen a couple of times before it reaches its end user. The alcohol will not break down the silicone when this is only done a couple of times but it is recommended for the user to not use alcohol for cleaning at home as it can cause degrading over time (Philips Respironics, 2015).

The products have a warranty period of 90 days. When they break down in this period, they can be send back to Philips SRC in Pittsburgh and the patient gets a new one. These products are inspected for faults before they are disposed. The polycarbonate is separated from the silicone and grinded to allow more room in the dumpster. The silicone is sold to a recycler who for example recycles it into playground tiles. The headgear is removed and thrashed to a landfill.

6.3 Information service

DreamMapper app

When a patient has a Philips Dreamstation, he can get access to the DreamMapper app from Philips. In this way, you can also look at your own CPAP data and night rhythm to optimize your therapy. The users can set cleaning reminders and therapy goals for used CPAP time in the app (Koninklijke Philips N.V. 2019d). Some explanation movies and manuals are also included, like cleaning instructions and device operation. It is not possible to order products through the app. In the app, there is a separate "problem solving" tap which includes several common discomfort problems. There are videos linked to these problems, but these are not specified according to specific masks that the patient wears. The videos mostly conclude with the tip to contact your supplier or nurse to discuss the problems or try another mask.

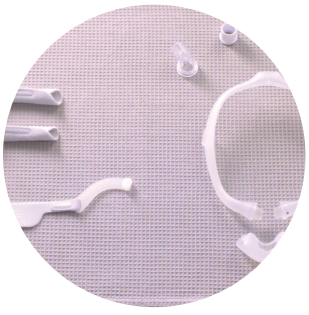
Figure 17. The DreamMapper app. Reprinted from Koninklijke Philips N.V. 2019d.

Cleaning

According to the product manual (Phillips Respironics, 2015) and the instruction video (see QR code, Philips Healthcare, 2019), the non-fabric parts should be hand washed daily with warm water and liquid dishwashing detergent. This is different than the nurse mentioned, which recommended to wipe it with a wet cloth (Appendix B). The headgear and fabric sleeves should be weekly washed in the same way and hanged to dry. The mask may be cleaned in the top rack of the dishwasher once a week, without the drying cycle. This is because the heating element of the most dishwashers is on the bottom, which means that the bottom rack is hotter than the top one. To prevent the Velcro in the headgear from breaking down, it may not be cleaned in the was machine and the dryer, but a lot of users do this because it is easier and cleans the product better.

Submerge and hand wash

Rinse thoroughly



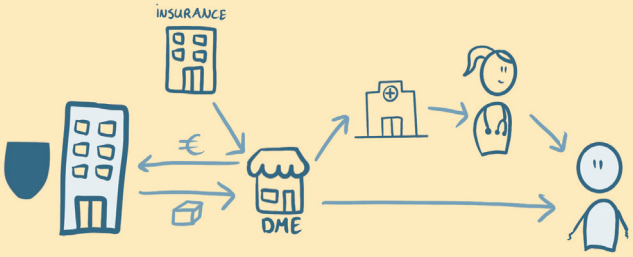
Let air dry

Figure 18.The recommended hand wash cleaning ritual. Screenshots from the movie; Philips Healthcare, 2019.

Section summary

Obstructive Sleep Apnea Syndrome and treatment

OSAS causes patients to have breathing stops during the night, which can cause sleepiness during the day and increases the risks on other diseases. It is a common disorder and it is estimated that a lot of people are not diagnosed yet. Most patients are men, but women can have it too. The primary risk factors for OSAS is living unhealthy, being overweight and being older than 40. Some specific facial features or muscle diseases can also cause the disorder.
The disease is treated with a CPAP machine which keeps the airways open by applying air pressure. The air pressure is guided from the machine to the airways of the patient trough a tube and a mask that is hold on the head by the headgear.
When someone is diagnosed with OSAS by a doctor, the products often get paid by their insurance. The OSAS nurse makes sure that the patient gets all the equipment and the right type of mask in the first 3 months after diagnosis. After this period, the linked Durable Medical Equipment supplier takes over the care of the patient and regular resupply of the products. There are different types of masks available that fit specific facial characteristics. It is important that the mask fits well on the face, to prevent air leakage and a less effective therapy.



Who are the key actors and what are their roles, values and wishes?

Philips SRC: *Product manufacturer and seller*
Values: Offer better care to patients, increase market share and product sales, lower CO2 emissions
Wishes: Increase market share by designing better innovative products than competitors.
Power: Determines product design.

Insurance company: *Buyer*
Values: Making money by preventing diseases and healthcare costs.
Wishes: Cheap, long lasting high performance products
Power: Determines reimbursement schedule.

DME : *supplier/ reseller*
Values: Making money per provided product.
Wishes: Provide as many products with less service time as possible.
Power: Middleman: Has the contact with insurance company, patient and Philips. In control over patient journey and supply of the products.

The OSAS nurse: *salesman and service provider*
Values: Providing care and helping the patients as good as possible within 3 months.
Wishes: Availability and overview of the best masks and headgear and providing efficient service.
Power: Determines which masks are best suitable for the patient and which they see first.

Patient: *User*
Values: Receiving good service, sleep comfortable
Main wishes: Comfortable and small products, with as easy and least time consuming care as possible.
Power: Determines if products are good, mouth-to-mouth (online) advertisement, responsible for the care of the products.

Patient's sleep partner: *Stakeholder*
Values: Sleep well, healthy partner
Wishes: Silent treatment, no air current towards him
Power: Point out disease, right of say for type of mask

How can the Patient Journey and User Experience be improved?

The **mask options** for a patient regarding their specific supplier and insurance should be clear from the beginning. The products are not available in unlimited sizes and combinations, which can result in a bad fit or tampering with the products. For example, by cutting and resizing the headgear. More sizes or a mask that is **custom** made for the patient would be ideal. Furthermore, when and how to get new products should be **transparent** for the patient and make him feel more in control.

There are many different **comfort problems** related to specific types of masks that can occur, like skin irritation, air leakage and displacement during the night. These problems can result in that patients stop wearing the products. Some patients are inventive with DIY- solutions when they experience problems with their equipment regarding performance and comfort. These solutions are not always the best ones and tampering can result in product failure. In the DreamMapper app, patients are referred to their supplier or nurse for tips. It should be **easier and logic to solve** these problems

Next to daily wearing the products, another burden is to take care of the equipment. Cleaning should be done by hand and this takes time and effort. Furthermore, the drying time is a struggle. This results in that many patients do not clean as much or in the way they should. This can result in discomfort, skin problems and a shorter lifetime of the products. Many patients know how to clean the products by the nurse instructions and do not read the manual. These instructions can differ.
An **easier and faster cleaning ritual** is preferred.

Why are the products designed as they are?

The Dreamwear products are designed to be modular, whereby different cushion types and sizes can fit one frame. The unique on-top tube connection and minimalist design are the main advantages of this specific mask. The headgear can be adjusted with Velcro to fit many heads and has a qualitative and soft appearance and feel due to different fabric types and layers.

The **main requirements** for the mask and headgear are:
- Stability during the night
- Good and tight fit
- Comfortable wearing, which leaves no skin marks
- As small as possible
- Material on skin bio- compatibility
- Easy assembling
- Easy to put on and off

Both products should be hand washed, the headgear's Velcro can break down when it is put in the was machine or dryer. The mask may be put in the dishwasher once a week.

Opportunities

- Most patients stay in contact with the supplier.

- The CPAP machine captures performance data

- The CPAP machine has rental options, where after they are given back to the supplier.

- Philips SRC does not have direct interaction with patients

- Philips SRC does not have control over the mask decision and procurement process

- The DreamMapper app

- New technology: 3D printing of masks

- The mask materials are separated and the silicon can be sold.

SECTION 3

Analysis: sustainability

In the Project Introduction chapter is explained that to design truly sustainable products, an holistic design approach with a combination of eco-design and circular product design is needed. In this section, the product and context is assessed regarding sustainability to find the main environmental problems and circular barriers. With these results, the direction for a new sustainable product service system can be defined.

Therefore, the research questions for this section are:

2. How can the environmental impact of the product be reduced?
- Which life cycle part has the highest impact?
- How can the product service system be redesigned to lower the impact?

3. Why is the product currently not circular?
- What barriers in the supply chain prevent the product and their materials from being reused?
- Why is the current product design not suitable for a circular business model?

Chapter

07

ENVIRONMENTAL IMPACT

7.1 Life Cycle Assessment

Method introduction

Life Cycle Assessment is a method to calculate the environmental burden of a product or service. There are two types of LCAs: The classical rigorous LCA and the 'Fast Track' LCA. This last type is meant to compare design alternatives. A classical paradigm of LCAs is that it should be used on an existing product or when the design is finished (Vogtländer, 2010). The drawback of this is that when the design is almost ready, it is harder to implement changes according to the LCA results. Therefore, the LCA method should be used parallel to the design process as part of several optimization loops (Vogtländer, 2010). Therefore, it is chosen to use the Fast Track LCA method in combination with a tool that is created during this project, to easy compare different designs and scenarios during the design process.
The Fast Track method uses look up tables and the calculations are made by multiplying the inputs and outputs of the Life Cycle Inventory with single indicators (Vogtländer, 2010). The inputs and outputs include materials, emissions and required energy across the different phases of the total life cycle of the product. There are many single indicators available. In this project it is chosen to work with kg CO2 equivalent which resembles Global Warming Potential. This is chosen because it is a globally well known and widely used indicator in regulations and sustainable targets (Milieucentraal, 2019). This is preferred as it will ensure easy communication and relativity of the different stakeholders.

Goal

In this chapter, the LCA method is used to analyse the current product life cycle to find the parts, materials and elements which causes the highest environmental impact. From these conclusions, a direction for the design of a new product service system can be defined. The results are used as a bench mark and are in the next chapter compared to other scenarios and designs.

Approach

The input data was gathered during a questionnaire with Users, interviews with a OSAS nurse and colleagues from Philips SRC. According to these data and insights, an estimation is made of the use cycle scenario. Next to this, a specified bill of materials from the current headgear and mask is used. The created tool can be found in Confidential Appendix 3. The details of the LCA, the method and discussed results can be found in Confidential Appendix 4. The main results and conclusions are discussed on the next page. The data is based on a year use of the dreamwear line, with the Dutch reimbursement schedule of a yearly total package as baseline.

Production

Materials
Packaging
Processing

Transport

Fuel

Use

Water
Soap
Heat

End of life

Incineration
Recycling potential

7.2 LCA results

Discussion of results

The use phase of the current Dreamwear product life cycle has the most impact on the environment. This is due to the amount of electricity that is used to heat up the water for washing the headgear and masks on a regular basis. The chart in figure 19 represents a washing scenario based on the user manual.

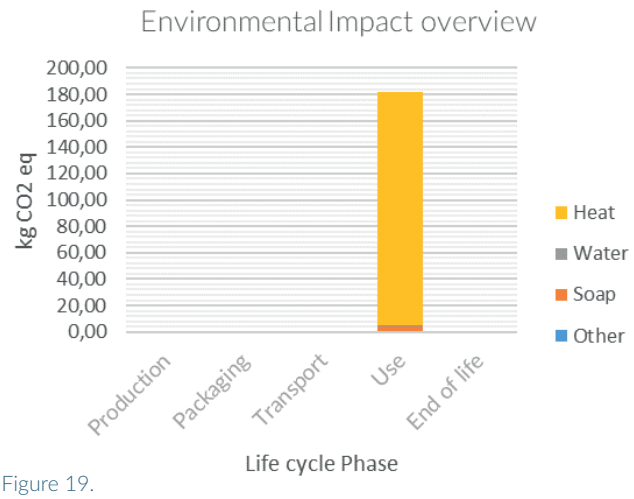


Figure 19.

When the use phase is not taken into account, the production of the products has the highest impact, as can be seen in figure 20.
The silicon products like the mask frame and cushion, cause the highest impact. This is mainly because these products have the most material. The impact per kg of silicone is almost the same as polycarbonat, the runner up: respectively 8,154 and 8,113.

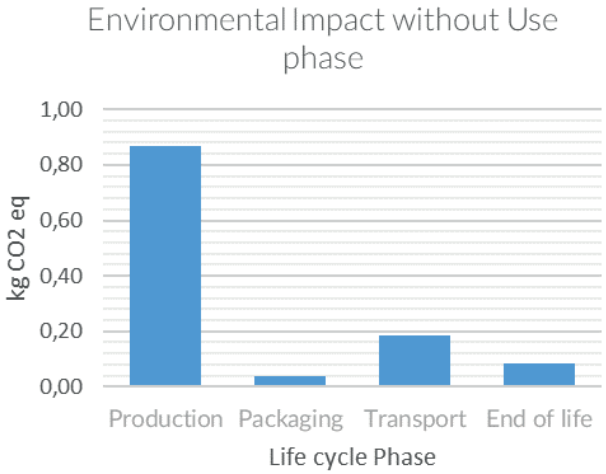


Figure 20.

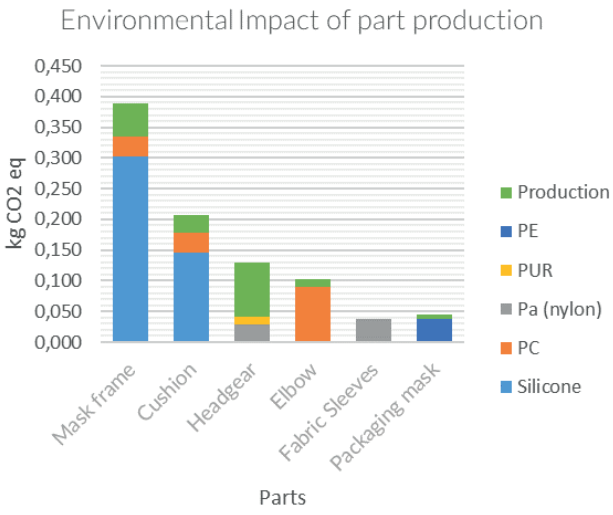


Figure 21

The reimbursement schedule in America causes a higher impact on the production, packaging and transport of the life cycle of the product system. It depends on the washing scenario if this increase is significant on the total impact or not. It has an 8 times higher impact than the normal scenario in the Netherlands when the use phase is not taken into account. When a weekly warm hand wash scenario is taken into account, the increase on the total life cycle is only 30%. With a daily hand wash scenario this increase is only 4%.

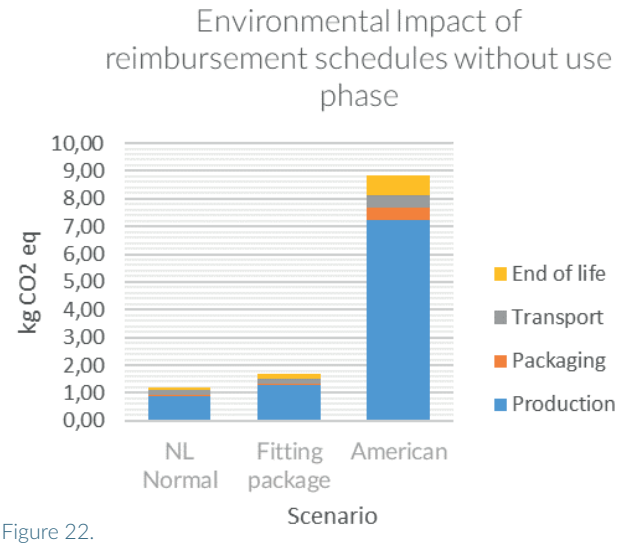


Figure 22.

Discussion hand washing scenario

Typically LCA studies of textile products conclude that the greatest environmental impact (75% or more) occurs during use by consumers in water and energy use for washing and drying clothes (Tomaney, 2015). This is also the case for the washing scenario of the user manual of the products. Though, users often do not clean according to the user manual (Appendix B and C). Several users clean their masks and headgear only once a week with warm water. Also the amount of water and the temperature can fluctuate highly per user and washing cycle. Therefore, the relative impact of the production on the total life cycle can be higher, as can be seen in the charts beneath.

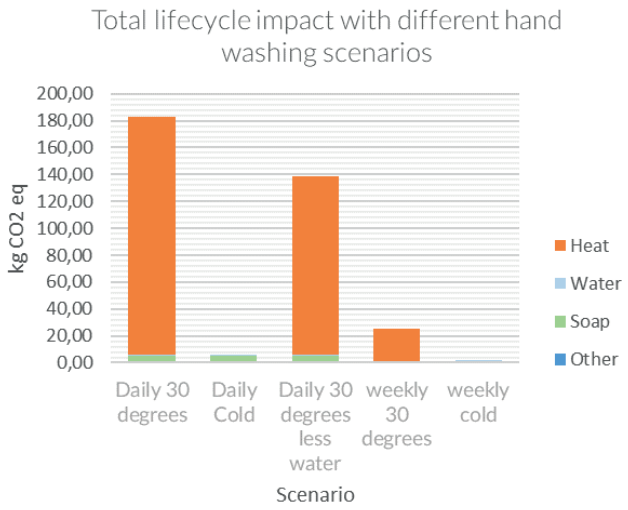


Figure 23.

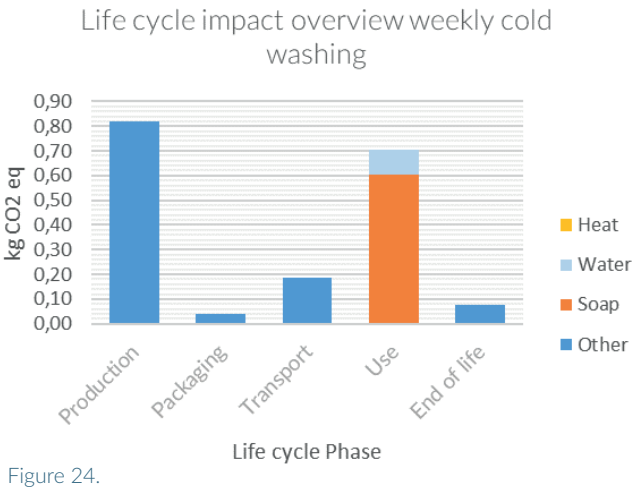
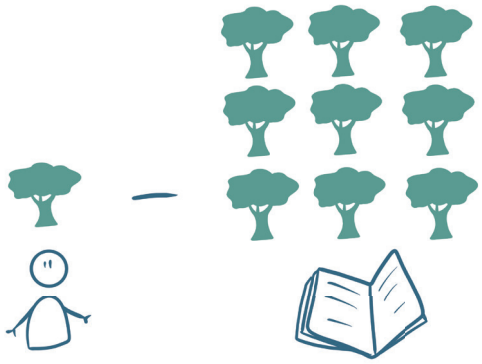


Figure 24.

Relativity

An average Dutch citizen caused 10 000 kg CO2 a year in 2017 (Ekker, 2017). One tree can compensate 20 kg CO2 a year. (Coöperatief Dutch Renewergy, 2019). The life cycle impact of an user who hand washes the products weekly with warm water is 25 kg CO2 a year. The scenario according to the manual can result in 183 kg a year.



Conclusion

The impact of the total life cycle can be most efficiently lowered by reducing the impact of the wash cycle. This means that the impact of the product life cycle depends highly on the user behaviour. Other wash scenarios which use less water and with a lower temperature will result in a large positive effect on the environmental impact. Next to this, the transport scenario could be lowered by local production of the mask and headgear, or no pre assembling of them at the mask production site. As the headgear is shipped from the other side of the world and back, which acounts for 30% of the transport impact.
A substitute material for the silicon that is recyclable is desirable as this material has the largest volume% of the package. There already is an End-of-life value available for the polycarbonate when it is collected and recycled.

In the end, a total material saving solution would be best. As this could reduce the transport and the production impact.

Chapter

08

CIRCULAR BARRIERS

8.1 Literature framework

Several circular barriers were defined during research. These barriers are things that could hold back or prevent the product system and business model from becoming circular. The barriers are not necessary rigid and unchangeable. These can result in design challenges, design requirements or facts that should be accepted.

Barriers for what?

In a circular economy, their are mainly two goals for product designers. These follow from the Inertia Principle described in chapter 1.1.:
1. Increase the product lifetime
2. Recover resources

The value of the materials should be kept in the economic system for as long as possible by extending the lifetime of the products that are made from them or looping them back into the system by a reuse cycle (Hollander et al, 2017).

The product lifetime can be best described in terms of obsolescence. A product can become obsolete if the value is dropped in the eyes of the user (Hollander et al, 2017). This can occur for many reasons and not only because the product stops functioning. Other reasons can be aesthetic, social, technological or economic. The state of obsolescence can even be temporary or reversed (Hollander et al, 2017).
The recovering of resources should be done at the highest level of integrity, which corresponds with the Inertia Principle.

Both goals can be applied at a material and product level, which corresponds to Design for Product Integrity or Design for recycling. Design for Product Integrity is an umbrella term for several circular design principles which aim a longer product use, an extension of the use or recovery from parts or material (Hollander et al, 2017).

The transition to a Circular Economy is a fundamental systemic and complex innovation (Kircherr et al , 2018). This transition does not only involve product design, as described in the building blocks in chapter 1. Therefore, anything that shortens the lifetime of the product or material, or prevents the product or material for being recovered at the highest level of integrity, are perceived as circular barriers.
The barriers can be divided into 4 categories; Cultural, Regulatory, Market and Technological (Kirchherr et al., 2018). One barrier can be the result of a chain reaction caused by another barrier, which resembles the complexity of the transition to the Circular Economy.

The barriers that are found during the research, are described in this chapter and categorized according to the 4 categories, figure 25.

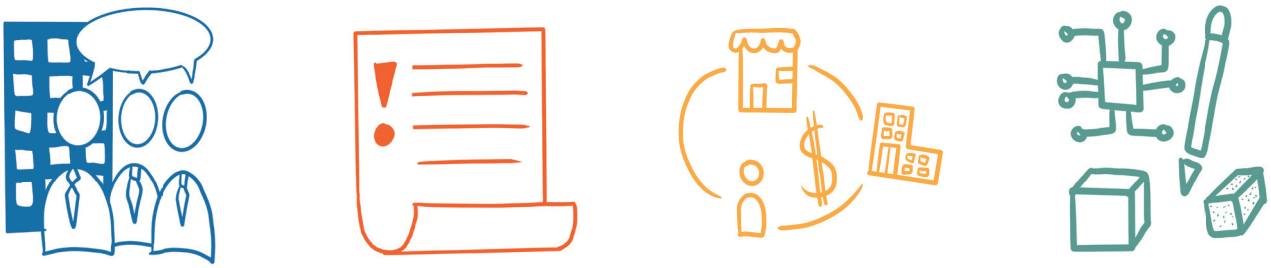


Figure 25. The four categories of circular barriers.

8.2 Cultural Barriers

Cultural barriers definition

Cultural barriers refer to behaviour and thoughts of consumers and companies. Four main types of barriers were defined in the literature:
"- Hesitant company culture
- Lacking consumer interest and awareness
- Operating in a linear system
- Willingness to collaborate in the value chain" (Kircherr et al, 2018) The consumer often determines when the product becomes obsolete due to their needs and fashion trends. The company can react to their behaviour by designing specific products and operating in a certain way.

User behaviour and perceptions

The perception of the users about the products is important, as they often determine when a product becomes obsolete (Hollander et al, 2017).
Next to this, the users are the last touchpoint of the product before it looses its value. They determine what happens with it. The patients mostly throw the mask and the headgear in the residual waste bin after they have received a new one (Appendix C). Sometimes they throw the mask in the plastic recycling bin, although it can not be recycled through this infrastructure. Several patients keep their old mask as a reserve, which means that the products are not always broken when they are replaced. The headgear is mostly perceived as "dirty trash" and is thrown in the waste bin (Appendix...users).

User determines end of life scenario

Next to the disposal behaviour, the user is responsible for the care of the products and the environmental cleaning impact. When they do not take care of the products in a right way, the lifetime of the products can be decreased. Therefore, it is important that the products are cleaned regularly. Currently, a considerable amount of patients do not clean regularly according to the manual (Appendix B) This results in the headgear breaking down earlier. Next to this, the tempering with the products by DIY solutions (as described in chapter 5.5), can result in a shorter lifetime of the products. Furthermore, the headgear and mask are delivered

User does not clean according to manual

User problems can result in tampering with products which shortens their lifetime.

assembled to each other, see chapter 5.1. The reason for this is among others, that it is hard to assemble the headgear and the mask.
With pre-assembling, they know how the products should be attached and they perceive it a good service from Philips. The headgear is shipped all around the world to the production site of the mask for the pre-assembling, and then shipped back to the user (Appendix ... transport scenario).

User wishes/ strategy results in high transport emissions.

Company structure

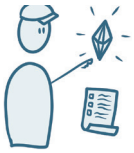
The user needs are not the only reason for the illogical transport scenario. This scenario is also the result of lack of awareness and sustainable motivation. The transport of the products is managed by a separate department within Philips. This means that the designers do not have a good idea of what the effect of design decisions is on the supply chain and costs. Furthermore, unforeseen changes in supply and demand can result in last moment shipping by air instead of boat, as this is faster. Flying has a higher environmental impact than transport by boat.

Supply chain is designed and managed separate from product design

Decision making

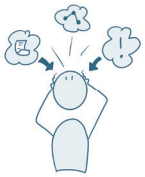
The marketing department defines the strategy of the SRC business. They provide the Core Engineering group with a requirement document for the functions, aesthetics and other physical characteristics for the mask and headgear. The Product Manager from the marketing department is the owner of the project in the end and the marketing department handles the product launch and sales. The engineering department or a group in Philips Design designs the product, but the marketing department has final say in design decisions (Personal communications with SR Manager Engineering SRC).
Although Group Sustainability has many sustainable and circular design targets and requirements, this is not always well integrated in the requirements list. In the past, this resulted in that recyclable materials were not chosen because of aesthetic reasons, which is also a technical limitation due to the quality of the recycled plastics that are available.

- Marketing makes the decisions; sustainability is not a key requirement
- Sustainable materials are not chosen because of aesthetic appearances



Next to the SRC Engineering department, Philips Design is working on several masks and innovation projects in separate offices. These projects seem to be conducted next to each other and due to the spreading of these projects over different departments, there is lack of communication and knowledge about what everybody is doing. This was also personally experienced through this project. This can result in a slower innovation process or barriers in convincing to go in a certain direction.

- Lack of communication between innovation and design projects.
- Designer expects manufacturer to mention other materials



Risk aversion

There are many regulations and requirements that the mask and headgear have to meet. There is not a clear overview of these requirements. Next to this, the tests that the materials and products have to go through, often takes a lot of time and money.
This results in the feeling of an overload of requirements and the aversion of experimenting with new materials. Therefore, the headgear is made in the same way for many years.

- Risk aversion material for bio-compatibility testing
- Risk aversion (medical) waste handeling

Conclusion

According to the literature, the hesitant company culture can be a result of the lacking consumer interest and awareness (Kircherr, 2018). This is confirmed by the way that the decisions are made at Philips SRC, but it is not the only reason. Another cause of the hesitant company culture in Philips SRC is that the **knowledge and motivation** to make the transition to the CE is restricted, which was also found in the literature (Kircherr, 2018). To move towards a circular proposition, the motivation, the structural way of working, the decision making process, and the priorities of the requirements in different departments in SRC needs to change.

Furthermore, the user's participation and their perceived value of the material and products can be the key to make a circular proposition work. Therefore, their **awareness** of this is important. It is best if the product service system and reverse logistics is designed as such, that it is made easy or valuable for the user to participate in the circularity of the products.
Another solution could be to take away the power or responsibility of the user in the reverse logistics.

8.3 Regulatory Barriers

Regulatory barriers definition

Regulatory barriers refer to obstructing laws and regulations that are often made by governmental institutions. These regulations do not always restrict circular propositions directly, but they can make it harder to implement or turn into cultural barriers by misconceptions.
It is hard to introduce circular design principles in the healthcare because of all the existing regulations for product safety (Kane, Bakker and Balkenende, 2018). It is already a challenge for designers to meet these. Any increase of risk and reduction of functionality can endanger a patients' health (Kane, 2018).
Furthermore, governmental interventions can lead to market barriers by subsidies at the wrong places. For example, many virgin material prices are artificially low due to subsidized energy (Kircherr et al, 2018).

Material requirements

The requirements for the headgear and masks are specified according to bio-compatibility guidelines of ISO 10993-1; "Biological evaluation of medical devices - Part 1: Evaluation and testing within a risk management process." The skin contacting materials are tested on cytotoxicity, irritation and sensitization. This means that for every material and yarn that is used, the compounds and used chemicals have to be specified in detail. For example; the bio-compatibility has to be reassessed for every colour change. It is unlikely that the bio-compatibility will be approved if there is recycled material in the products whereof the content is not specifically known, controlled or always the same (Personal Communication with Mechanical Engineer SRC on 13-5-2019).

- Bio- compatibility testing = no- use of recycled material in headgear
- FDA/ISO standards

Waste handling

Any producer of waste is legally and financially liable for disposing of that waste in a manner that is safe for people and the environment, even if some of the processes are sub-contracted (International Committee of the Red Cross, 2011).
The stakeholders and contacts in the business of Philips Sleep and Respiratory Care mentioned their concern about waste handling for the circular economy, regarding terms of medical waste handling and hazardous material.

- Waste handling concerns

Medical waste is a term that covers all the waste that is produced in health-care or diagnostic activities (International Committee of the Red Cross, 2011) Though, 75%-90% of the hospital waste is similar to household or municipal waste and can be put through the same collection, recycling and processing procedures (International Committee of the Red Cross, 2011). The classification of hazardous medical waste is divided in 5 categories, whereof subcategory 2.a is "Waste entailing risk of contamination". This category refers to "Waste containing blood, secretions or excreta entailing a risk of contamination" (International Committee of the Red Cross, 2011).

The Dreamwear headgear and mask are not hazardous medical waste. Most of these products are taken home (Appendix B, nurse interview) and must be disposed of in accordance with local regulations, as is stated in the user manual (Philips Respironics, 2015). This means that the mask and headgear are thrown in the municipal waste bin or plastic recycling bin, as is confirmed by Dutch OSAS patients (Appendix C, User research questionnaire). Even when it should be send in a package in the mail after use, it does not fall under the medical mail regulations (Koninklijke PostNL, 2019a). Even if it did, it could still be send internationally by the user in the regular mail with a note on the envelop (Koninklijke PostNL, 2019b).

Reimbursement

The insurance companies and the reimbursement approval in the US have a large influence on the design requirements for the mask and the headgear. A product has to receive a certain label before it can be reimbursed by insurance companies. Such a label is called a Current Procedural Terminology code. These labels are developed and maintained by the American Medical Association (AAPC, 2019). The rules for assigning a specific code are very complex and often not clear for the designers. The marketing department, the insurance companies and even outside contractors evaluate the codes and all masks and headgears. For this reason, the Dreamwear headgear had to be made with 2 back straps or it would risk to loose the reimbursement code (Personal communication with Mechanical Engineer SRC).

Reimbursement coding determines design

Conclusion

The tough material requirements make it harder to use recycled material in the mask and headgear. This does not mean that it is not possible in the future, but the content should be well tested and regulated which can be time consuming and expensive.

Even though legislations around waste handling were mentioned several times during interviews, it does not resemble a no-go for recycling of the mask and headgear. In the EU, the transition to the circular economy is a policy priority since 2015, which means that regulations are changed to stimulate companies to work towards the CE (European Commission, 2019). Circular products and 2nd life raw material will be stimulated by subsidies and waste regulations are renewed.(European Commission, 2019).
Next to this, the legislations around hazardous waste and hospitals will not be an issue for the largest part of the Dreamwear products, as the headgear and mask are mostly used at home and disposed through the municipal waste.

The reimbursement coding does not have to be an issue if it is taken into account earlier in the design process and when the requirements are made more transparent to the designers and engineers.

8.4 Market Barriers

Market barriers definition

Market barriers can have a major impact on the decision making process of a company. Therefore, they can be the cause of cultural barriers. Raw virgin material prices and investment costs for circular business models can prevent circular products to outcompete the unsustainable and uncircular ones (Kircherr et al, 2018). The market barriers are also defined by existing recycling facilities, infrastructures and competitors.

Market structure

The DME does not take back the headgear and masks which they have provided to the patients. Philips SRC does not have direct interaction with patients and does not have control over the mask decision and procurement process, like explained in chapter 5.4. This causes that the Philips SRC department does not have control over the end of life of the products and a possible reuse cycle.

- SRC has no control over the product End of Life scenario
- The DME does not take back the headgears and masks

The insurance companies pay the suppliers for the products. They reimburse them according to standard reimbursement periods. The result of this is that these reimbursement periods often determine the lifetime of the products. Interesting is, that these periods differ per market. For example, in the US the lifetime of the headgear is often 6 months while in the Netherlands it is 12 months (American Sleep Association, 2019). In the Netherlands, the insurance companies replace the headgear and mask together in one package, which means that the products do not have an independent lifetime (Philips, 2019). The products are even tested with use cycles towards double the required lifetime, respectively 2 years (Mechanical Engineer SRC).The result of this system is that products are currently often replaced when they are not broken, as was confirmed by the Dutch users (Appendix …User research questionnaire).

- Reimbursement determines product lifetime

Supply chain and costs

The supply chain is currently distributed over the whole world, as can be seen in the map in Confidential Appendix 5. The mask is manufactured on a different location than the headgear.

- Production facilities are spread globally.
- Manufacturing cheaper on the other side of the world

Both are not locally produced in the countries in which they are used, like the US and Europe. This is mainly because manufacturing is often cheaper on the other side of the world due to low labour costs. The different parts of the headgear are sewed together and the loose Velcro pieces are applied by manually welding them. Relocating the manufacturing facilities would result in high investment costs.

- High investment costs to change the supply chain

Material market

The volume of the materials and their 2nd hand material value are important for the economical viability of a new circular proposition.
SRC does not take back the mask and headgear because the products are small and they question their value. Therefore, the mask and headgear products should be disposed locally. This means that local waste management facilities has a large influence on the current End of Life of the products and material.

Municipalities are responsible for the collecting, separating, cleaning and processing of home plastic waste. Both groups of Polyamides (including nylon) and elastomers (including silicone) have a low market share, see figure 26. This makes collecting and reusing them on a high level hard and expensive. Even the other plastics with a high market share such as HDPE and LDPE plastic packaging, are not all recycled with a high

- End of life scenario depends on local facilities

integrity. For example, packaging is 40% of the plastic production in Europe and only 30% of this is recycled (plasticseurope, 2018).

As a result of the market share and local facilities, the silicone of the mask is often not recycled but burned in a waste incineration (PlasticsEurope, 2019). The silicone cannot be easily re-heated and melted into another product because it is a thermoset (PlasticsEurope, 2019). There are other options to recycle silicone in specialized facilities, but there are no municipal collections bins to get silicone based products from homes to these facilities.

- Municipal collecting and recycling rate is not high
- Silicone needs to be recycled in specialised facilities
- Products are not made from most common and easily recyclable plastics

Re-granulated plastic is often not a perfect substitute for virgin plastic (Centraal Planbureau, 2017). Therefore, re-granulated plastic is often mixed with the virgin type for production. Re-granulated plastic can therefore not be sold for the same price as virgin plastic.

- Regranulated material value is not as high as virgin material

The headgear could be made with recycled yarn when it is well certified. An engineer at SRC mentioned that they have looked at it in the past but it was more expensive than the not recycled yarn.

- Recycled yarn is more expensive

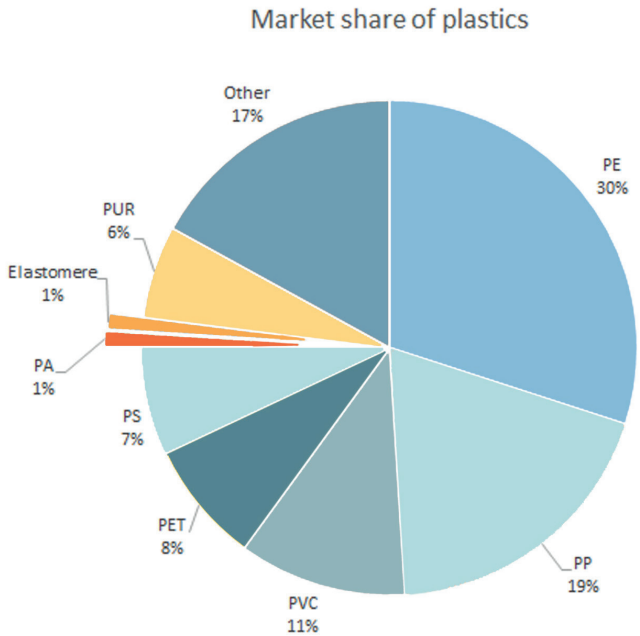


Figure 26. Market share of plastics. Data source: Centraal Planbureau, 2017.

Conclusion

The supply chain is spread globally and the material flow is not controlled during the lifetime of the product. The end of life scenario of the material depends on local facilities and user behaviour. The current materials do not exist in high volumes in the market and local municipalities do not collect and recycle it through municipal waste. Research needs to be done to other materials and methods to make recycling easier.
A reuse scenario and collaboration is needed to make the material flow controlled and circular. In this way, local reverse logistics can be established whereby the relative material value needs to be checked against needed investments.

8.5 Technological Barriers

Technological barriers definition

The relevant technology and circular design needs to be in place before the transition to the CE can be made (Kircherr et al, 2018). In this chapter is referred to technology barriers as design choices and manufacturing principles that reduce the lifetime of the product or make it harder to reuse, re-manufacture or recycle.

Design

It is mainly possible to disassemble the mask, as can be seen in figure 27. This makes it also possible to clean the product easily. The only exception is that the polycarbonate snap fits inside the mask and cushion are permanently attached to the silicone. In this way, the polycarbonate pieces cannot be easily separated. Silicone is a thermoset plastic, which means that when it is heated, it cannot be re-melted and reformed into another product through the general plastic recycle facilities (Plasticseurope, 2018). In some special facilities, it is possible to chemically recycle Silicone into other products.

- Permanent click inserts in mask frame
- Silicone not easy recyclable

The headgear and mask are delivered assembled to each other, like described in the Cultural barriers. If the headgear and mask is designed as such that it is not hard and logic to assembly, maybe this could be prevented.
In this way, the impact of the transport phase of the life cycle could be lowered.

- Pre assembling of the mask and headgear

The headgear is designed with Velcro pieces to make adjustment possible. The pity is, that this damages the outer layer of the headgear itself, due to repeatedly attaching and detaching. Next to this, the Velcro wears down because the hooks melt in the dryer or clothes stick to it in the was machine. Although the manual says that the user should not put it in the was machine and dryer, a lot of them do it anyway because it cleans better and easier. The mask should be cleaned daily because it gets greasy and dirty which can cause slipping off the face and skin irritation. This causes a high environmental impact. There is a need for easier and safer to clean products or a material that gets less dirty and is bacterial repelling.

- Materials not optimized for cleaning ritual
- Velcro causes headgear to break down

Manufacturing

The headgear is a one piece product that contains several types of material, see figure 28. Some of these materials are recyclable and some are not, but it is not possible to separate them. The nylon is a thermoplastic and can be easily recycled into other products (PlasticsEurope, 2019). Polyurethane, the material that is used for the foam layer on the inside of the headgear, is a thermoset and cannot be recycled (PlasticsEurope, 2018). All these layers

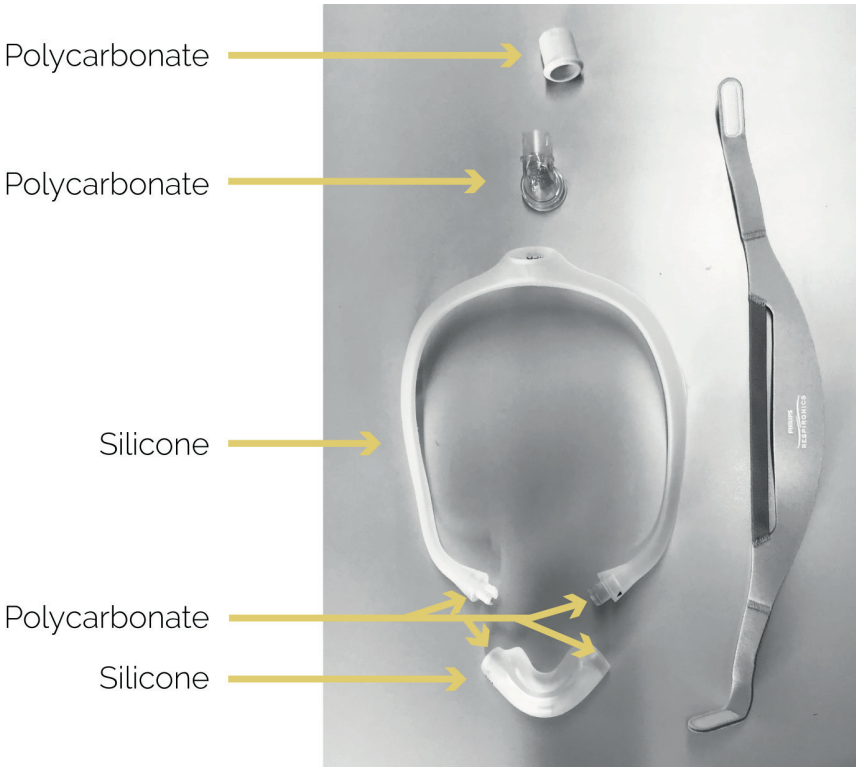


Figure 27. Mask parts and materials.

of material are flame laminated on top of each other, which makes them inseparable. The Nylon Velcro pieces are ultrasonically welded onto the fabric, and therefore are also permanently attached. The reason that this is done, is that the headgear should stay flexible for comfort of the patient. There was no glue used because that often becomes rigid when it is dry.
The thickness of the headgear is needed to stabilize it on the back of the head, as the material section fits the mask frame slots perfectly.

- Flame lamination of different materials
- Thick foam is used for stability
- PUR foam is not recyclable

Conclusion

The mask is already designed to make it easy to disassemble, except for the polycarbonate click inserts in the frame. The headgear contains some layers that could be recyclable but flame lamination prevents this from happening in the future. The products need to be redesigned for easy and better cleaning, a longer product life and optimized reuse possibilities.

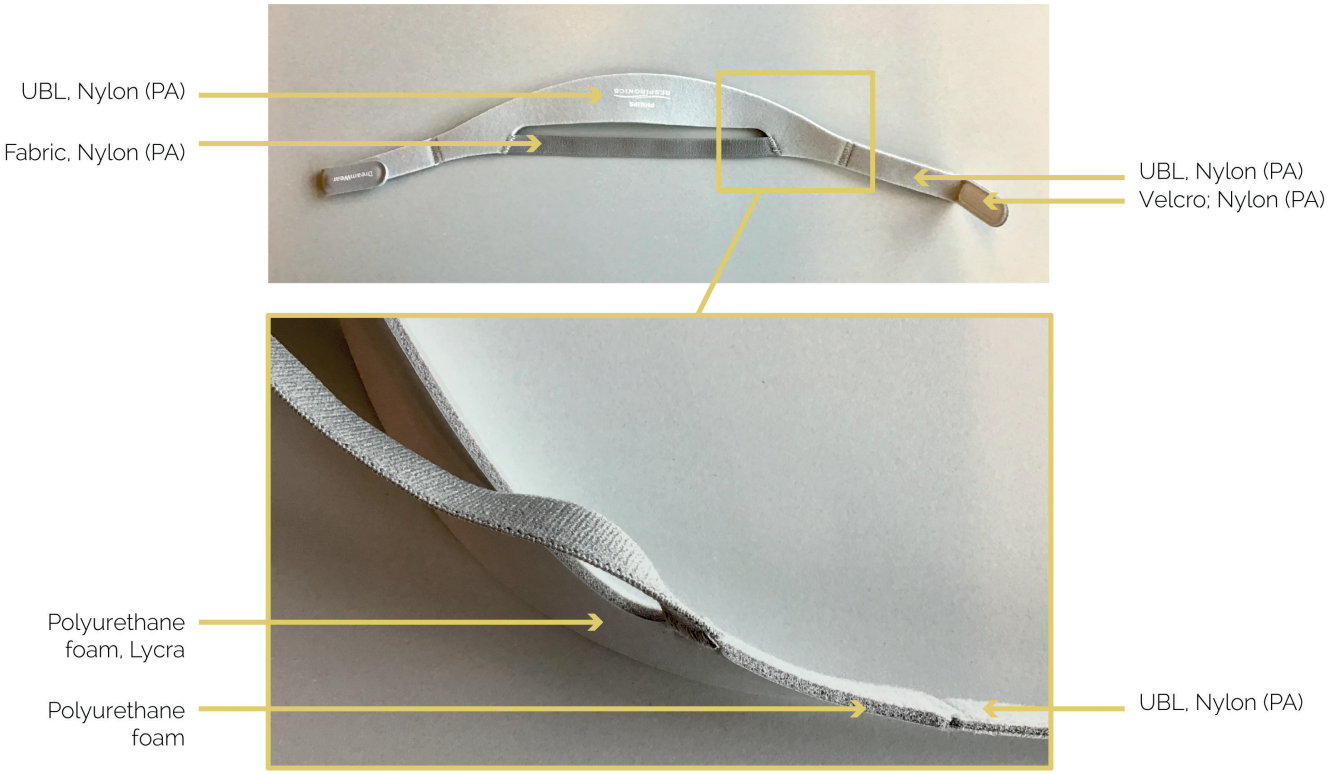


Figure 28. Headgear layers and materials

Chapter

09

KEY PROBLEMS

What are we going to do in this chapter?

9.1. Main problems

"CE is not a 'quick win', but a major long-term undertaking" - Kircherr et al, 2018

Problem network

One barrier can be the result of a chain reaction caused by another barrier.

The barriers, chain reactions and the relation to the 3 fundamental strategies for circular resources (Bocken et al, 2016) are displayed in the problem network on the next page:
1. Slowing resource loops
2. Closing resource loops
3. Resource efficiency

The cultural and market barriers are identified as the most pressing ones in the EU (Kirchherr et al., 2018). These barriers are also the main reason that the current product is not circular. The other barriers are mainly the result of company decisions based on their priorities and market factors. From the network can be concluded, that more factors need to change than just the product design, before the product can be circular. Regulations of the EU and local recycling facilities cannot be changed: but the EU is working towards policies to stimulate the transition to the circular economy.

Conclusion

Tackling the main problems below, will result in a more sustainable and circular headgear.

1. Decision making process: risk aversion + lack of motivation and knowledge

Which results in:
- The design of a non recyclable product
- No use of 2nd life materials
- No responsibility over the product end of life

2. Philips SRC does not have direct interaction with patients and control over the mask decision and procurement process

which results in:
- No control over the material flow
- User problems result in tampering with products
- Reimbursement schedule determines product lifetime

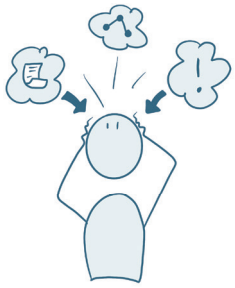
3. Product design is not optimized for an easy cleaning ritual

Which results in:
- High CO_2 cleaning emissions
- Users that do not follow the cleaning instructions
- Headgear's Velcro breaking down

4. Current headgear design is not suitable for a circular proposition

Which results in:
- No local recycling options
- Obsolescence

9.2 Problem network



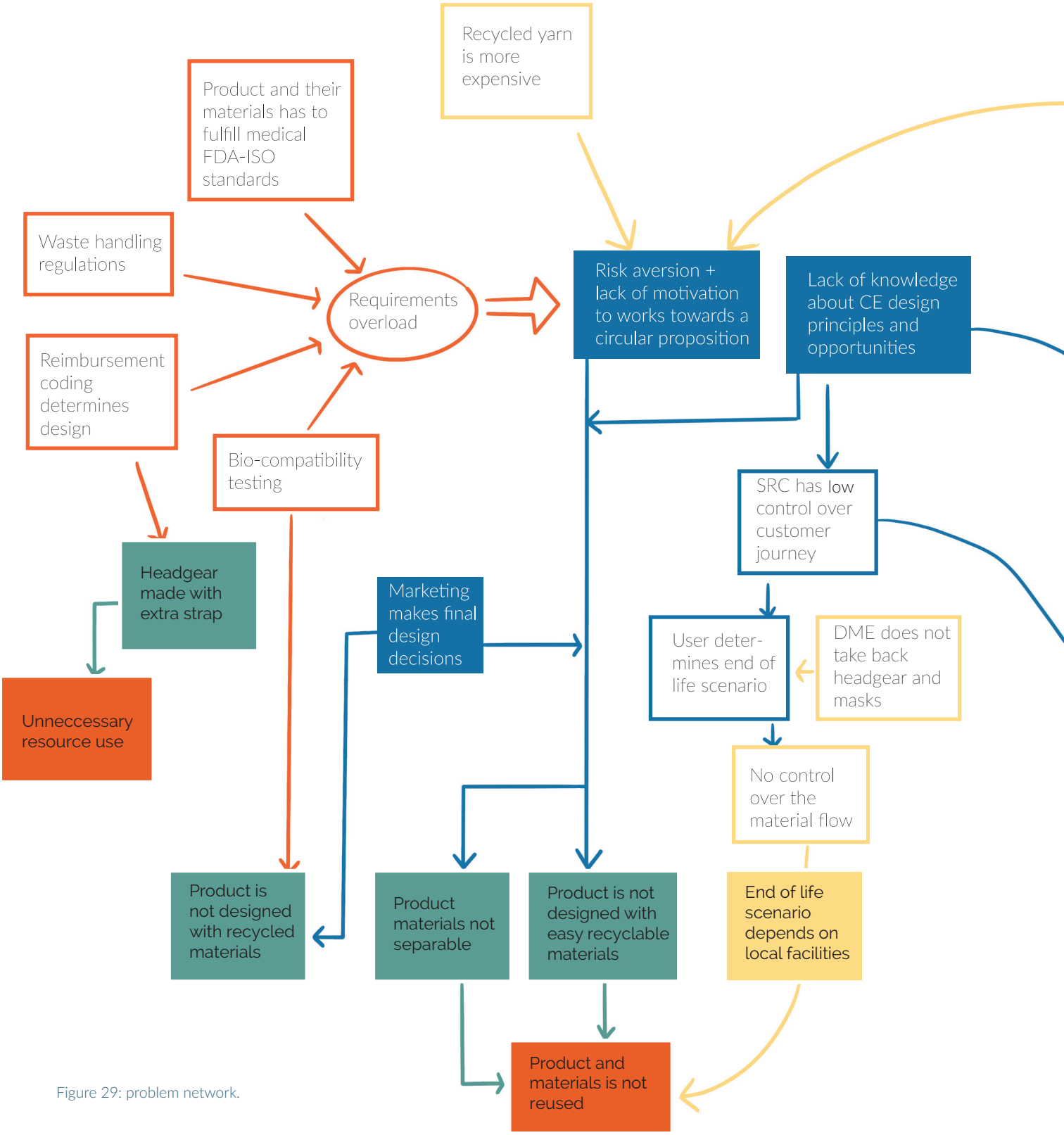
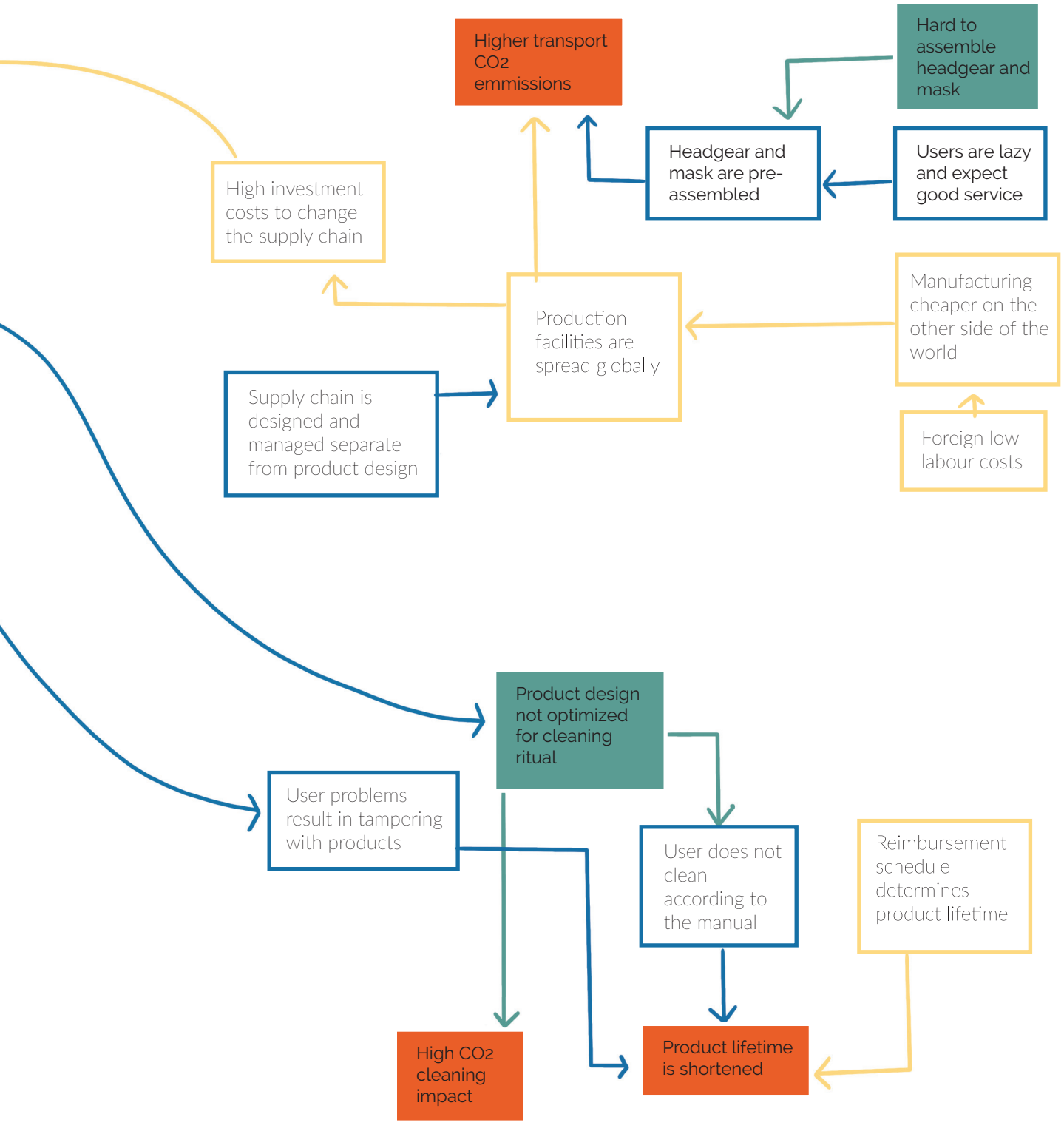


Figure 29: problem network.


Higher transport CO2 emmissions
Hard to assemble headgear and mask
Headgear and mask are pre-assembled
Users are lazy and expect good service
High investment costs to change the supply chain
Production facilities are spread globally
Manufacturing cheaper on the other side of the world
Supply chain is designed and managed separate from product design
Foreign low labour costs
Product design not optimized for cleaning ritual
User problems result in tampering with products
User does not clean according to the manual
Reimbursement schedule determines product lifetime
High CO2 cleaning impact
Product lifetime is shortened

Section summary

Environmental impact

A Fast track LCA analysis and an assessment tool is created to assess the life cycle of the products and compare different scenarios. The highest impact of the product life cycle is caused by the washing of the products and especially the used energy to warm up the water. The headgear production is responsible for only a small part of the total environmental impact. Furthermore, the impact of the transport of the headgear is as large as the production of the headgear itself. The silicone and polycarbonate material of the mask and cushion have the highest impact of the production part of the life cycle. The silicone is the majority of the material in the package and is not recyclable. The polycarbonate that comes in 2nd place is recyclable.

The best way to reduce the environmental impact of the total package and content, is to

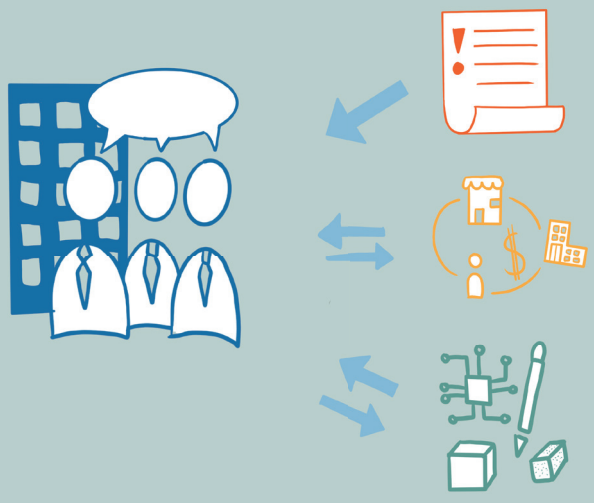
1) reduce the cleaning impact by saving water and heat
2) establish an End of Life potential for all materials
3) create another solution for all the packaging and extra cushion sizes
4) create local production possibilities

Circular barriers

The three fundamental circular strategies are;
1. Slowing resource loops
2. Closing resource loops
3. Resource efficiency

Circular barriers are things that could hold back or prevent the product system and business model from becoming circular towards these strategies.

The four circular barrier categories are Cultural, Regulatory, Market and Technological, as displayed in the figure on the right. The transition to the circular economy is a fundamental systemic and complex innovation. This can also be concluded from the problem network diagram in paragraph 8.2. The barriers do not stand alone, but are often linked to each other. The cultural and market barriers are the most pressing ones and these create chain reactions.



Main lifetime reducers:

- Users tamper with products because of comfort problems

- Headgear should be hand washed
- User does not clean according to the manual

- The reimbursement schedule determines the product lifetime

- Velcro in headgear breaks down

Prevention of material loop:

- Philips SRC does not have direct interaction with patients

- The DME does not take back headgear and masks
- The supply chain is spread globally

- The headgear and mask are not designed with easy recyclable materials
- The headgear and mask is not designed with recycled 2nd hand material
- The headgear materials are not separable

Conclusions

The main reason for why the product is currently not circular, is that Ecodesign and CE-ready design requirements have not been embedded yet in the product development process of consumables within Philips, although this is future requirement. This is a result from several market and cultural barriers. The main conclusions from the research are:

1. Risk aversion and lack of knowledge for and about circular propositions, results in less sustainable or non circular designs.

2. SRC Philips does not have direct interaction with patients or control over the mask decision and procurement process, which results in no responsibility and control over the material flow.

3. The product design is not optimized for an easy cleaning ritual which results in a high CO2 impact and the headgear breaking down.

4. The current headgear design is not suitable to be recycled, refurbished or remanufactured.

SECTION 4

Design Brief & Ideation

In the previous chapters, the product, the context and the main problems regarding circularity, environmental impact and user experience are analysed. In this section, the focus for the design phase is established by defining the main problems, boundary conditions, design vision and focus point. Furthermore, the design process is explained and the different solution directions are evaluated.

10. Design Brief

Looking back

The main goal of this project is to inspire SRC to make the transition to the Circular Economy by creating a circular proposition for the headgear. At the beginning of the project, the plan was to create several new business models and designs whereof one proposition would be with the current design. After the research, the main conclusions are;

1. An holistic design approach is needed

2. The system is complex and there are many requirements and stakeholders

3. There is a complete different headgear design needed to make a successful circular proposition.

The main reasons for why the product currently is not circular are the lack of motivation and action to move towards circular propositions by a requirements overload and other priorities during the creation of the design brief and the product design. This results from the idea that it is too hard or not possible to create a circular proposition and that there would be no advantages for SRC. It seems too hard because the system is complex and there is no clear overview of the influences and the design requirements, for example for the reimbursement requirements and materials.

Most fundamental circular and market barriers can be solved with the right motivation and investments. To achieve this, a mind-shift in the company culture's decision making process and main priorities is needed.

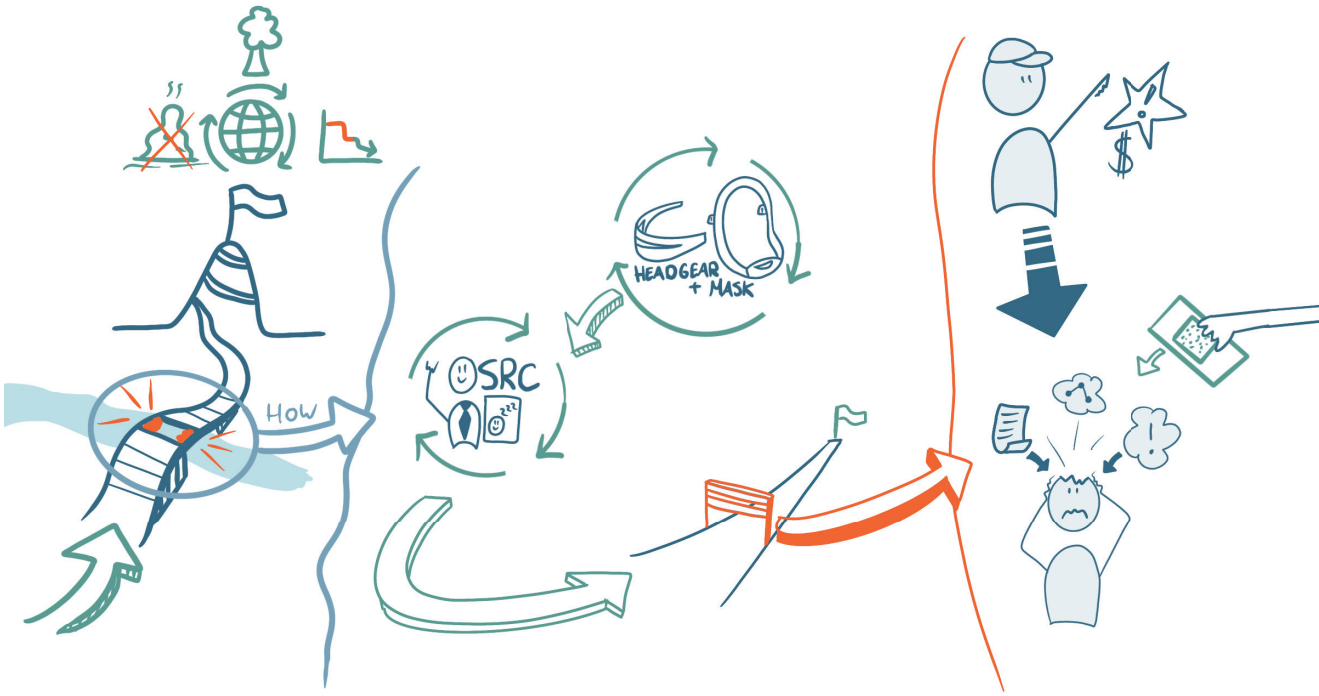
Therefore, to stimulate SRC to make the transition to the circular economy it is needed to:

1. Show that it is possible to create a circular solution

2. Show the advantages of such a circular solution for SRC

3. Create a structured overview; to break down the complex system and overload of requirements.

4. Show that a truly circular proposition is in need for an holistic solution and not just a quick fix by changing some materials.



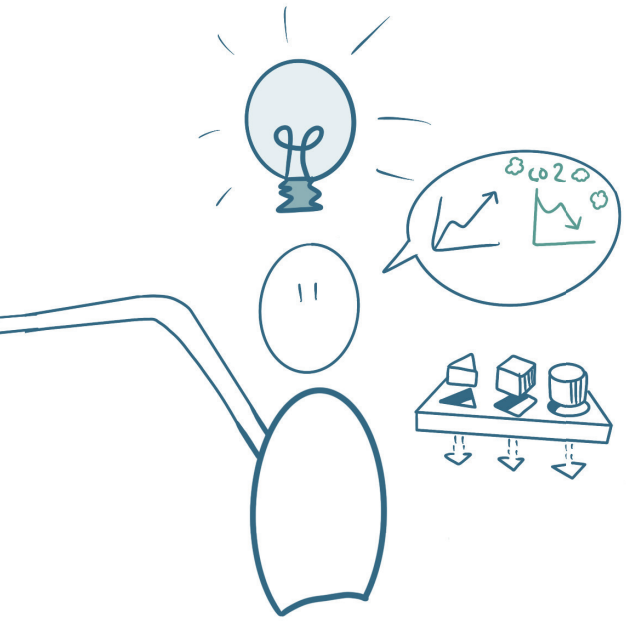
Look further than what's in front of you

Oké, so what does this mean?

In the first phase of this project, the patient journey, the supply chain and the product life cycle was mapped. This overview will already help in addressing the complexity of the system by creating order and is thereby part of the solution. Furthermore, feasibility and relativity is key for this already complex system. Therefore, the circular proposition needs to focus on already existing solutions and logistics as much as possible, while addressing the 4 main problems. Collaboration through the supply chain is needed to manage tasks and roles over the different stakeholders.

Design vision

"..improve the motivation to work towards a circular solution with an holistic design approach and showing that such a circular proposition is of advantage for SRC; by increasing contact with patients and gaining control over mask decision process, while increasing the control over material flow.."



How?

As discussed in the introduction and with the idea of an holistic design approach, eco-design and circular design should be integrated. Therefore, I will focus on creating a new headgear design that is circular ready and explore circular business models, while lowering the CO2 impact. Whereby the main opportunity to lower the Co2 impact is to optimize the cleaning ritual.

Therefore, in the design phase I have focused on these key ingredients:

1. Circularity
2. Philips SRC advantage
3. CO2 reduction

while keeping in mind the user; whereby a user advantage can result in an advantage for SRC.

Main opportunities for user advantage:

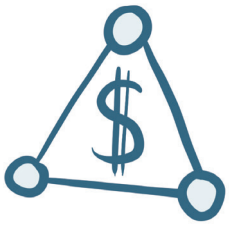
1. Make the patient feel more in control over the mask decision process and resupply.

2. Make it easier and logic to solve common comfort problems

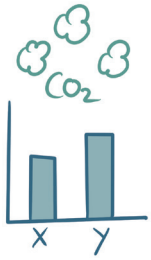
3. Create an easier and faster cleaning ritual

Approach

To address the 3 key ingredients, the focus in the design process will lie on:

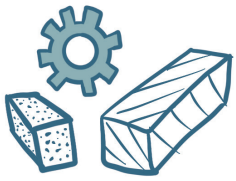


Exploring circular business models



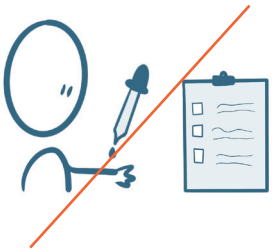
CO2 calculations

Circular design principles

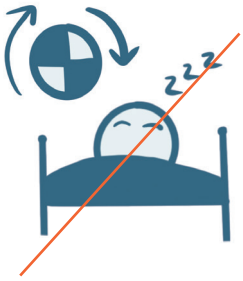


Explore materials and production

It is chosen to not dive into the many bio-compatibility and other requirements documents, because the many regulations and requirements are complex, a whole different legal department with consultants in SRC are assessing these and there is not a clear overview available.



Furthermore, because the main goal of this project is to explore circular propositions and create a sustainable design, the focus will not lie on extensive user testing for comfort.



Product design

From the analyses are two main problems defined that are specified to the product design:
The current headgear design is not suitable for a circular proposition and it is not optimized for an easy and environmental friendly cleaning ritual. These lead to the following 4 possible design changes that result in a positive impact regarding sustainability.

No/loose Velcro on headgear	No polyurethane grip layer on headgear	No flame lamination of different materials	No pre assembling of mask and headgear	
Design for disassembly/ separate materials Extend product life	Eliminate non recyclable materials	Design for disassembly/ separate materials	-	Advantages Circularity
Extend product life + less resources over time	Recyclable End of life	Recyclable End of life	Less transport needed	CO2
Cost reduction on manual labour + RF welding	Eliminate most expensive material: reduce production costs	Eliminate expensive production process	Less transport + Less labour costs	Philips SRC
Throw in washing machine + dryer	Easier to clean	Less thick headgear could result in more comfort	depends: easier to assemble? = easier cleaning ritual	user
Other attachment method Other resizing method	Without grip layer, headgear is less steady on the head.	Less luxury aesthetics Soft cushion effect gone Less sturdy= less stable on the back of the head	Perception of bad service by user Possible unclear how to assemble	Possible new design problem

11. Circular business models

A different circular business model in combination with circular product design principles, will together result in control over the product lifetime and a circular material flow with the highest integrity. Another business model could result in more contact with the patient and more control over the mask decision process. This is an advantage for SRC, which results in motivation to work towards a circular business model.

Circular business models

There are different circular business models that could be applied to products. In the Circular Design Playbook from Philips Design, like described in paragraph 3.2, are multiple circular revenue categories defined that resemble a certain business model. This can be found in Confidential Appendix 1. These categories are explained and their benefits, risks and requirements are listed.
There are three circular revenue types defined in this document: software, service and hardware. Herein are eight **circular revenue categories**, as displayed in figure 4 in chapter 3.2.

The **software** category describes digital solutions which reduce the need for hardware or optimize resource use (Philips Design, 2019).

The **service** category describes business models that gain revenue by performance and access based models and can extend the product lifetime by automatic upgrades.

The **hardware** category describes ways to gain revenue from taking back and reselling products, reusing parts and implementation of recycled contents. These tactics can reduce production costs and increase the used value of the products and materials.

Discussion on different business models

Integrating circular economy principles into design for healthcare is difficult due to legal barriers, as explained in chapter 8.3. Disposable products in the healthcare industry have decreased the risk on infection and improved health outcomes (Kane, Bakker and Balkenende, 2018). Therefore, reusing devices on multiple patients has a high risk factor. Healthcare products that are refurbished or remanufactured are often complex and expensive products like X-rays and MRI machines (Kane et al, 2018). This is mostly done to reduce cost for the end-user, as there is a consumer demand for lower product prices (Kane et al, 2018).
This circular strategy is successful for these kind of products because they have a high value and the refurbishment costs are relatively small in compared to the production of a new one. Translating the refurbishment strategies to consumables products like the current Dreamwear mask and headgear is challenging. This is because these products have a short lifetime and are not easy to restore in their original hygienic and aesthetic state. Bringing the products back from an obsolete state after use by a patient, should mean that a sterilization or disinfection process should be applied (Kane et al, 2018). These processes can mechanically and chemically damage the product which could also result in loss of properties.

Next to this, the CPAP supplies have a hybrid business model which means that the system has a long lasting product in combination with disposable ones (Haffmans, 2018), wherein the disposable products are more profitable. In this case, the CPAP machine is the long lasting product and the mask and headgear the disposable ones. The production costs of the headgear are only a small part of the selling price, of which the material costs are again also only a small part, see Confidential Appendix 6 Financial data. This is the same for the mask. Though, sometimes the masks are sent back to SRC by the user for warranty service inspecting. After this, the polycarbonate is separated from the mask and the silicone is sold to a third party.
All these arguments make that the headgear is perceived as invaluable at its end of life and is not suitable for taking back to the manufacturing site of Philips for recycling. The headgear and mask are therefore unsuitable for the circular revenue categories refurbishing and parts harvesting and reusing by other patients, even when they would be redesigned.

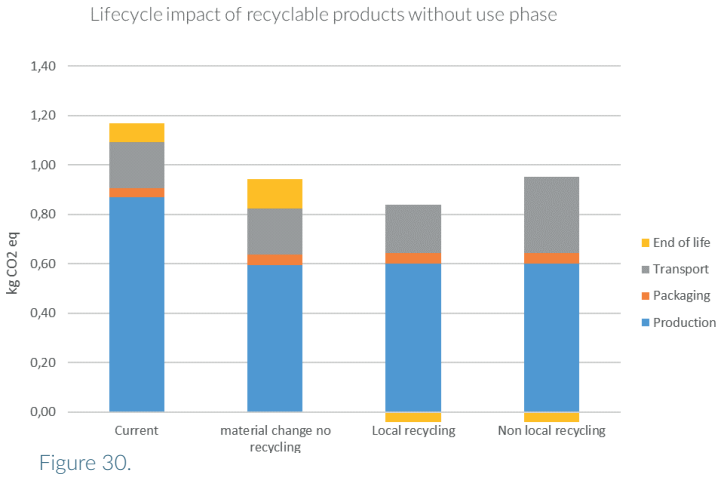


Figure 30.
Production scenario: When headgear is 100% nylon fiber and silicone is replaced with recyclable TPE.
Local= within Netherlands
Non local= shipped back to mask production site

"The greenest product is the one that already exists"
- John Donahoe, CEO of eBay

The **performance based business model** is the best option for a new circular business model for the headgear and mask, which is also a circular revenue category of Philips. The CPAP machine is already part of an Access based model (Haffmans, 2018) as in some cases it is rented to a patient and the ownership stays with the DME or insurance company. In some of these cases, it is returned to the DME, cleaned and re-rented to another patient (Appendix.... Interview with OSAS nurse). The cleaning is done by the DME, a partner or by Philips. The difference of a Performance based model to an Access based model, is that a function is rented instead of a product (Haffmans, 2018). This means that the patient pays for the service or guarantee that the product or product system always works, whereby maintenance and replacement products are included in the service.
In some way, the current business model of the Dreamwear mask and headgear can be described as a Performance based model, because a patient gets a prescription for CPAP therapy and gets supplied with the needed products. Though, the resupply of these products is not necessary linked to the performance of these products as the resupply is done within a fixed time scheme in which the products did not always stopped functioning. Improving this business model in the right way, so business increases the control over the patient journey, will enhance the circular potential.

As refurbishment and remanufacturing are not promising for the headgear and mask, an end of life scenario as recycling is a good option. Therefore, the current headgear and mask should be redesigned to be '**circular ready**'. This means that they should contain other materials which are separable and recyclable. A fast estimation is made of the potential positive effect of recyclable materials on the life cycle impact of the total product system. In this scenario, all the headgear materials are replaced by nylon. The silicone in the mask is replaced with SEBS, a TPE. This is displayed in the chart in figure 30. When these products are locally recycled, this could lower the impact with 41% when the use phase is not taken into account. This is only 1,3% of the total use phase when weekly warm hand washing is considered.

Conclusion

The circular strategy that is chosen for the new circular product service system is the **Performance based business model.** This will contribute to the circular revenue category of **service**. The software of the CPAP machine can track the performance of the therapy and products, which can enable a resupply system wherein the lifetime of the products is optimized.

It is not viable to take back the products to the current Philips manufacturing site with respect to cost, motivation and environmental impact. The products are now made in a central place and then spread globally. Therefore, it is chosen to focus on local recycling and possible local manufacturing options. Another reason for not taking back and recycling the products by Philips is that recycling technologies and especially yarn recycling from textiles, are complex and done by specialized facilities. More about this can be read in paragraph ... 13.1 and chapter 17.

Furthermore, options should be explored to use recycled content in the products. These material changes could take some time to develop or implement due to the strict regulations and besides other requirements, demands bio-compatibility testing.

The implementation of a new procurement model, (reverse) supply chain and recycled materials, can take a long time.
Because of this **long term strategy**, the product design should first be optimized for a longer lifetime to **slow the resource loops now**. Next to this, the product should become ready to be able to recycle it again. The new procurement model and business model can be implemented in steps over time, to work towards a circular solution. Furthermore, we need to get control over the patient journey now to enable recycling and reverse logistic strategies in the future!

12. Product design process

There are different circular design principles that are applicable to the circular business model and strategies that were discussed in chapter 11. During the design phase, the main goal is to redesign the headgear to extend the product life time and make the product recyclable.
The designing of the headgear, designing of the cleaning scenario, choice for circular business model and material research, were conducted next to each other instead of 1 by 1. This was needed because many design decisions were linked to the other categories. For example, a design that lasts long can fit to a access based business model. Therefore, the materials should be durable. These durable materials can have specific characteristics that are or are not suitable for specific attachment methods, and therefore this should be integrated again in the product design in a way that it lasts long. Then the circle is round!

The matrix on page 71 formed the start of this design process. Therefore, the main design challenges were:

Attachment to mask
Stability
Adjustment
Recyclable, durable, washable material(s) and components

Other defined variables were taken into account were the vector direction of the headgear on the back of the head, which resembles the stability, the fabric cutting pattern, the fact that all heads are different and OSAS patients are often overweight. The complete list of requirements can be found in appendix G

Design process

During this design process, many ideas were formed, see appendix H. Many of these ideas for attachment methods, forms and concepts were developed through multiple idea forming and prototyping cycles. During these design cycles, the main problems that were found with alternative designs were:

Curling up of fabric causes skin marks

Not enough stability

Hard to assemble

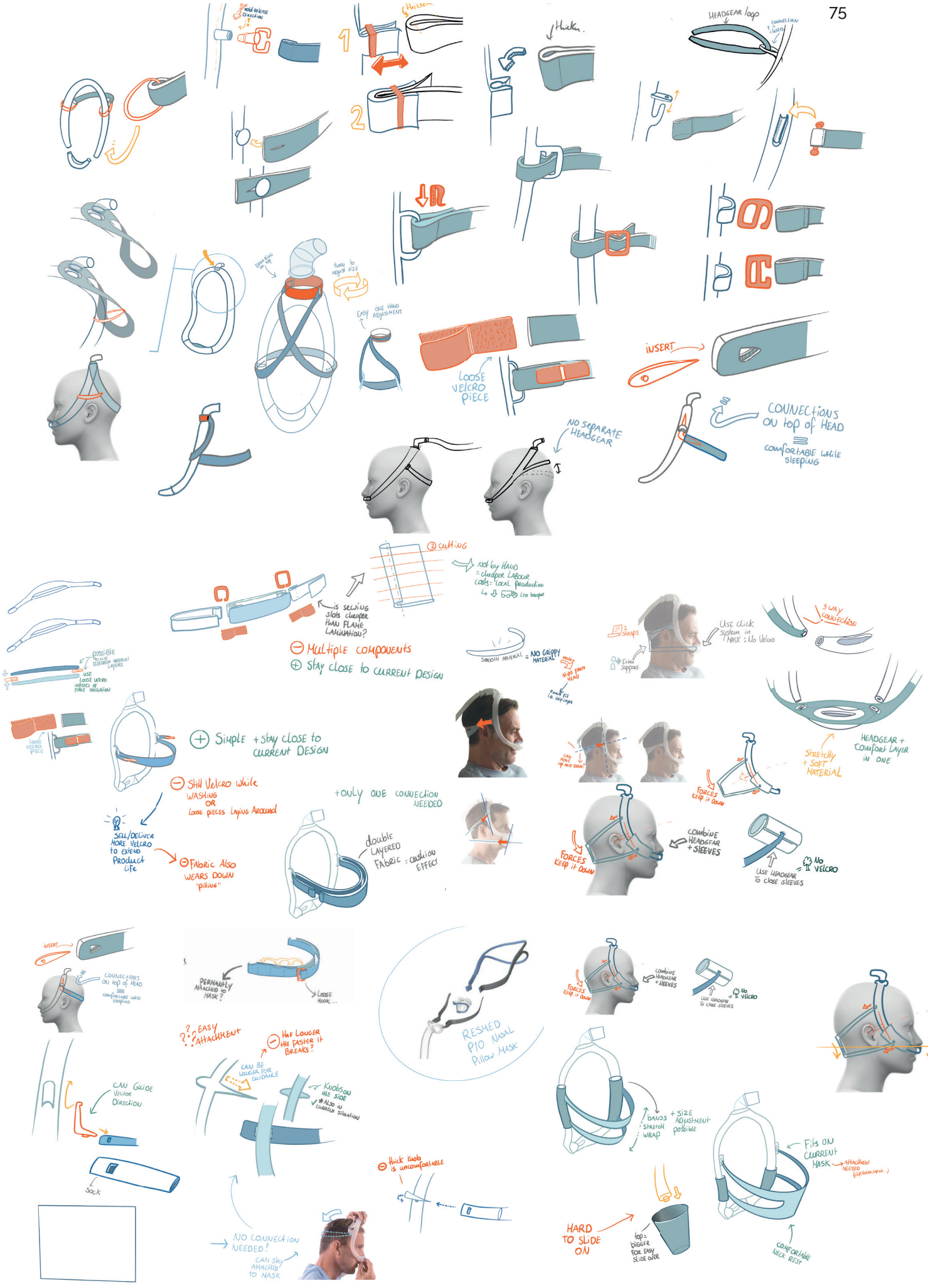
A more extensive review of all the prototypes can be found in Appendix I. The main conclusions are that an on-top tube connection is not ideal for the force direction, using the front tube connection is not comfortable and a single strap is not stable enough. A total rubber headgear which is attached to the mask is not comfortable due to hair that can stick to it and does not reach a good fit at the many different patient head sizes.

From the prototype tests and reviews with different stakeholders, was the sock slip on principle chosen. This design is optimized according to the following design characteristics:

Edge durability

Aesthetics

Assembling


HEADGEAR loop
NO SEPARATE HEADGEAR
CONNECTIONS ON top of HEAD
comfortable while sleeping
INSERT
LOOSE VELCRO PIECE
EASY ONE HAND ADJUSTMENT
cutting
not by HAND = cheaper LABOUR costs = local production
is sewing slots cheaper than flame lamination?
Multiple components
Stay close to current design
SMOOTH MATERIAL = NO GRIPPY MATERIAL
3 straps
Extra support
Use click system in mask : No Velcro
3 WAY CONNECTION
HEADGEAR + COMFORT LAYER IN ONE
stretchy + soft material
Simple + stay close to current design
Still Velcro while washing OR Loose pieces laying around
Sell/deliver more Velcro to extend product life
Fabric also wears down "pilling"
+ONLY ONE CONNECTION NEEDED
double layered fabric = cushion effect
FORCES KEEP IT DOWN
combine headgear + sleeves
use headgear to close sleeves
No Velcro
PERMANENTLY ATTACHED to mask?
Loose hook...
RESMED P10 NASAL Pillow Mask
? EASY ATTACHMENT
the longer the faster it breaks?
can be longer for guidance
Knobs on the side
also in current situation
can guide vector direction
sock
Thick knob is uncomfortable
NO CONNECTION NEEDED?
can stay attached to mask
bands stretch + wrap
+ size adjustment possible
Fits on current mask
attachment needed
comfortable neck rest
HARD TO SLIDE ON
top = bigger for easy slide over

13.1 Material research: headgear

Approach

In the first LCA calculations, the data was derived from the Idemat datasheet. Though, this data seemed insufficient because materials were not specified till yarn levels and the complex yarn production methods were not taken into account. The Higg Materials Sustainability Index (MSI) is a cradle-to-gate index that uses a life cycle assessment approach to compare environmental impact of different materials (Sustainable Apparel Coalition, 2019). The Higg MSI was originally developed by Nike and was adopted and matured by the SAC to engage product design teams and the global supply chain of apparel, footwear and home textile products in environmental sustainability (Sustainable Apparel Coalition, 2019). The following is included in the index; processing of materials, the Global warming potential (GWP), eutrophication, water scarcity, abiotic resource depletion, use of fossil fuels and chemicals (Sustainable Apparel Coalition, 2019). This makes the Higg MSI more suitable to compare and choose the right material for the headgear than the Idemat datasheet. In the Higg MSI tools are many types of fabrics, yarn and other materials included.

Material comparison

An overview of the possible headgear materials and their Higg index is displayed in figure 31.
Interesting is that the bio-based or partly bio-based fibers like cotton have a much higher impact than the non bio-based ones, due to the Global warming potential. For example; the raw material production of Nylon 4.10 bio-based is 195,6.
From the data can be concluded that virgin Cotton has the highest index and that the index from all the recycled materials do not differ that much from each other. The graph only represents the manufacturing of the yarn. Typical LCA studies of textile products conclude that the greatest environmental impact (75% or more), occurs during use by consumers, through water and energy use for washing and drying clothes (Tomaney, 2015). Therefore, the Higg Index should not be the only driver for the material choice. For example; resistance to wash cycles, durability and user comfort are other variables that should be taken into account. Next to the impact of the yarn from production, the possible recycle solutions of the end product should be taken into account. A material that is made from recycled materials, is not necessary easy to recycle again. A detailed comparison scheme of different materials can be found in Appendix J. Cotton is a widely used textile material, which is breathable and comes from a renewable natural source. Though, it has a high Higg index, it is not durable, has a long drying time and stains easily. Polyester is cheap, more heat resistant than nylon, and can be made of PET bottles. Though, it is less soft and durable than Nylon.

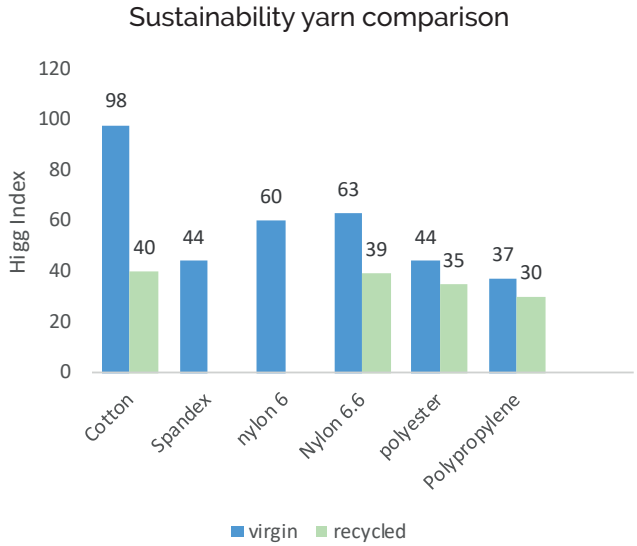


Figure 31. Yarn material comparison. Data source: Sustainable Apparel Coalition, 2019.

The most textiles in the world are made from a combination of fibres like cotton and polyester. The standard textile recycling methods shred textiles into fibres, which causes a reduction of length and quality (Eco-Business, 2017). Blended textiles can in general not be recycled in this way as the different materials can not be separated. Though, a lot of research is done to textile recycling and a company has found a way to separate and recycle polyester and cotton blends chemically (Eco-Business, 2017). Furthermore, Nylon Spandex material can through new techniques be recycled through melt processing (Lv et al, 2015).

Conclusion

For the right material properties, fibres are mostly blend. For the new design, a stretchy fabric is needed to ensure a better fit and stability during the night. Nylon 66 is chosen as the main material for the headgear in combination with spandex (elastane). The spandex blend is needed if the knitting production does not give enough stretch for a good fit. This is chosen because nylon is very durable, and therefore will ensure a longer lifetime of the headgear than when polyester is chosen.
As textiles and the infrastructure are currently not yet very suitable for recycling, slowing the loops is the best short term circular strategy. It is advised to work together with recycling yarn companies to develop and test a yarn from recycled material, that has a bio- compatibility approval to reduce the environmental impact.

13.2 Material research: mask

The current mask frame and cushion is made from the material silicone. As was explained in the circular barriers chapter, this is not easy recyclable. Therefore, research was done to alternative materials through literature research and conversations with experts. Although these materials are no textiles, the Higg index can be used as this also contains non-textile materials. The Higg indexes of these materials can be found in figure33. These do not differ that much from eachother and are therefore not decisive. Though, Silicone has the lowest Index.

Silicone

- Silicone material is perfect for the medical industry because it has excellent bio-compatibility.
- It is resistant to heat.
- The material is a rubber which means it is elastic
- It can be transparent

The silicone that is used in the mask and cushion is not easily recyclable in general waste facilities (PlasticsEurope, 2019). Though, it can be recycled chemically or shredded to use in other purposes (Silicone Recycling, 2014). It can for example function as a filler in a new mold in combination with fresh silicone (Shaller, 2015). When silicon is recycled, this is mostly done in downcycling solutions such as rubber tiles for playgrounds. Next to this, it is possible to recycle it to PDMS and use it as rocket fuel (Materials and finishing Engineer Philips).
In 2016, 8,2 million car tiles were collected by Dutch initiative RecyBEM to be recycled into playground tilers or small particles for artificial grass on sport fields (RecyBEM, 2019). Currently, the company Granuband is testing with devulcanisation to make the rubber totally circular, by bringing the material back in its original state at the End-of-life of the product (Schenk, 2017). The research to these recycle principles is ongoing by several researchers, and could be widely applicable to silicone in the future.

TPE Sebs

An alternative for silicone is a thermoplastic elastomer, or TPE. This type of material combines the physical advantages of a rubber elastomer and the manufacturing of thermoplastics, whereby it does not make cross links in the material after vulcanisation (Korrels, 2014). TPE-S, the styrene group of TPEs, is a good alternative for silicone regarding its easy processing, design freedom, recyclability and environmental resistance (Franplast, 2019). The SEBS variant has a high resistant towards alcohol and glycol and are often used in the medical industry (Korrels, 2014). SEBS is recyclable and is soft and transparent, though the material can be expensive (Franplast, 2019). According to a Materials and Finishing Engineer within Philips, a TPE is mostly cheaper than silicone but also lasts less long. Furthermore, it is not as soft as silicone.

Figure 32. SEBS granulate

Conclusion

At this moment, specialized TPEs that could be a substitute for silicone are in development and still expensive. The TPEs that are currently on the market do not yet have the desired specifications (Interview Philips, 2019). Meanwhile, a lot of research to these materials and to their recycling is done. Therefore, it is best to stay with the silicone material for now as it has the desired characteristics and lasts long, while research and developments of alternatives should be initiated and monitored in the future.

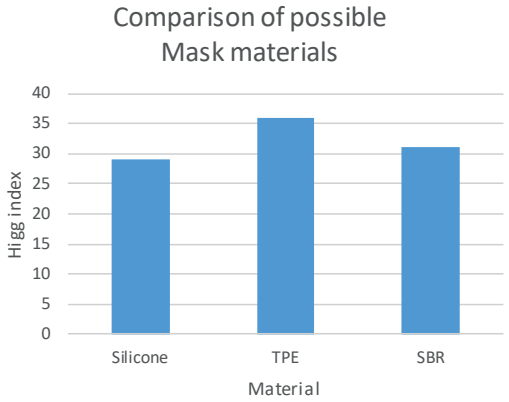
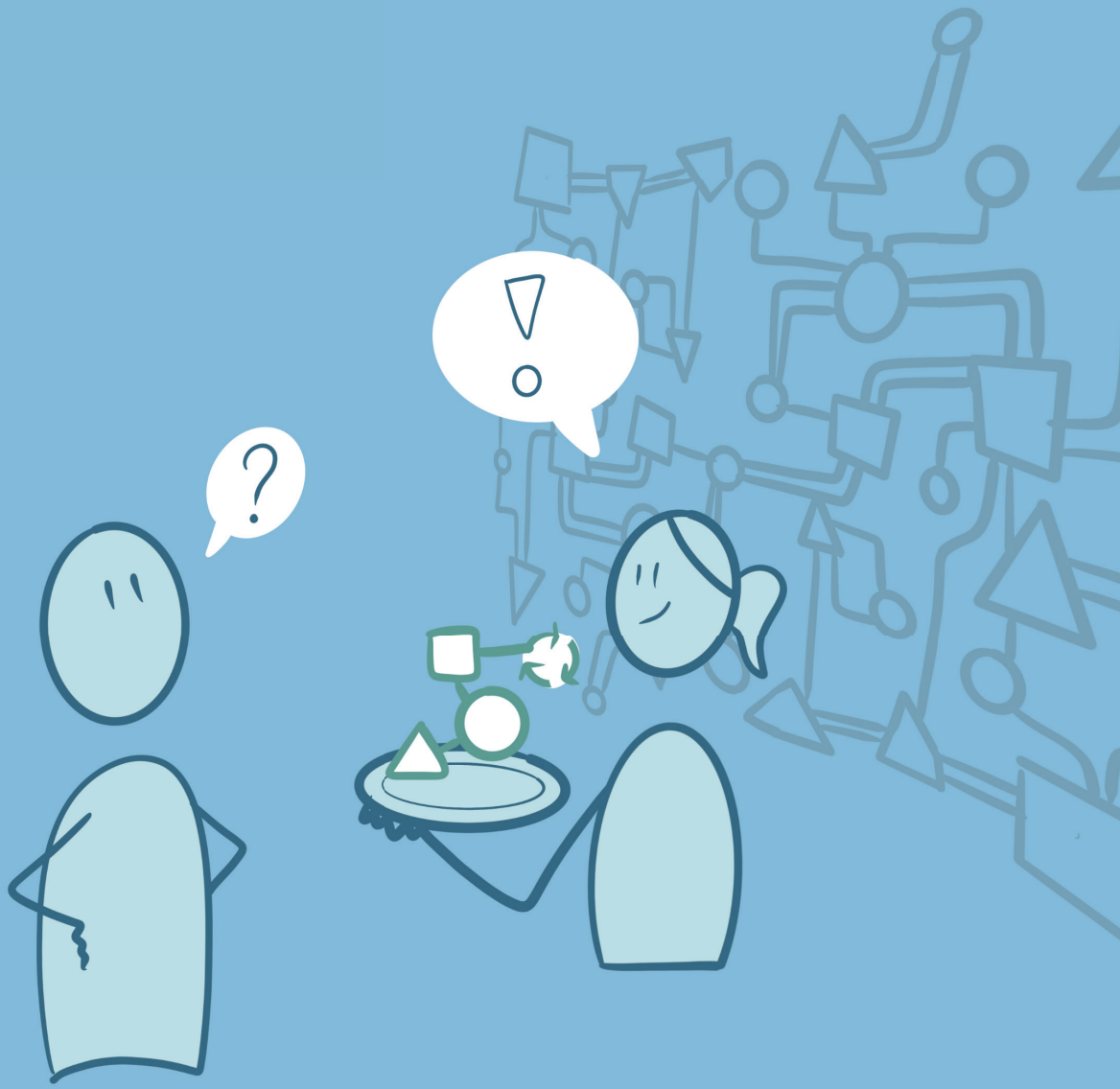


Figure 33. Higg index of alternative mask materials. Data source: Sustainable Apparel Coalition, 2019.

SECTION 6

Final design



Chapter

14

A MODULAR EVOLVING SOLUTION

14.1 Solution introduction

To create truly sustainable and circular innovations, we need an holistic design approach, as was explained in chapter 1. Therefore, the created solution does not only involve a redesign of the product, but also a new business model and a scenario for reverse logistics. This circular business model in combination with circular product design principles, will together result in control over the product lifetime and a circular material flow with the highest integrity. The three circular strategies; slowing and closing resource loops and resource efficiency, are represented in the different parts of the solution. The implementation of the new procurement model, (reverse) supply chain and recycled materials, can take a long time. Because of this **long term strategy**, the product is first optimized for a longer lifetime to **slow the resource loops now**.
The design solution consists out of four parts, which can be gradually integrated in the current system.

The new procurement model and business model can be implemented in steps over time, to work towards a circular solution. The advantage of this is that positive sustainable changes can be achieved on the short term, while a larger sustainable goal is achieved on the long term.
In the design brief was formulated that **feasibility** and **relativity** is key, while addressing the problems in the complex system. Next to this, to stimulate SRC to implement a circular proposition, **structured** overviews are needed. The solution is broken down in different parts also because of these reasons. Therefore, the solution can be more effectively communicated to the stakeholders. This fits the main objective, which is to **inspire** SRC to make the transition towards the circular economy.
The four main parts of the solution are explained on the next page. The relations between the different parts are displayed in figure 34.

14.2 An overview

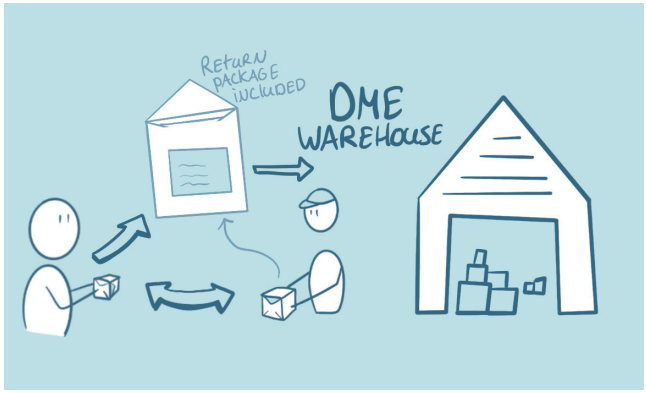
1. New product design

1.The headgear and attachment to the mask have been redesigned to become circular ready and to support the next three proposition parts. This design has been optimized for a longer lifetime and easier cleaning ritual, as a first short term strategy. The new headgear will be made with a knitting production technique and two arms that slide in this fabric piece. This design is based on the just released headgear with arms design of Philips. This design ensures comfort and more stability for the user and material efficient production.

2. New procurement scenario

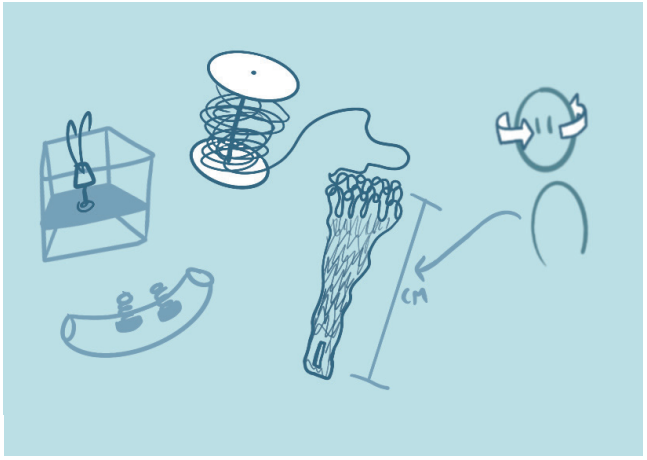
2. The business model is redesigned in combination with a new procurement scenario that can be included in the already existing DreamMapper app. This is done to link the replacement to the performance of the products and stimulate a longer product life. Next to this, several extra functions are integrated in the app. The mask select software is integrated to pick the right mask type and size and patients can buy comfort products from the DME directly through the app when they experience comfort problems. A good partnership with the DME is needed to make this a success. Therefore, their products have also been incorporated in the app for sale.

3. Recycling and reverse logistic scenario



3. A recycling and future reverse logistic scenario has been created. The silicone of the mask could be taken back and sold for recycling. The DME is the centre of the supply chain and therefore the products should be collected at their warehouse. The user can sent the products through the normal mail with the help of information from the app. The headgear can be recycled through the municipal textile recycling stream that should be implemented in Europe by 2025.

4. Future vision: custom made products



4. All the proposition parts are designed with the eye on the future and technology trends, to make it feasible and viable on a long term. The future of CPAP supplies are custom made products, supported by digital production techniques and the 3d face scan software. The custom made products will result in a perfect comfortable fit for all users and this can extend their product life. Furthermore, the production techniques are material efficient and the digitization could enable super local production.

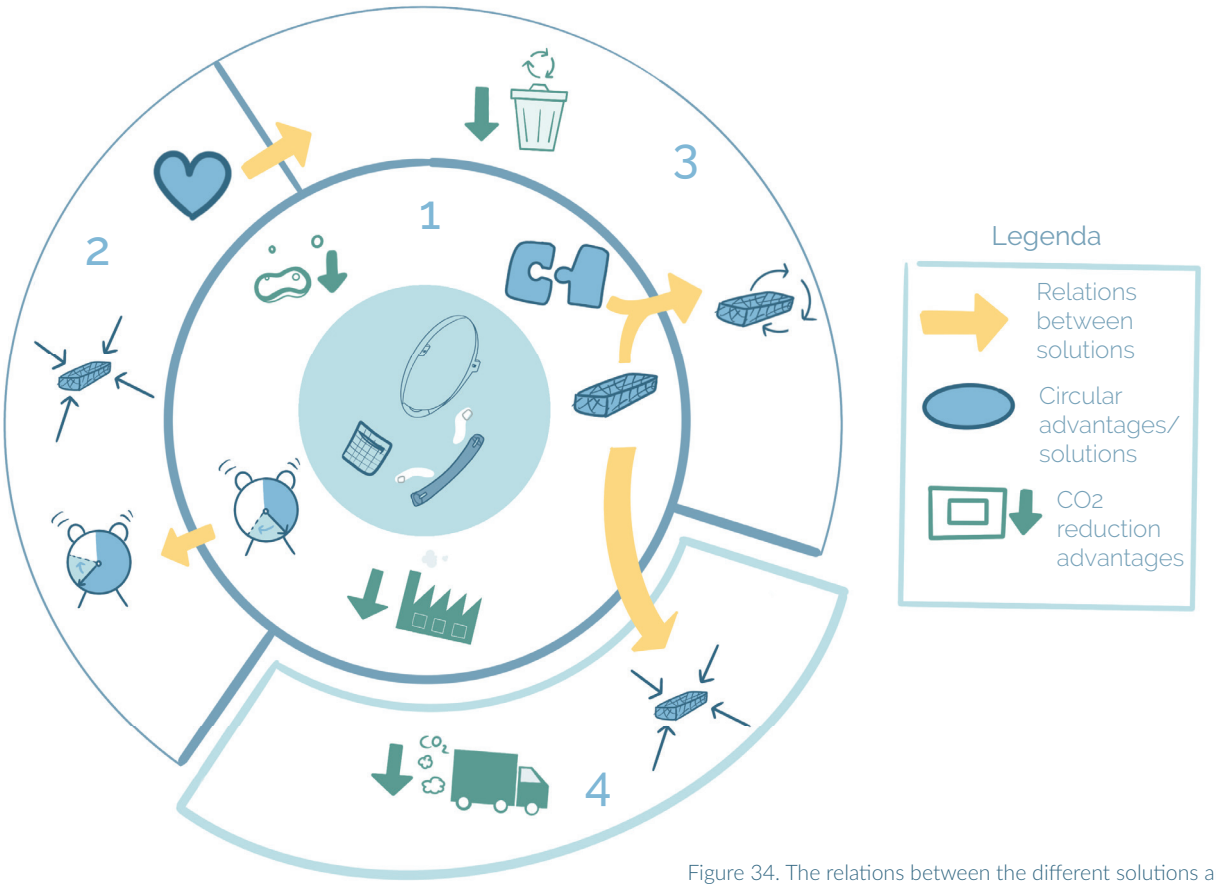


Figure 34. The relations between the different solutions and their sustainable advantages

1

- Extend product life
- Optimized production
  Use recycled material
  Reduce cleaning impact
- Grow customer engagement
  Reduce production costs
- Easier cleaning ritual

2

- Optimize product lifetime
  Prevent product tempering
  Build partnerships
- Reduce package content
- Data is power: insights on product break down and insatisfaction, better relation with DME (seller)
- Control over mask selection and resupply
  Better help with problems

3

- Close the material loop
- Reduce End of life impact
- € by selling materials
  circular targets
  tackeling extended producer responsibility regulations
- Yay better world!

4

- Resources: optimize package content
- Super local production
- Grow customer engagement
  Service revenue
- Control over mask selection process
  Custom fit is super comfortable + stays on better

Chapter

15

NEW PRODUCT DESIGN

15.1 New Dreamwear design

Circular economy tactic

There are different circular design principles that are applicable to circular business models as discussed in chapter 11 and the Circular Design Playbook in Confidential Appendix 1, to make the headgear 'circular ready'.

The main goal of the redesign of the headgear is to optimize it for cleaning in the washing machine, extend its product life and make it recyclable. Next to this, the production costs could be lowered and the user comfort should be taken into account. Different redesign possibilities and their advantages were displayed in the section Design Brief. These were the starting point for the design phase of the headgear. Many different design ideas and concepts were formed for the headgear and the connection to the masks, next to circular business models and circular loops. These ideas included variations with different materials. The different ideas, concepts, prototypes and reviews can be viewed in Appendix H and I. Out of the prototype tests and reviews with SRC Engineers, the chosen sock slip on principle was chosen.

Design introduction

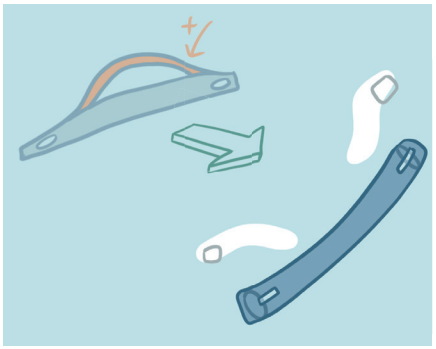
This new design for the Dreamwear nasal headgear includes two arm pieces that click into the mask frame, as can be seen in figure 35. A knitted piece slides over the two arms, which hold this piece in place. Together, these three parts form a stable headgear of which the materials can be separated and recycled. The implementation of this new headgear requires only minimal changes to the mask frame, which makes the new design easy to implement.

Figure 35. Final prototypes

15.2 Design characteristics

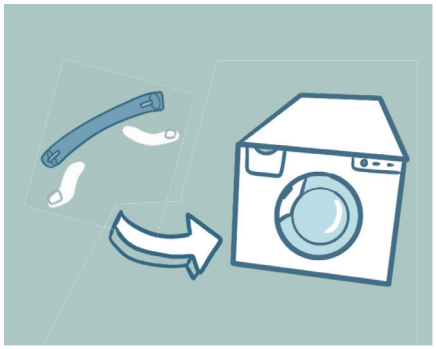
Headgear arms

The design is inspired by the new headgear with arms that was released in August 2019 by Philips. This design is already extensively tested for comfort and stability with users. The results of these tests are that 88% of the users thought that the stability and comfort was better than the old headgear (Koninklijke Philips N.V., 2019e).



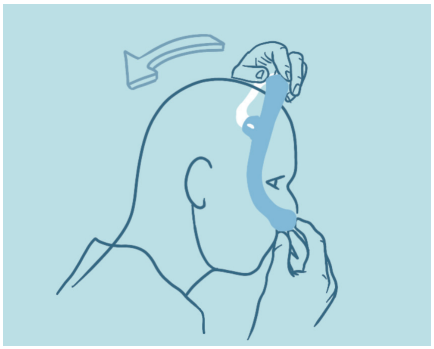
Reimbursement

Reimbursement codes are a requirement that is important for the business case, as explained in chapter 8. This new design exists out of 3 loose parts, which does not make it a simple single strap. For this reason, adding an extra strap to the headgear to qualify for reimbursement is not needed.



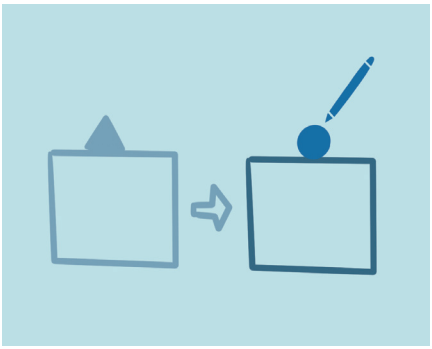
No Velcro

Velcro currently breaks down the fastest in the headgear and stimulates pilling of the fabric. The new headgear design does not contain Velcro pieces, which also makes the headgear suitable for washing in the washing machine. This will ensure an easier and more efficient cleaning ritual for the user and prevents the headgear from breaking down earlier.



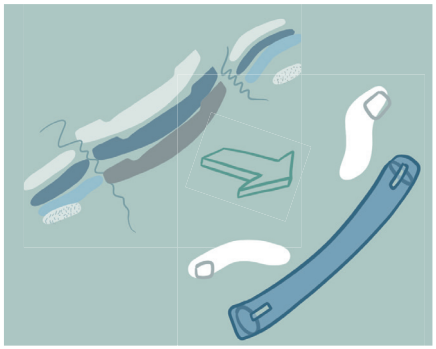
Put on over the head

The design can be easily put on over the head, just like the current headgear design. The headgear can stay attached to the mask during this action. Taking the products off can be done in the same way. This is pleasant for the user, as it is fast and does not require small precision actions while the product system is on the head and can not be seen.



Close to current design

The headgear is designed as such, that the total product system of mask and headgear stays close to the current design. This is done to ensure the implementation feasibility of the new design, according to the design vision as described in chapter 10. Minimal changes to the current mask frame design are needed; only the attachment slot needs to be altered.



Disassemble

The current headgear contains 6 different materials and every piece is made of 3 different layers. Furthermore, it is assembled from 7 parts. The new headgear only contains 2 different materials and is contains 3 parts, which do not need to be assembled during the production process.

Aesthetics and experience

The fabric headgear sock slides over the arms which form the attachment to the mask slot. This creates a coherent look for the headgear, in contrary to the current headgear with arms design which involves bold transitions between all the parts. The products are mostly used at home because there are different respiratory care product lines for to use in medical settings. The seamless knitted fabric gives a comfy look and feel, which can be associated with comfortable sweaters and plaids. Comfort is very important for the experience of the user while using the products in the bedroom. Therefore, the knitted fabric will fit better in this context, while it is still easy to clean. The inside of the sock is medium dark grey, to make stains less visible. This will stimulate a longer product life. The outside of the headgear is blue which fits with the Philips brand.

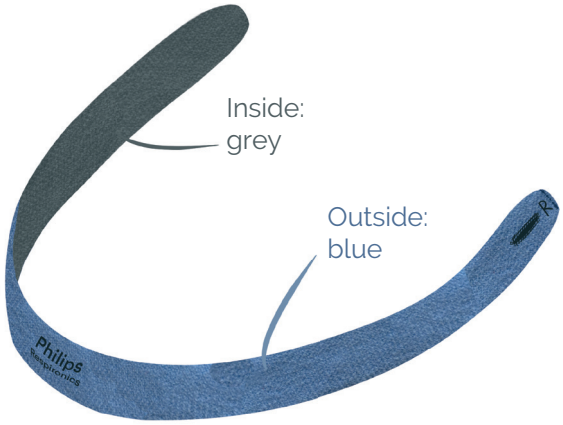


Figure 36. Introduction of the new Dreamwear design

15.3 Product use

Sleeping with the headgear with arms

The headgear with arms design helps to reduce slipping during the night because of its improved stability (Koninklijke Philips N.V., 2019e). This was tested with 140 patients, whereof 88% preferred this new headgear design (Koninklijke Philips N.V., 2019e). Because of this improved fit and stability, the headgear also reduces leaks and improves the therapy (Koninklijke Philips N.V., 2019e). This is due to the arms that have greater stability than the thick foam that is used in the previous headgear. It also keeps the headgear lower on the head, which makes sure that it does not slip to the top of the head during turning and moving in your sleep.

Sizes

The headgear sock is made with stretchy material in contrast to the current headgear. This ensures a good fit for multiple users, although there is no sizing mechanism in the product.
As described in chapter 5, the average users are older adults or are obese. The head circumference of Adults over the age of 60 is 560 mm on average with a standard deviation of 25 mm (Molenbroek, 2017) and Appendix K. P90 and P99 is respectively 32 mm and 58 mm wider than the average. As the head circumference can differ with multiple centimetres between users, the headgear needs to be available in different sizes. One headgear with a stretchy material is not sufficient to provide a comfortable fit for every user because when the stretch fabric is too tight, the force on the skin increases and can cause skin marks and irritation. In the future, custom sized headgear can provide a perfect fit for every user.

Note: In all the pictures of the prototyped models, the blue and grey colours are reversed. This is due to the knitted piece that was already at hand. A new knitted piece with the right colours and with the right delicate structure could not be prototyped in the scope of this project.

Figure 37. Final prototype on foam head.

Assembling

As described earlier, the attachment principle of the headgear arms to the mask is the same as the current headgear with arms design. As this principle is already tested with that headgear, the hypothesis is that the new design is also easy to assemble. Putting the headgear sock around the arms can be perceived as harder. Therefore, the arms have been optimized for easier assembling, as can be seen in the pictures on the right. The end hook makes it easy to find the slot and does not stick out too far, which otherwise could have caused sticking through the fabric.

Slot comfort

The slot of the mask is designed with a cavity that fits the end piece of the arms, as can be seen in figure 38. This is integrated because it creates a smooth surface transition of the mask frame to the headgear. This creates more comfort when a patient sleeps sideways. A non smooth transition or thick hard parts in this area can cause skin marks or a bump that presses in the head.

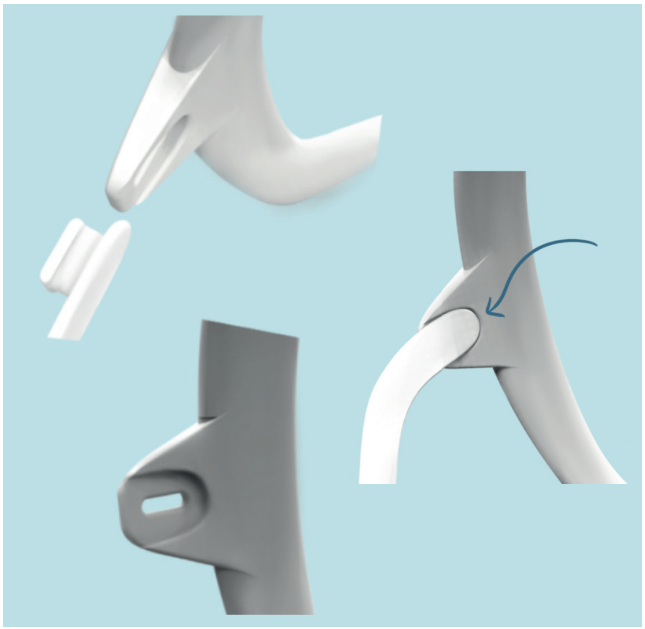
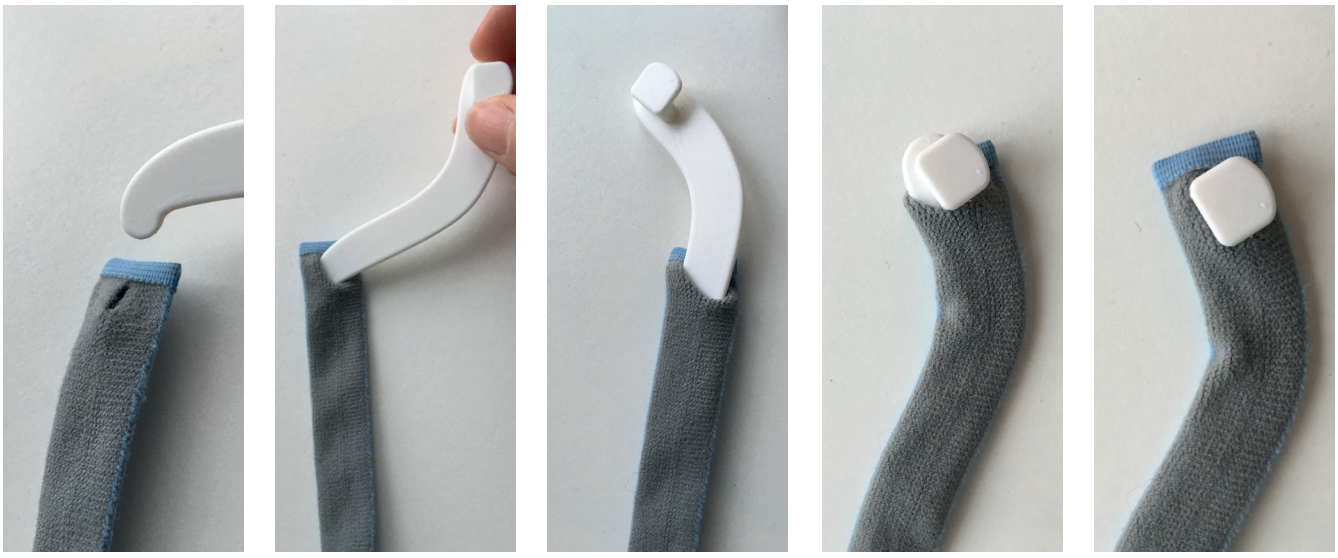


Figure 38. Details of the mask slot



Hook the end piece inside the sock slot

Pull the sock over the arm

Lock the sock in place by pulling it over the edge

Figure 39. Assembly steps of headgear and arms.

15.4 Cleaning

Lowering environmental impact

In the life cycle analysis was found that the washing scenario has the highest environmental impact of the total life cycle of the headgear and mask products. Therefore, an alternative washing scenario is preferred.
It is estimated that the average water consumption of a dishwasher is 9,8 liters, while washing the dishes by hand is 110 liters per wash for the same amount of dishes (Ceced, 2017). Cleaning by hand washing results in a higher environmental impact of water and energy when it is compared to modern dishwashers, which are designed to be water and energy efficient (Schein, 2018). Next to this, the machine cleans more hygienic than hand washing does (Schein, 2018). When the headgear and mask are cleaned in a washing cycle with other products which was happening anyway, it does not use extra water. Therefore, washing the products with a dishwasher or a washing machine is an environmental friendlier cleaning ritual than doing an extra hand wash.
Philips recommends to wash the mask daily, but not everyone uses its dishwasher daily or even has one. As other hand washing techniques or additional products that were explored will not make the hand washing ritual easier or lower its impact, see appendix L, it is recommended to stimulate users to use less water during this ritual. These tips should be included in the current instruction movie, DreamMapper app and paper manual. For example by stimulating to rinse the products for a specific amount of time, using a smaller bowl for the soaping of the products and using less soap while doing this. Though, the instructions should clearly state that it is important for your health to wash off all the soap from the products. Therefore, using less soap is better.

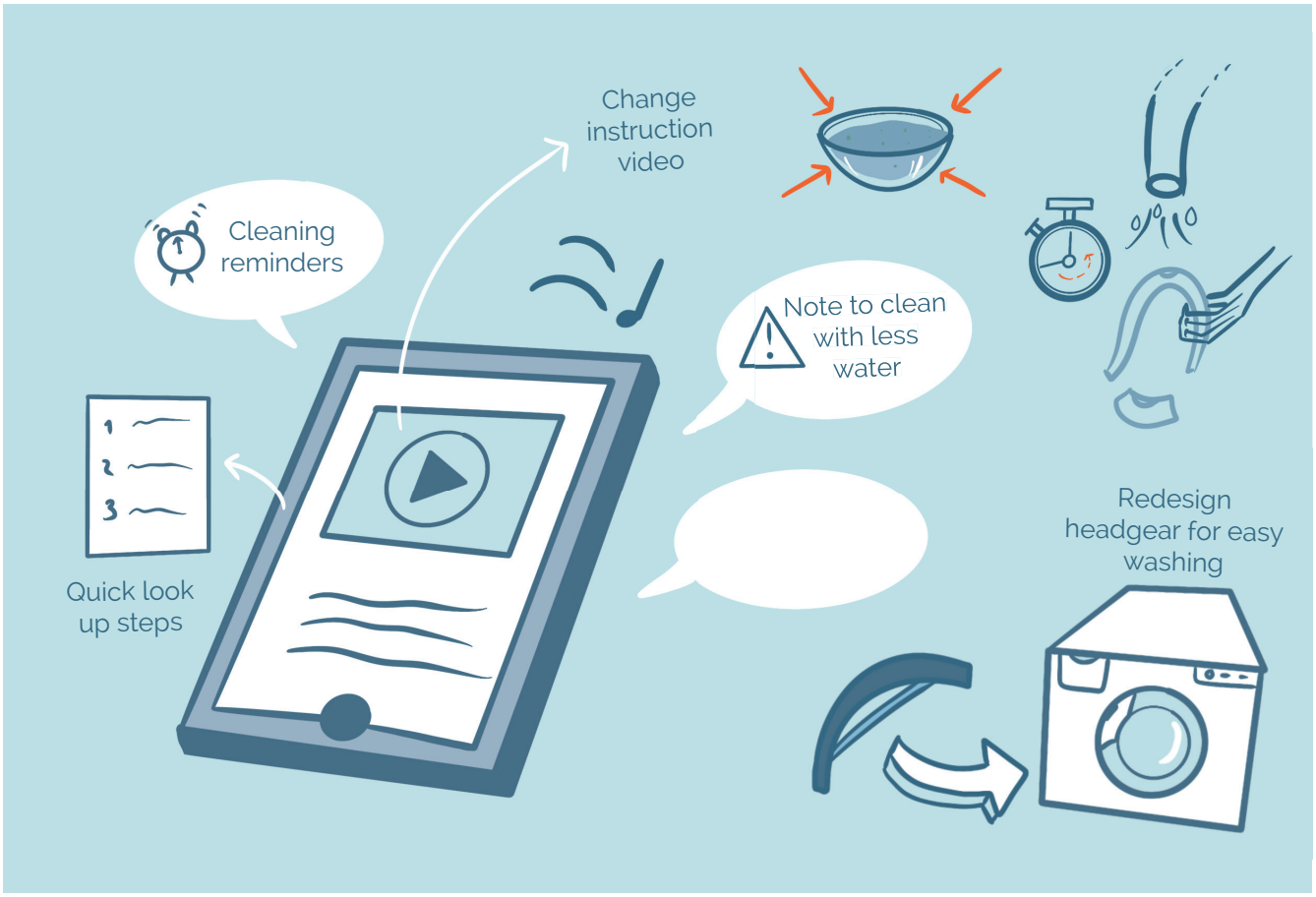


Figure 40. Design of a new washing scenario

The cleaning ritual

The headgear design has been optimized for the cleaning ritual, as this can lower the environmental impact, will prevent the product from breaking down earlier and is easier for the user. The new design can be washed in the washing machine or top rack of the dishwasher, as it does not contain Velcro and is made from Nylon/spandex. This will also clean better than hand washing, which will ensure a longer fresh fabric.
The current mask frame can already be washed in the dishwasher once a week. Washing in the dishwasher is an easy cleaning ritual, but not every one has one. In 2015, 45% of the European households owned a dishwasher (Ceced, 2017). In the UK in 2018, 49% of the households owned a dishwasher and 98% owned a washing machine (Statista, 2019). Furthermore, the thin new headgear design can fall through the rack of the dishwasher and become damaged by the turning part.
For this reason, it is recommended to wash the headgear in the washing machine. This is not recommended for the mask frame and tubes, as the hard pieces of the tube will clatter against the drum. The arms and fabric of the headgear are small pieces and can get lost in other clothing during washing. Therefore, a small washing bag is delivered within the product package to prevent damage and keep the parts together.
The washing bag is small, to minimize material use and to indicate to not put the mask in the washing machine. There is no zipper used, which means that the total bag can be made of polyester yarn, which is easy recyclable. Washing instructions are printed on the washing bag, to keep them easy to find.

Figure 41. Washing bag prototype

15.5 Manufacturing

Knitting technique

Knitting is an ancient activity and art. There even exist artefacts from knitted socks that date back to the 11th century, which were found in Egypt. Knitted fabrics are made from interlocking loops, formed from a single or multiple yarns (Eberle, 2008). The knitting production technique is chosen for the headgear because of many reasons. This technique is more material efficient than using pre woven fabrics and cut and sew them in a specific form. Next to this, it causes minimal production waste as the yarns are directly used to create the form, and there is no excess waste due to cutting patterns. Knitting can create highly stretchable, light and breathable fabrics. In contrary, sewing can cause surface irregularities and less stretchable stitching lines.

There are two types of knitting techniques: weft and warp knitting:

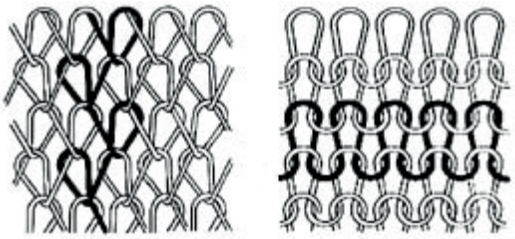


Figure 42. Warp and weft knitting structure. Reprinted from Dongguan Rosawell Interfacing Fabrics Co., 2019.

With both techniques, different knitting structures can be achieved. Warp knitted structures are made with a warp sheet which contains multiple yarns and are made on special knitting machines. The needles on this knitting bed are moved together, which creates Tricot fabric or lace. The advantage of this technique is that the fabric does not unravel or ladder and can be created with higher productivity than weft knitted structures (Choi, 2005). Though, the weft knitted technique is the most widely used and has more design possibilities. Weft knitted structures are more resilient and can be made on a double flat bed V machine, which is why the weft technique is chosen for the new headgear design.

On weft flat bed knitting machines, every course or stitch can be programmed separately. Due to these options, the seamless knitting of total garments technique was introduced in 1995 (Choi, 2005). The V-bed flat knitting machine was already invented in 1863, which was already used to create gloves and skirts (Choi,2005). On a double flat bed V machine, two separate sheets can be linked to each other. The computer aided design system in combination with this knitting technique, can create several types of tubular knitted forms with diverse design structures on both side of the garments.

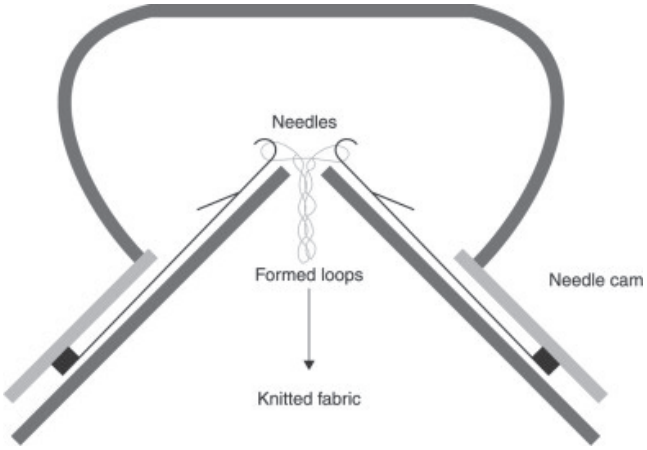


Figure 43 Double flat V bed knitting machine. Reprinted from Kirstein, 2013)

On a flat bed machine, stitches can be manipulated to form different patterns and structures. In this way, open structures or strengthened stitch lines can be created.

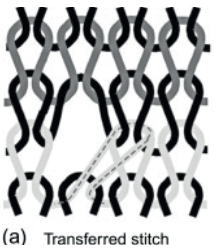
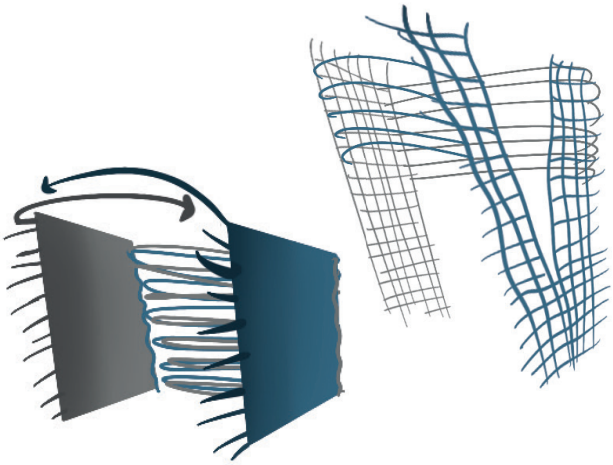


Figure 44 Transferred stitch, reprinted from Duserre, 2015)

Many advantages of the seamless knitting technique have already been mentioned. This technique can also reduce production costs. The current production costs of the headgear consists of 20% manual labour. This new technique could reduce this part of the production cost significantly and reduce production time. Next to this, the automation of the production reduces the risk of defects and ensures a consistent product quality over a large production quantity (Choi, 2005).



Headgear knitting design details

The design of the headgear sock needs to be tailored to this specific production technique. A knitted fabric has an open mesh structure. Therefore, it is important that the headgear arms do not have sharp edges or small pointy ends as this could damage a knit loop and can cause laddering. Furthermore, the forces that can appear when the mask and headgear combination is put on or off, need to be well spread along the fabric.

Slot attachment

As can be seen in the figure below, a slot attachment method is used which is comparable to the current headgear with arms design. The slot is turned to a horizontal position, as this fits with the knitting production technique of the sock and creates a more durable edge. This open piece can be easily made by the knitting machine by splitting one knit loop row. Therefore, the blue side should be made with two threads who each form a half of the fabric, see illustrations at the top of this page. These threads will connect in the middle of the fabric and only split at the slot. The sides are connected to the grey part, to form a tube.

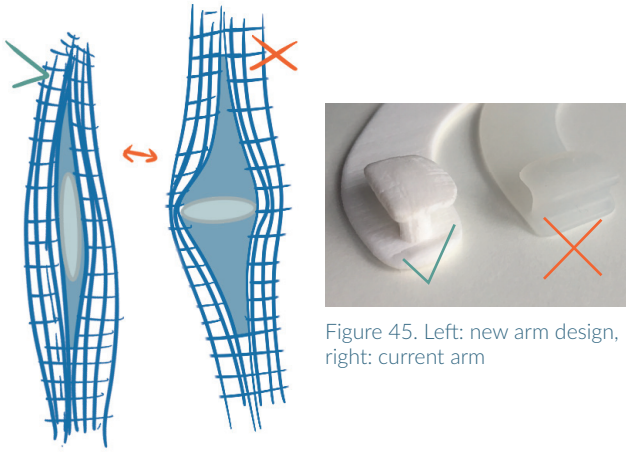


Figure 45. Left: new arm design, right: current arm

Arm design

As can be seen in figure ... the end piece of the arm is curved. This is done to create a smooth guidance path for the sock to the lower back of the head, without pinching through the fabric. The end of the arm has a smaller circular form, for easy assembling in the slot of the headgear. Though, this piece is not too small and does not extend too much from the curve, as this would create a part that would pinch through the fabric when assembled, see figure 46. The design of the headgear arm has been optimized by creating and testing many different forms, as can be seen in appendix I.

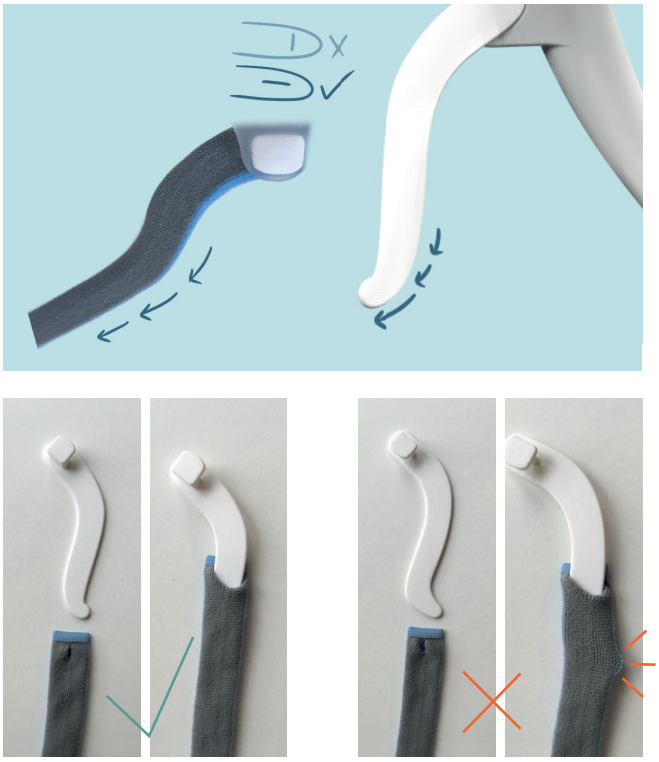


Figure 46. Example from optimization of arm end point

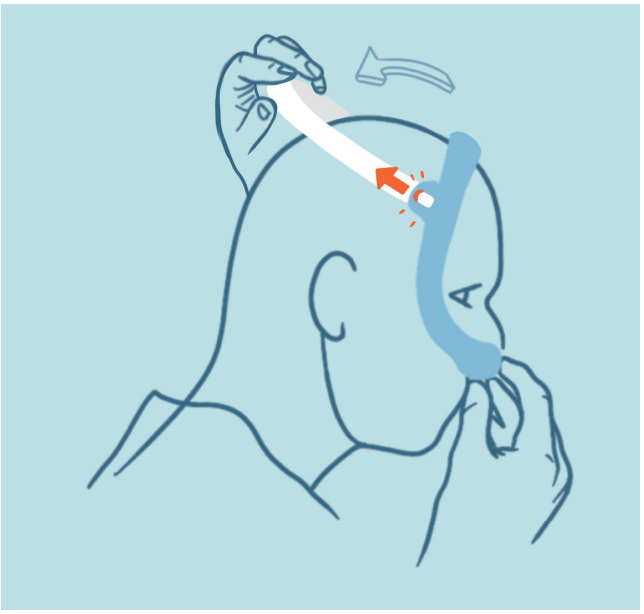
Injection moulding

The arm pieces will be produced by injection moulding, just like the arms of the current headgear with arms. The part includes rounded edges and is totally releasable from the mould in one direction.

Strength analysis

In this new design, the slot in the mask needs to be adjusted to a horizontal position. This slot connection is a critical point, therefore it is important that it can endure the daily load without breaking, as can be seen in the illustration on the right. To evaluate the strength of this connection and the effect of the slot change, a tensile test has been done. The approach, test setup and results can be read in Appendix M. In this test, the current mask frame slot and headgear arms are used, next to several 3d printed arm hooks with various dimensions. Some snaps of the tests are pictured below this page.
From the test is concluded that the arm hooks should be made of a flexible material, as this makes sure that the hook releases from the slot when the pulling forces become to high. This prevents the slot from breaking and ensures a longer product life in daily use. The 38 N force, that was needed to release the connection, was way lower than the force that caused plastic deformation of the slot. The area of the new mask slot is big enough to withstand this force till the yield strength of the material.

Furthermore, this release force of 38 N can only cause fatigue after 10^7 cycles when stress on the loaded area is higher than 2,8-4,59 MPa. This



is not reached with the dimensions of the mask. Furthermore, 10^7 cycles would correspond to 136 years if one cycle is putting the mask on or off and this is done twice a day. This is far beyond the current mask life. This means that the slot of the mask is suitable for a longer product life than it currently has.

Current design and materials: arm hook bends and releases

Current slot with hard material arm

Current slot with turned load direction

15.6 Materials

Material choice
For the final design, it was chosen to work with a fabric material because it is soft and has stretching abilities. Foam, thermoplastic and elastomers were early in the design process dismissed as option due to discomfort and non recycling characteristics. More about the material choice can be read in chapter 13.

Headgear fabric
Nylon 66 is chosen as the main material of the headgear in combination with spandex (elastane). This is a stretchy material that ensures a better fit and stability during the night, next to the elasticity that the knitted structure gives. Nylon is very durable, and therefore will ensure a longer lifetime of the headgear than when polyester is chosen, which is the chosen short term circular strategy.

Bio compatibility testing
Furthermore, it is advised to work together with recycling yarn companies to develop or test a recycled nylon yarn that has a bio- compatibility approval to reduce the environmental impact. During interviews within Philips, concerns regarding bio-compatibility testing were shared for using recycled materials in the mask and headgear. The main concerns were related to the costs and the risks of extensive material testing, and the uncertainty of the composition of recycled contents. Though this does not mean that using recycled material is not an option.
If a recycled material is used in a new medical product, the re-manufacturer of the materials needs to meet the requirements of the Medical Devices Directive, including the CE-mark for assessing the quality and risk (Rivm, 2008). This means that wherever the material comes from, in Europe the quality of the product is guaranteed in the CE- mark that it gets after manufacturing. So it is possible to use recycled materials if the supplier of the material ensures to meets these requirements. Therefore, a collaboration is needed with a recycling company or yarn manufacturer, which could guarantee the content of the material and could take away the risk for Philips.
Recycled nylon yarn is already made by several different companies. For example, ECONYL is made by the company Aquafill from waste like fabric scraps and fishing nets from the oceans (Aquafil S.P.A., 2019). The company claims that this nylon yarn reduces the global warming impact by 80% compared to the material from oil while it has the same properties. This yarn can be recycled over and over again and is already used by many apparel companies like Speedo, Triumph, Prada and Patagonia (Aquafil S.P.A., 2019). These are high quality brands, which means that the material could be suitable for Philips too while maintaining a high quality headgear.

Headgear arms
The arms should be made from a thermoplastic elastomer material for user comfort and to ensure a long product life of the mask slot, as was concluded from the tensile tests. The material that is currently used for the headgear arms is the right choice (confidential).

Mask frame
The mask frame needs to be made from silicone to ensure bio- compatibility, a long product life and user comfort. Thermoplastic elastomers do not have the right quality yet, therefore it is recommended to stay with silicone. The recycling techniques of silicones and TPEs are evolving, and this should be monitored to find the right material choices for the future. TPEs are easier to recycle now, but this and their quality compared to silicone can change.

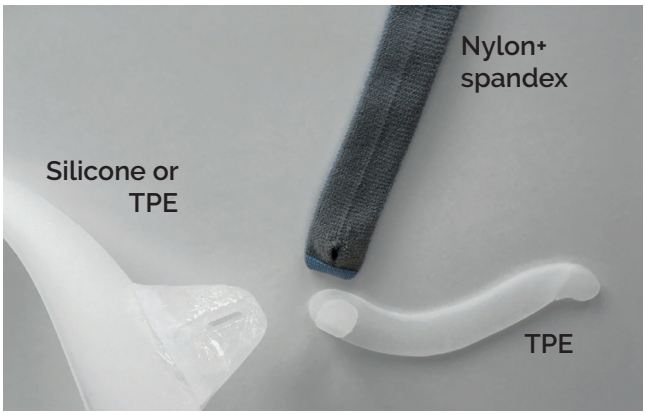


Figure 47. Parts and their materials

16

NEW PROCUREMENT SCENARIO AND APP FUNCTIONS

16.1 New procurement scenario

Recap

As explained in the previous chapter, the new headgear design reduces the chance of product break down and can ensure a longer product life. Next to this, during the research phase was found that the lifetime of the headgear and mask is often determined by the reimbursement schedule. The products are often replaced when they are not broken yet. This is also apparent in the differences between the replacement schedules of countries, wherein the products that are used are the same but replaced on different intervals. Therefore, to really prolong the lifetime of the products, a change in the replacement procedure is needed to optimize the lifetime.
Like what was stated in the design brief, it is important to create advantages for Philips to implement a circular solution. As was discussed in chapter ..., this could among other things be done by implementing a performance based business model. All these insights are combined into a proposal for a new procurement scenario, that increases circularity and creates value for Philips and the user. The value for the user can be created by addressing the main opportunities for user advantage, as described in the design brief: "Make it easier and logic to solve common comfort problems" and "create an easier and faster cleaning ritual". It is often not clear for the patient what all the mask and headgear options are and how and when they can get new products. The current DreamMapper app does not make this any easier, as all the messages end in "contact your DME supplier", see figure 48. The tab of "solving problems" and "correct mask leaks" guides the patient to a general movie of how to wear and adjust mask, which also ends in the message to contact your DME if there are other problems.

Proposition summary

The new procurement scenario can easily be implemented in the current DreamMapper app by adding some functions and screens to the framework. Next to this, it is needed to work together with the DME supplier. In the current system, as can be read in chapter 11. The DME supplier arranges the supply of the products to the patients, yearly check-ups and the contact and finances with the insurance companies. These are tasks that could not and should not be taken over by Philips. Therefore, this new procurement scenario should work with the current supply chain system.
Furthermore, some other functions are implemented in the app to give the users more insight in the replacement schedule and to support them in daily use and comfort problems.

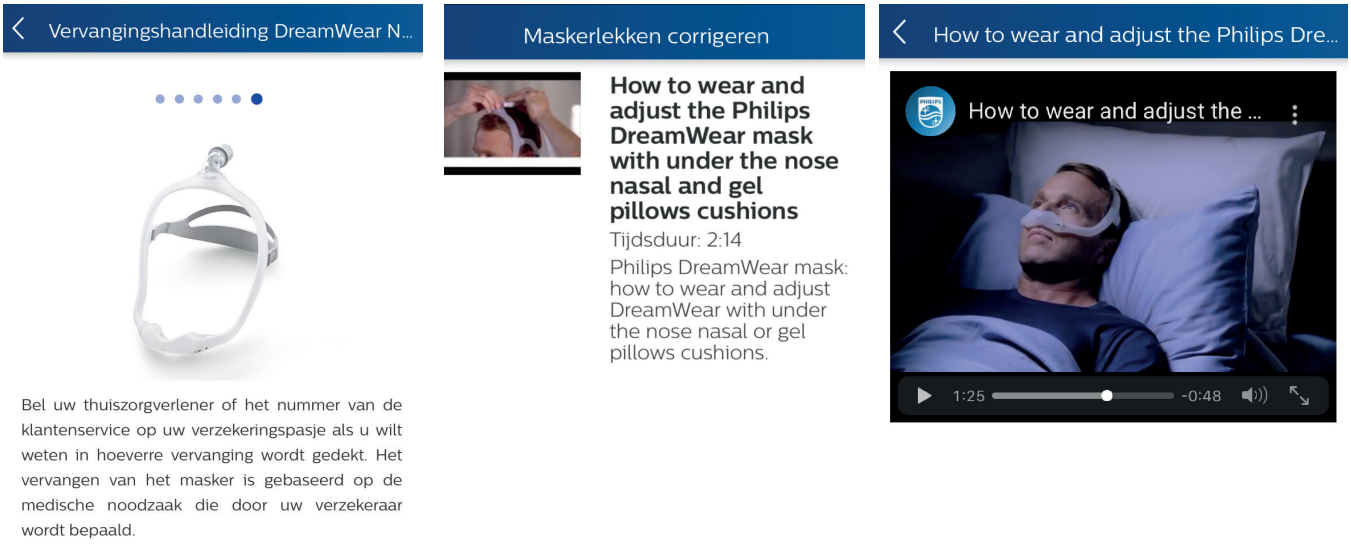
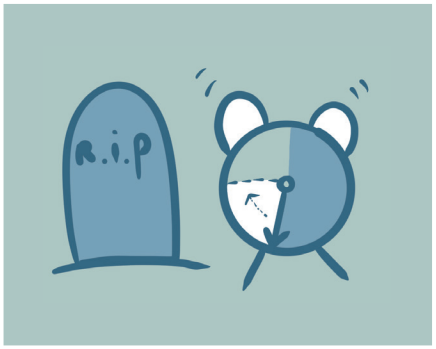


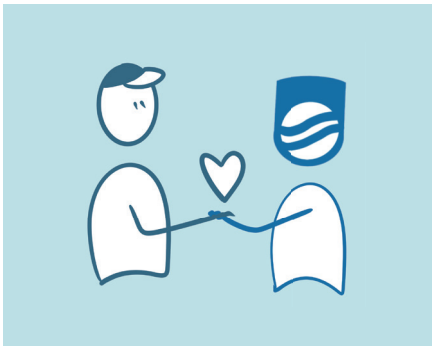
Figure 48. Some screens of current DreamMapper app (Philips, 2019)

16.2 Design characteristics



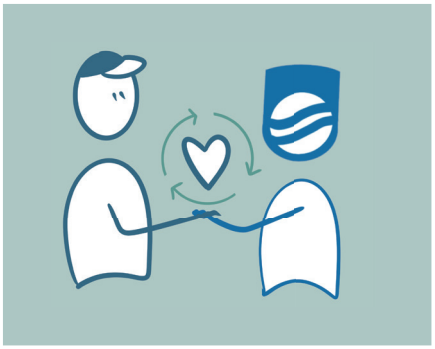
Prolong product life

Data management systems are essential for the circular economy (Lewandawski, 2015). The software to track the performance of the products and the quality of the therapy, is already implemented in the app. Now we need to link the replacement schedule to the performance of the products, while replacing the products is discouraged. In this way, the lifetime of the products will be prolonged.



Enhance relations with DME

As the cooperation of the DME supplier is essential to the supply, finances and success of the new business model, their values are incorporated by adding their additional products in the new order part of the app.

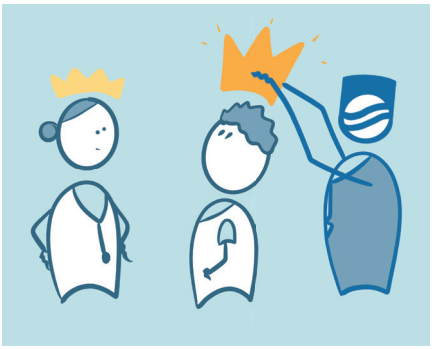


Enable implementation of closing the loop

The partnership of Philips with the DME suppliers is essential for the outlet of the products and to gain control over the end-of-life scenario of the material flow. Therefore, enhancing these relationships will also improve the opportunities of implementing a circular supply chain in the future.

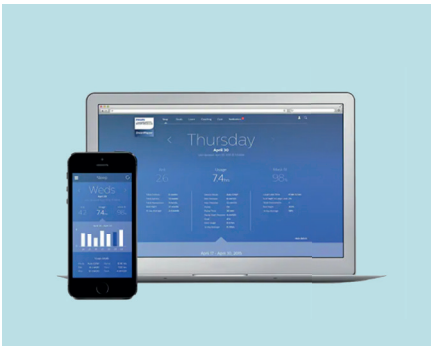
Improve user relations

Currently, Philips has little direct contact with the patients or control over the mask decision and procurement process. By improving the user experience and positioning the Philips brand more visible in the procurement process, it is possible to create brand loyalty from the users and the DME. This can create a higher market share for Philips and can create more revenue.



Improve user experience

With the new functions in the app, the user is given more information and control over their user experience, mask decision process and solving of problems. This fits with the main opportunities of improving the user experience as was defined in the design brief.

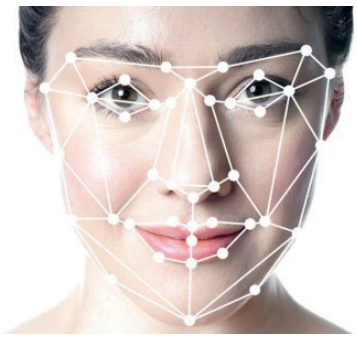


Uses current DreamMapper app

There already is an app available for users of the Dreamstation of Philips. This makes it easy to implement new app functions and making these available to the users.

Mask select software

As concluded from the research, currently the OSAS nurse has a large influence on the selection of the mask for the patient. Many mask types and brands are available, which are supplied by the DME, see chapter 5. Philips currently has no control over this mask decision process
In June 2019 at the world SLEEP forum, Philips unveiled a new software program that can choose the right Philips mask according to a scan of the patients face (Spear, 2019). The software works with an ipad, a camera and facial analysis algorithms and needs specific hardware. It records the size, shape and curvature of the face to choose the right mask type and size (Spear, 2019). Having the perfect fit, can reduce the amount of patients that stop therapy due to sleep comfort problems, which is estimated to be at least 35% (Wolkove, 2008). The software is meant to be used by a sleep professional, who helps the patients through the decision process and asks additional information, f.e. regarding the patient's sleep position (Spear, 2019). The face scan and select software is a very promising technology. It can not only help with the selection of the perfect fit for the patient, but can also be a stepping stone towards custom made masks.



This software that will be released at the end of 2019 is for sleep technicians who need specific hardware. If the technology is made available to the user, the user experience is improved by giving the user more control and information about the mask selection process. In 2020, the new Iphone will have 3 lenses and a 3D-lasersensor that can capture depth and can create augmented reality experiences (iCulture, 2019). This will bring the 3d camera technology to the masses which makes bringing the Mask Select software to the patient possible.

Figure 49. The iPhone 12. Reprinted from iCulture, 2019.

Save materials

The fit package of the Dreamwear contains multiple cushion sizes to pick the right size, whereof only only will be actually used. Furthermore, there is a paper manual that helps picking the right size, as can be seen in figure 50. Picking the right size with the help of the mask select software instead of trying out all the different sizes will save this material.

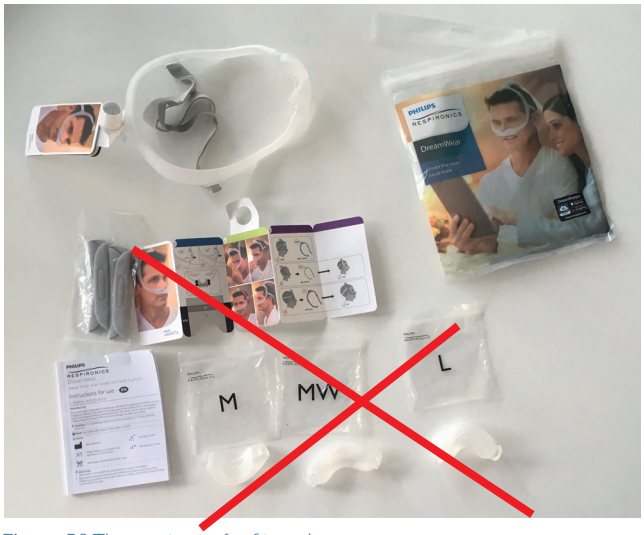


Figure 50.The content of a fit package

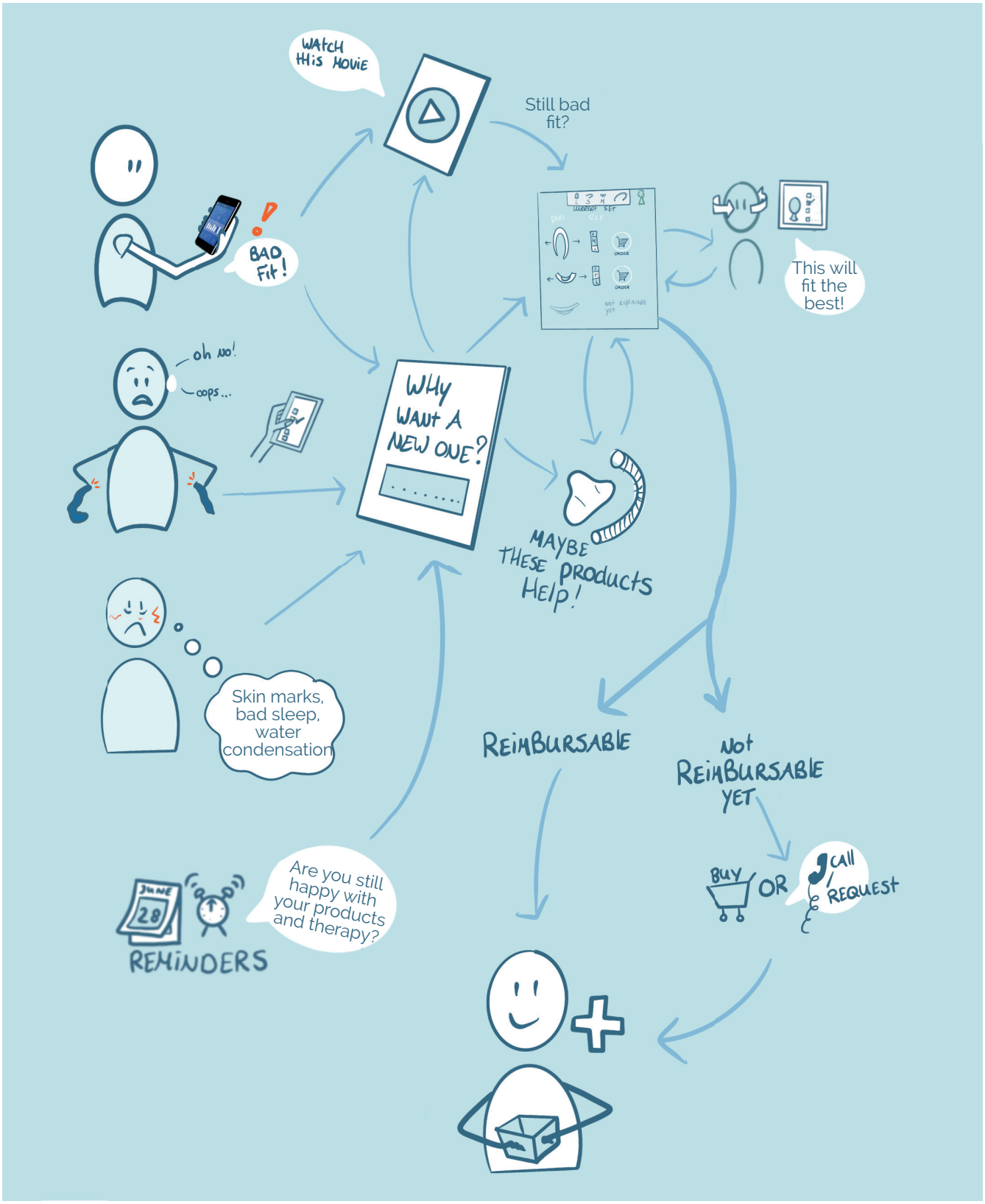
16.3 Business model

A longer product life should not equal less revenue for Philips, because that would result in a disadvantage. The performance based business model is the best fit to prolong the lifetime of the products, as was discussed in chapter ... The performance data of the CPAP machine can be used to track the performance and fit of the mask. The incentive is that the products will be replaced less often, while **Philips** gets a fixed amount of money in a time frame by renting their CPAP machines in combination with CPAP supplies. The CPAP products are not automatically replaced, only when the patient asks for it.
With this system, it should be prevented that patients do not order new masks in time when these do not function anymore. Furthermore, patients who are likely to forget to order these, should be able to get automatic replacement or someone to take care of it. The number one priority is still to provide the best therapy and a good night sleep to the patients.

The insurance company
When less products are used, less products need to be paid. Though, the revenue of Philips should not be extremely lowered and the partnership of the different stakeholders are required. The new service model can be cheaper for the insurance company and still make the same revenue for Philips, as it also saves production costs. Furthermore, when the mask fit and the comfort of the products are optimized, patients are less likely to stop using the therapy. This prevents them from developing heart and vessel diseases which in the end saves the insurance company money.

The **DME suppliers** are responsible for matching masks to patients but get paid one time. Therefore, the longer and more appointments it takes to fit the right mask to a patient, the more time and money this costs. When this is made more easy, while the wishes of the patient are also more clear from the beginning, the more time and money it saves for the DME. Furthermore, the additional comfort products of the DME, like skin protectors and tube hoses, can be implemented in the DreamMapper app. This can result in more product sales.

16.4 User experience with app scenario



16.5 Additions to DreamMapper app

The app screens on these pages are impressions of how the implementation could look like. It is needed to further design and test the user interface as this was not a focus of this project.

Mask fit indication

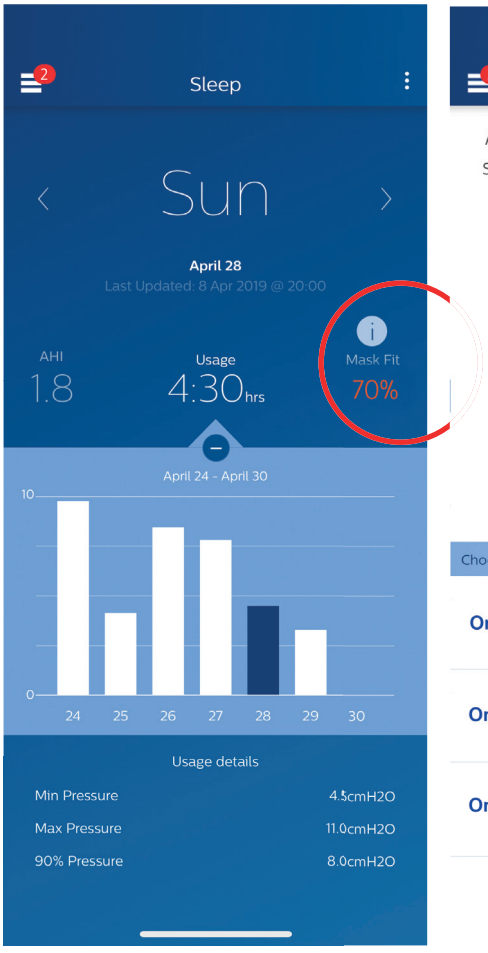
The mask fit indicator which is already there, includes a direct action button that guides to more information to solve this problem or to order new products. When the mask fit is well, this action button will be hid to discourage early replacement. The functions can then be found in the general menu.

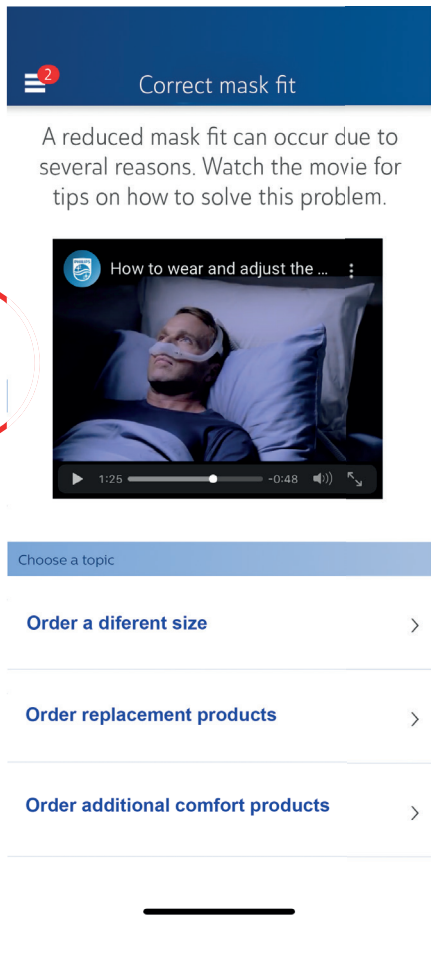
Call to action

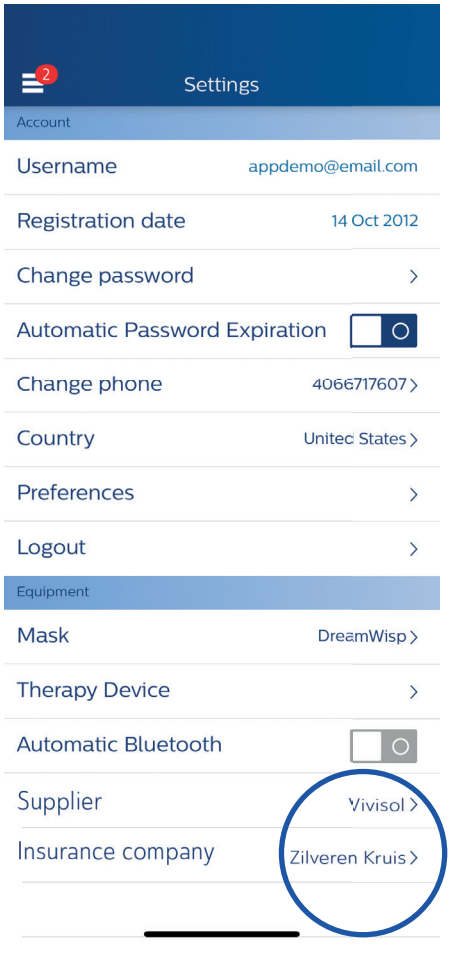
Next to the video that was already there about how to wear and adjust the products, extra functions that could give direct solutions to the user in the form of better or additional products should be implemented. This will help the user from tempering with the products and create more revenue for the DME suppliers

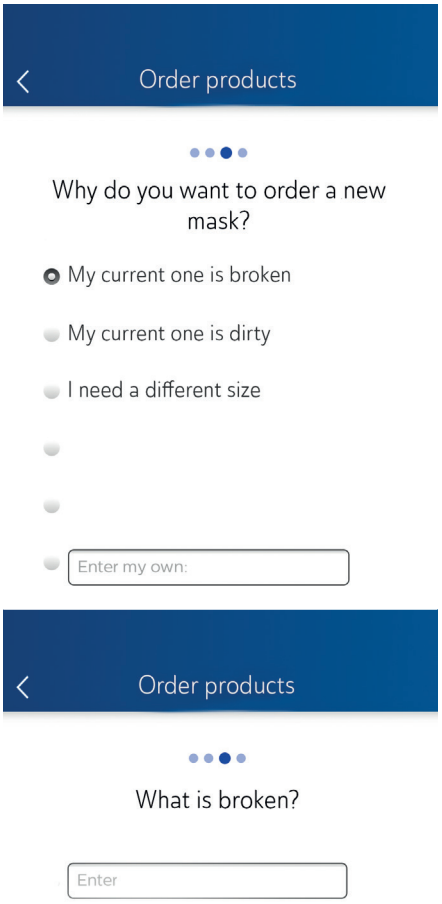
DME & Insurance company

The available additional products and the reimbursement schedule can differ per DME and Insurance company. Furthermore, the products need to be ordered at the specific DME supplier of the patient. Therefore, they need to be linked to the app.







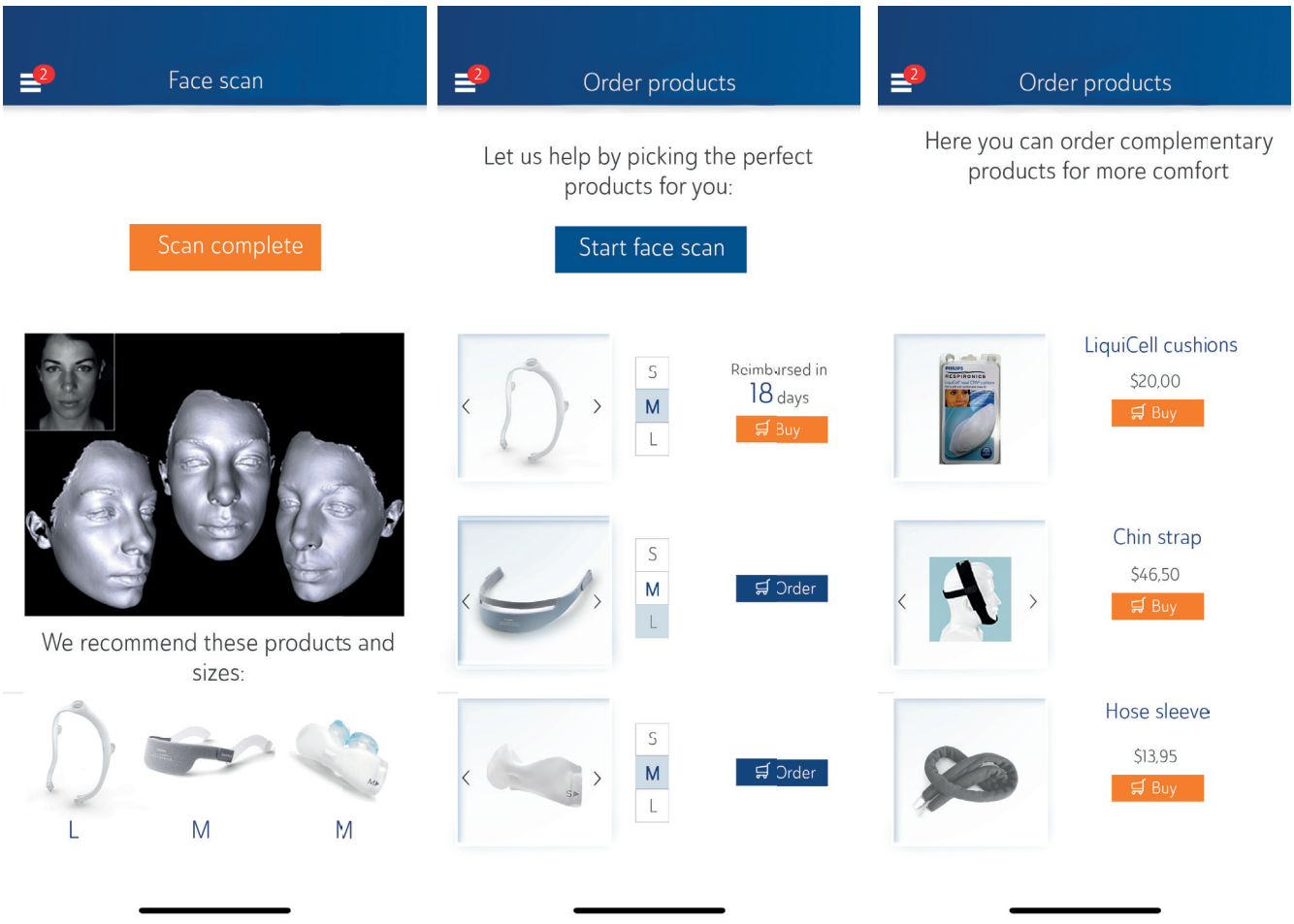


Improvement opportunities

When the user indicates that he wants to order new products, he is asked why. This helps Philips to get insights in product break down and user experience. Furthermore, it is meant to give the user awareness about the replacement of the product. When this is done in the right way, it can discourage the replacement of the products when it is not needed.
Furthermore, when products are broken, sometimes they fall under warranty and users can get a free new one. Next to this, sometimes insurance companies reimburse extra products. Both of these scenarios could be linked to the questions.

Order products

After the re-linking through the "bad mask fit" page or the questions, the patients can order replacement or additional products. Herein, the reimbursement schedule is clearly stated. The products and sizes which the patient currently uses, are highlighted. This makes it easy to order the same products or pick a larger or smaller size that maybe fits better. The Dreamwear mask, cushions and headgear is designed in a modular way, whereby multiple type of products fit on the same mask frame. This is represented by the interface by sorting the products and the possibility to scroll through different types of headgear and mask cushions.
The right size and mask can be picked with help of the face scan software.



17

3. REVERSE LOGISTICS + RECYCLING

17.1 Recycling strategy

Circular strategy

In the previous chapters are the first propositions to work towards the circular economy defined. These are mostly focused on the circular strategies; slowing resource loops and material efficiency. Though, the propositions are designed as such to make the products and the system 'circular ready', which in this case means; ready to close resource loops.

As refurbishment and remanufacturing are not promising for the headgear and mask (see chapter 11), the end of life scenario 'recycling' is a good option. This can still be done in many ways and through different channels.

The products are now manufactured in separate places and then spread globally. Taking all the products back to recycle them into the same products on the other side of the world, does not have a positive impact on the environment, as was explained in chapter 11 and calculated in Confidential Appendix 4. China is the world's largest producer of fibre and fabric as they are responsible for 54,8% of the global production (Barrie, 2019). Furthermore, it is the largest investor in electronic flat knitting machines as they take 95% of these world shipments (Barrie, 2019). Therefore, it is most likely that the future headgear will also be produced in China. This fits the supply chain of the mask better than the current headgear as can be seen in confidential appendix 5, and will therefore lower the transport impact. Though, local production of the products is better to lower CO2 emissions. Therefore, other production factories should be researched. But for now, we should be realistic and the current supply chain is based on China. It takes a lot of investment and time to change this, therefore in this chapter is focused on what is most feasible in the near future. Like was discussed in the material chapter .. and product design chapter ..., the headgear should be made from recycled yarn in the end, but this does not necessarily mean that this should be made

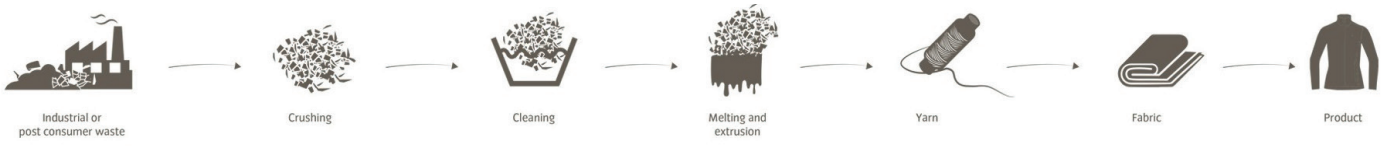
Therefore, it is chosen to focus on local recycling and possible local manufacturing options, which results in the lowest CO2 emissions. To achieve this, we need collaboration in the supply chain and especially with the DMEs, as was explained in the previous chapter. The relations with the DMEs are enhanced by the proposition in the previous chapter, now we can take it a step further! As the scope of this project was set on Europe, as explained in chapter 1, the recycling and take back scenarios are also focused on the EU.

Silicone recycling

As was explained in the market barriers in chapter 7, silicone waste is currently not recycled through municipal waste but burned in a waste incineration. Higher level recycling of silicone is nowadays possible but this is a specialized technique.
The silicone from the masks that come back to Philips SRC in Pittsburgh for warranty checks, is separated and sold to a recycler. This means that there is value in the silicone in terms of money and 'potential', as was described in chapter 1. In the US, there are multiple silicone recyclers of which ECO USA claims to be the first, established in 2009 (ECO USA Recycling, 2018). Silicone is now mostly downcycled, f.e. into rubber tiles for playgrounds. Philips is already doing research into silicone recycling with a higher integrity and searching for the right partnerships. As the techniques keeps improving and the research done is promising, it is expected to find the right silicone recycling method and company in the future.

Textile recycling

In April 2018, new waste rules in the Circular Economy Action Plan of the European Commission were approved (European Commission, 2018). This includes the recycling targets of collecting textiles separately by 2025. As the headgear is only a small piece and does not have a high material value, as was discussed in the introduction and in chapter 11, municipal waste recycling is a good option to give the yarn a new life, while keeping the transport emissions and costs low by making use of already existing solutions.

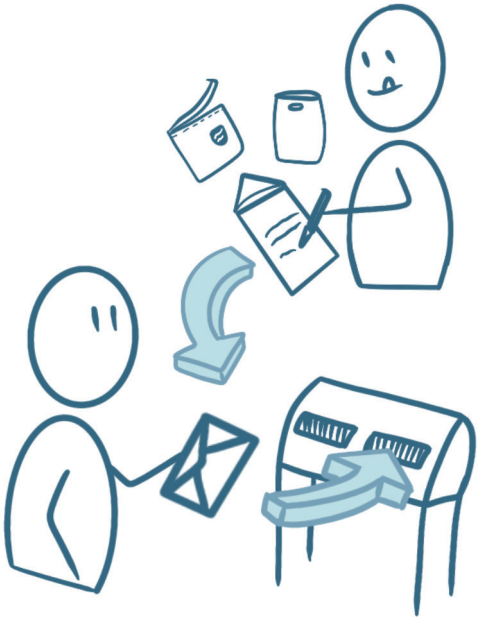


17.2 Take back logistics scenario

Reverse logistics

There are multiple reverse logistics scenarios possible to take back and sell the silicone, due to many different operators in this system as can be seen in Appendix F. The DME is the centre of this system and is in contact with the patient, Philips, hospitals and the insurance companies as was discussed in chapter 5. The DMEs manage the storage of multiple brands of CPAP supplies in their warehouses. These warehouses can become the centre of the take back loops and even gives the opportunity of collecting masks of other brands at the same time. The implementation and business model of such a collaboration should be further researched. The advantage for the DME can come out of a fee for collecting the materials as a part of the profit from selling these. Furthermore, this could be a package deal with the advantages for the different stakeholders of the previous chapters, as a wider partnership.

Figure 51. Inspiration: Ziggo replace and take back strategy.



The mask package fits through a normal mail slot in the Netherlands and has a weight below 2 kg (Koninklijke PostNL, 2019a). Furthermore, there are no limitations in sending these type of used products (Koninklijke PostNL, 2019b). Therefore, it can be send in a large envelope through the normal mail. This is again a nice way to use existing infrastructure.

This take back scenario, requires the users to take action by sending the products pack. This is a common principle in the current society of ordering products online and it is expected that the patients will collaborate when it is made simple and clear enough. The inspiration for this take back scenario comes from two examples. The pictures in figure 51, come from the return instructions of sending products back to Ziggo after getting replacements, which were taken in personal experience. Ziggo includes a letter with clear step by step instructions and a sticker with return address to paste on the same box as the new products came in. The instructions on the website of clothing company Costes mention that the return sticker is not necessary for sending their products back free of charge (Costes Fashion, 2019). It is mentioned that just writing the address on a package and give it to PostNL, is enough.
This last way is the most environmental friendly solution, as stickers are not recyclable and create extra waste. The adhesives in stickers can even get

caught in recycling equipment and the sticker is made of several material layers. Also the backing sheet is not recyclable, as it contains a combination of paper and a coating of silicone, PET or PP (Granger, 2018).

Therefore, the address of the DME warehouse where the products should be send to, can be included in the app. The patient can write this address on an paper envelop, the original Philips package or any other bag. In the new procurement scenario described in chapter ..., the app is already linked to the right DME. The address of the right warehouse can therefore easily be coupled to the patient, and displayed after ordering new products. A reminder of this address should be send after the patient has received the new products, including clear instructions to sent the products back. An example of how this could be implemented in the DreamMapper app, is displayed in figure 52.

Figure 52. Reverse logistic implementation in app

Philips' Incentive

As was defined in the design brief, this motivation to work towards circular propositions is most important. Therefore, when there is an investment needed for a recycling scenario for the headgear and mask, "how?" is not the most important question to make it happen: "Why?" is. During this project, the ideation of several possible advantages of a new circular/ sustainable proposition for Philips SRC has been summarized in a visual diagram, displayed in Appendix N.
What needs to be mentioned here is that contributing to Philips own circular targets and ambitions in their sustainability program 'Healthy people, Sustainable planet' to lower their carbon footprint and to close the loop on products and materials, are already great 'advantages' on their own. Furthermore, the advantages and revenue that is created by the propositions in the previous chapter, can also justify the investment in a recycling model.

Next to this, selling collected materials can create revenue, without the need to recycle and reuse the materials yourself. There are different companies and platforms available that match resources to a buyer, like the Excess Material Exchange company. Philips is already partnering with this initiative and this could be extended for the silicone. This company helps with identifying, tracing and monetizing materials, to find their right and sustainable next life (Putten, 2019).

Another reason to invest in the reverse supply chain and make recycling possible are the Extended Producer Responsibility (EPR) schemes that are included in the EU directives on waste and in national legislation. EPR ensures that producers take operational or financial responsibility for the end of life of their products (European Commission, 2019b). Currently, these measures are focused on the packaging industry, but new guidelines are waiting for approval by the Member States of the EU. These set new obligations and financial contributions for product producers, that take into account the durability, repairability, re-usability and recyclability of these products (European Commission, 2019b).

18

CUSTOM MASK AND HEADGEAR

18.1 Technique introduction

Circular strategy

The new headgear design from chapter ... is ready for the future. The knitting technique and the already modular design of the Dreamwear line enables the implementation of custom made masks and headgear in the future. This would create an optimal fit, which is more comfortable for the user. A more comfortable fit will help prevent the users from quitting their therapy, as discomfort is currently the main reason why patients quit (Wolkove, 2008). Furthermore, this will prevent users from altering the products due to discomfort, which has the risk of breaking down the products and therefore reducing their lifetime.
Next to the mask select software which can be implemented in the earlier procurement scenario, custom made masks eliminates the need for different cushion sizes in one package, which is waste of material.
The custom made masks and headgear can also enable a super local production process as these knitting and 3d printing techniques can be done on small machines. The automatic knitting technique on small machines for at home use, is currently developed for mass production by at least one company called Kniterate. This company promises to ship their pre-ordered products in April 2020: on desk automatic digital knitting machines (Kniterate, 2019). Imagine: by refinement and development of this technique, in the future the users can even print their custom products from home or in local shops with the help of the service from Philips. Which lowers the carbon emissions that are occurring during transport.

The technique: 3D printing silicone masks

The 3d printing of silicone is very desirable as the material has perfect bio compatibility properties and custom forms can be widely applied in the medical industry. Hardened silicone material can not be reheated and melted into another form, which makes it unsuited for a common 3d printing filament (Beamler, 2018). In 2016, the company WACKER introduced the technology that makes it possible to 3d print silicone while maintaining its resistance to temperature and bio-compatibility (Wacker Chemie AG, 2017). This 3d printing technique works with liquid silicone that forms the product drop by drop. UV light is applied to directly vulcanise the silicone. The support material can be washed away with water. In 2019, they released new software and hardware that makes printing with multiple types of silicone and colour at the same time possible with an extremely high precision (Wacker Chemie AG, 2019). This makes the printing of blood vessels and cloning detailed tissue parts possible.
This detailed 3d printing technique with silicone is highly applicable to custom made CPAP masks.
In 2015, the Company Metamason won a start up competition with the first 3d printed CPAP mask Respere[tm]. The Scan Fit Print platform was designed to scan a patient's face and translate it with an algorithm to an unique medical grade silicone 3d printed mask (Makeit, 2019). In 2016 they raised 3 million dollars with crowdfunding and they planned to go to market in 2017. Though, at this moment their website is offline and nothing can be found of the company after 2017. When we look at the design of the mask in figure 53, we see that the product has a front tube connection. Next to this, the straps are thin and flexible and the connection piece of the headgear to the mask has a sharp transition. This can leave marks and skin irritation; not only the mask cushion fit is important.

Figure 53. Metamason 3d printed mask.

Custom fit nasal pillow mask

The current nasal cushion of the Dreamwear can start to "flubber" over time, while the nasal pillow type fits perfectly but can leave sore nostrils and wounds, figure 54 and 55 (Appendix B Nurse interview). The 3d printing of custom made parts that fit the nostrils of the patient, can ensure more comfort and keep a good fit. The already existing two-material-injection-moulding technique can even provide a softer silicon for the intra nasal parts, while providing a harder silicone for stability and a good connection with the rest of the cushion. Multiple variables can be taken into account with a 3d face scanning algorithm, see figure 56 for the idea.

Figure 54. Current Dreamwear nasal pillow cushion

Figure 55. Current Dreamwear nasal cushion

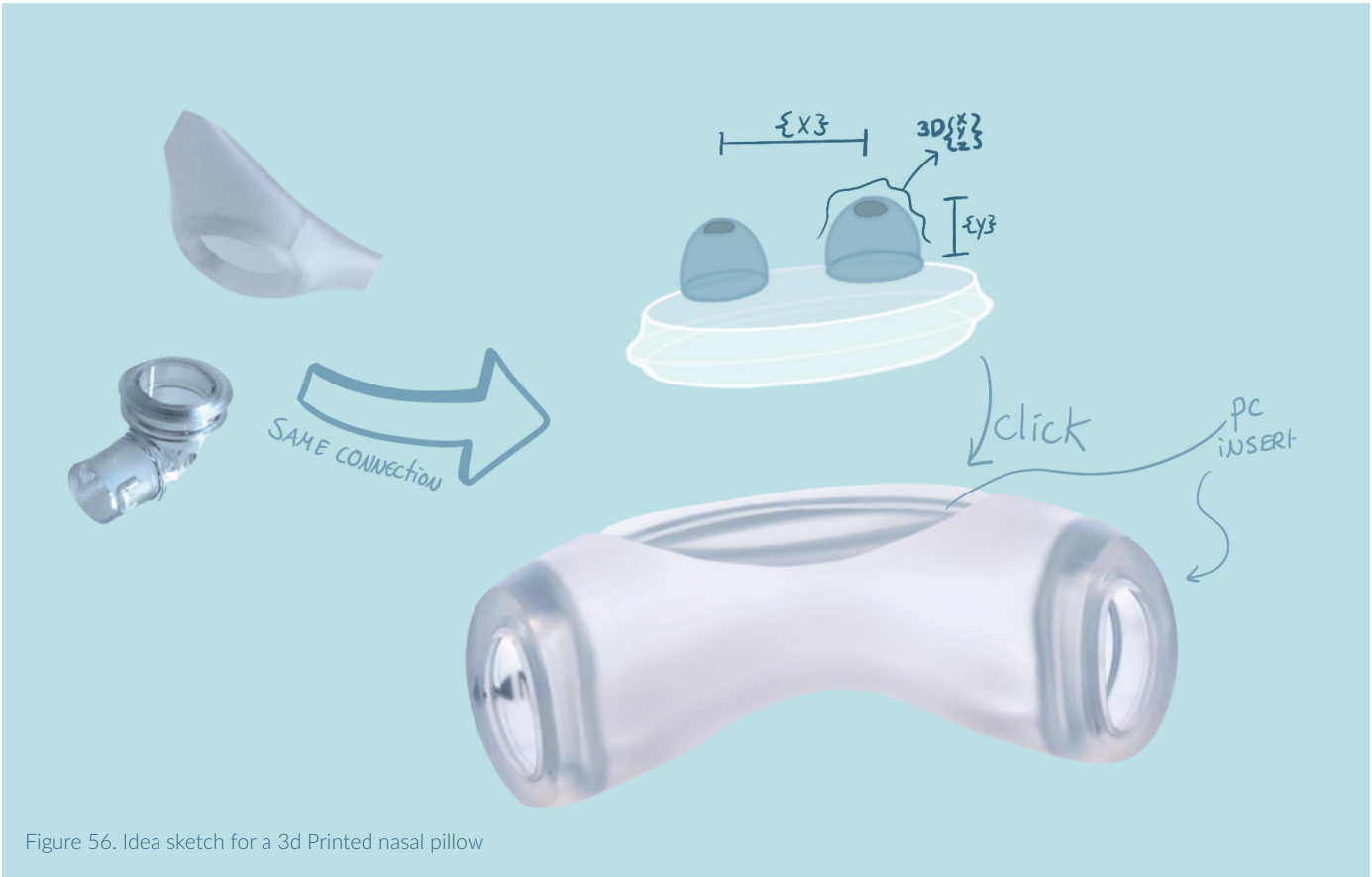


Figure 56. Idea sketch for a 3d Printed nasal pillow

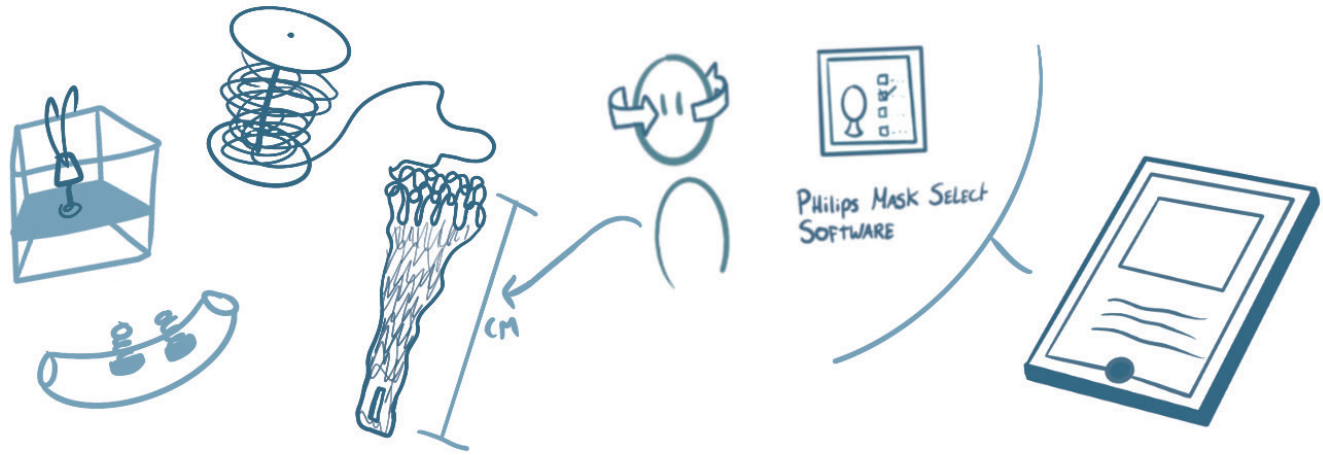
18.2 Trends & the future

Trends Knitting

The complete garment computerized knitting technique that will be used to create the headgear, makes quick-response and customized production of the headgear possible (Choi, 2005). The computer-based design and manufacturing software can instantly change the patterns and designs of the knit wear to the head circumference of a specific patient. Therefore, different standard headgear sizes will not be needed, but the headgear length, and even width and amount of stretch, can vary per patient to optimize their comfort.

Feasibility

Philips is constantly innovating and looking for more sustainable solutions. Signify is the world leader in lighting which was previous Philips Lighting, but now a separate company. Still, we can learn from them. On November 14 2019, Signify announced the world's first service for consumers wherein they can custom and order 3d printed luminaire from recyclable material (Aziz, 2019). The consumers can choose a base design and personalize the colour, size, texture and the type of light bulb, This proves that customizing by users and 3d printing the products on a large scale is possible. Next to this, Philips is already researching additive and digital manufacturing possibilities for the Sleep & Respiratory Care sector.



Chapter

19

IMPLEMENTATION: ROADMAP

19.1 Roadmap

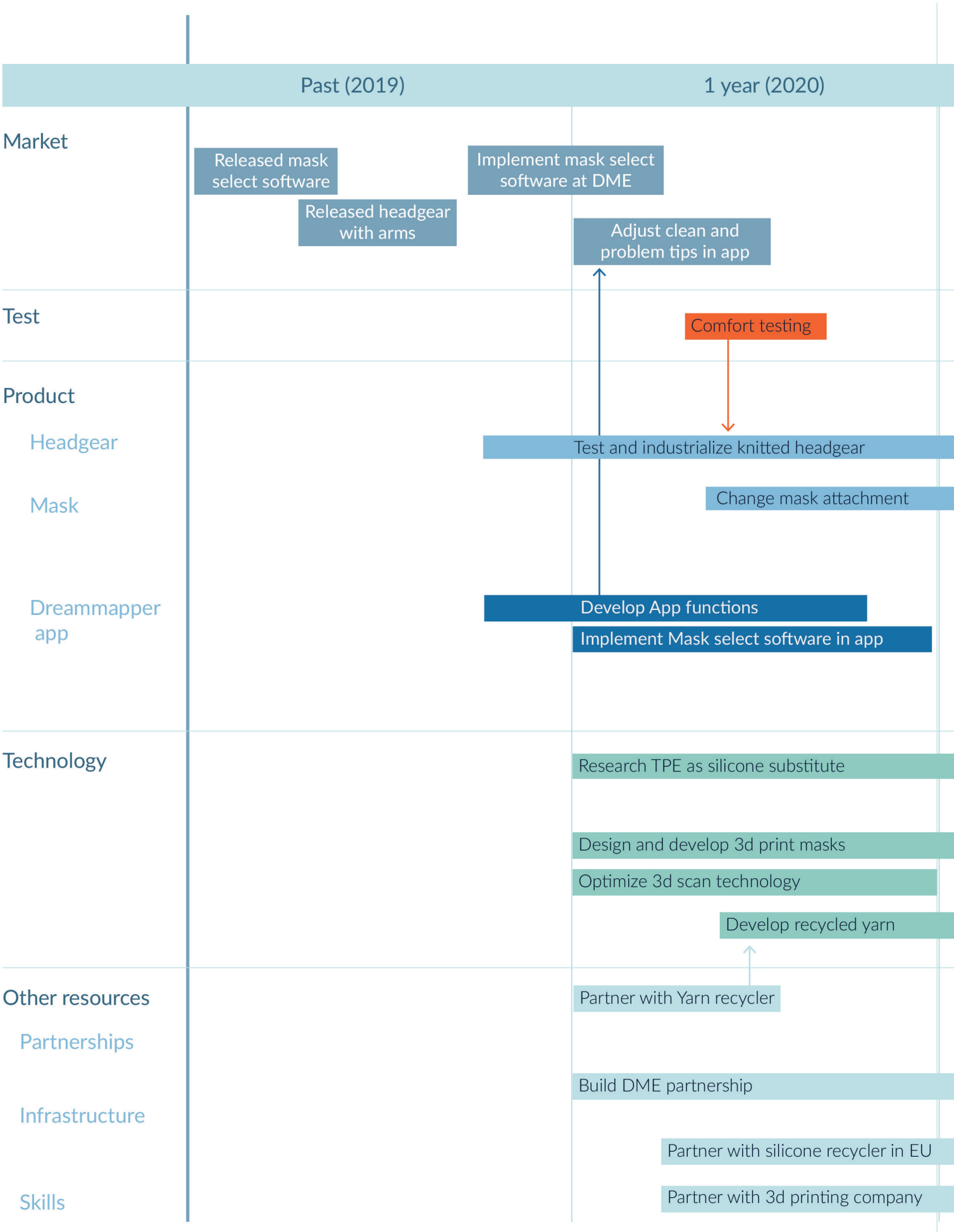
Method introduction

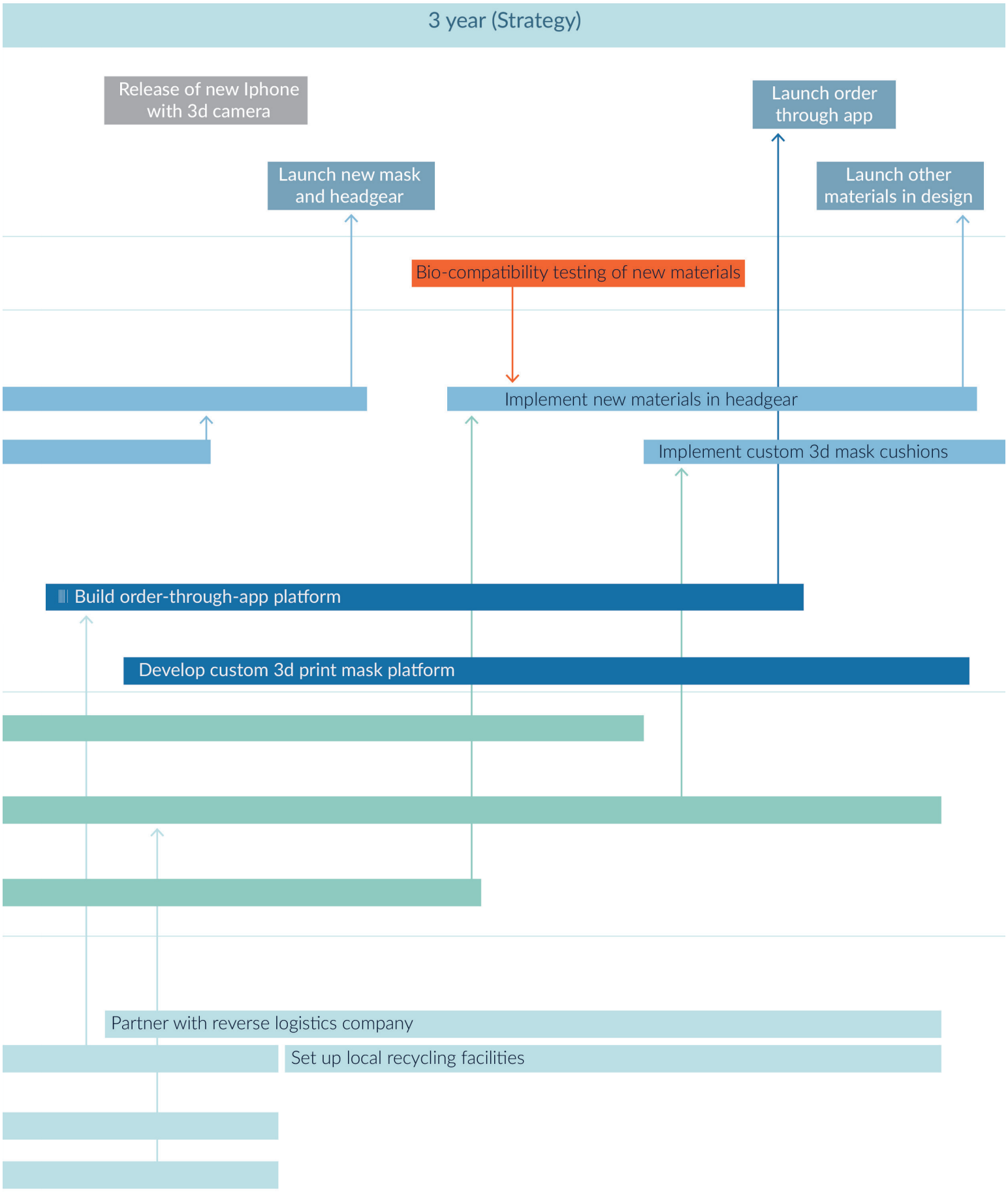
Technology roadmapping supports strategic and long-range planning (Phaal, Farrukh, Probert, 2004). There are many different formats available, which fit with different projects, contexts and goals. These frameworks can be used to visualize and assess the impact of new technologies on business plans and systems, which makes it perfect to use in the end of this project.

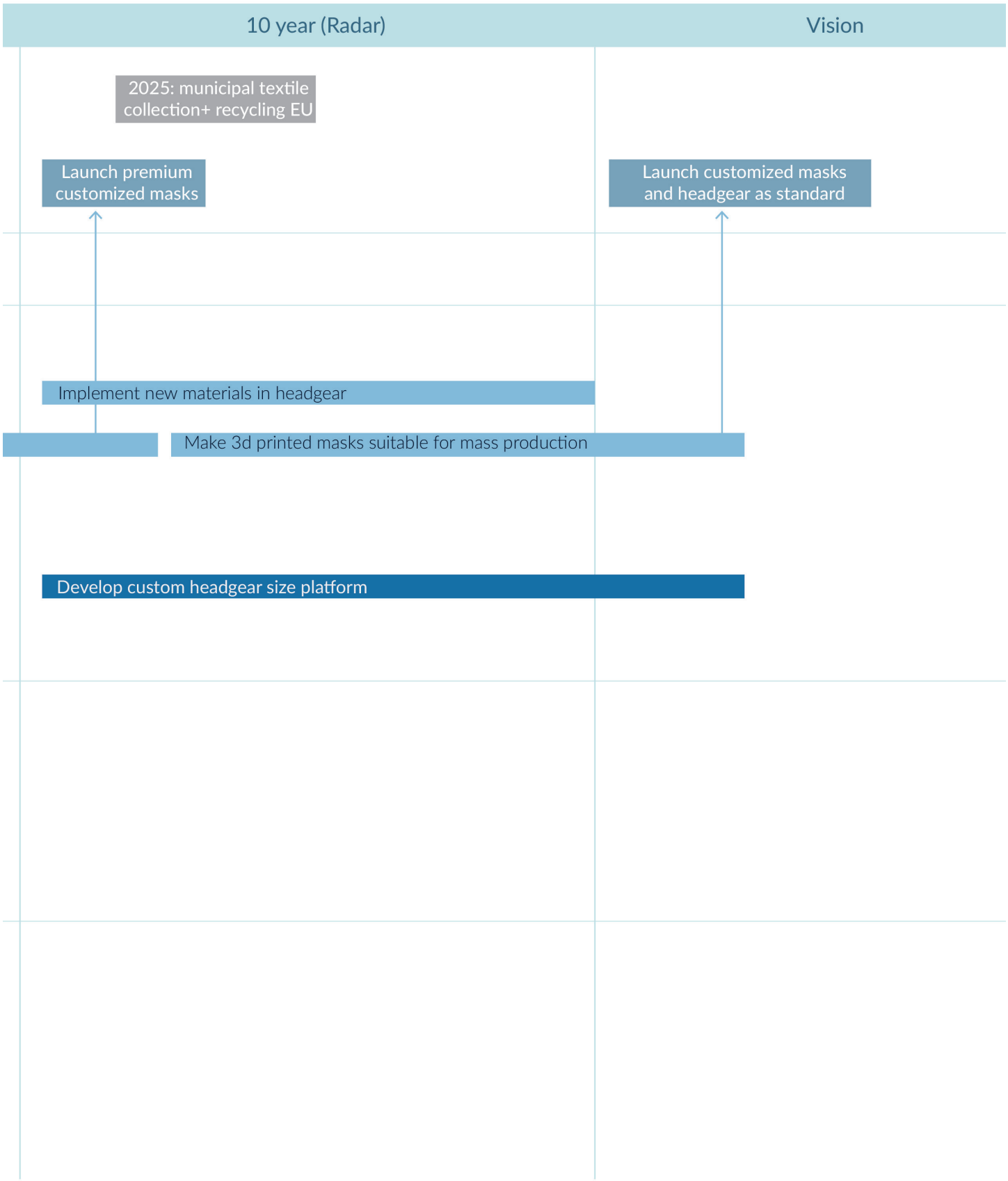
As was described in the Design Brief, it is needed to create structured overviews, showing possibilities and showing an holistic design approach to inspire SRC to make the transition to the Circular Economy. A roadmap is a time-based chart, which consists of multiple layers, including commercial , technological and product development. The evolution of these parts can be explored through the roadmap and future needed capabilities and resources can be identified. This helps to create concrete steps now, that are useful for the future. This is the same for the multiple steps of the created solution proposition in this project, wherein in the product design future scenarios and possibilities are taken into account.
As Philips works with roadmapping themselves and already has strategic roadmaps for the future, this is a good way to communicate in a recognizable way and creates the possibility to align or extend both roadmaps.

Roadmap explanation

The roadmap of the circular proposition is displayed on the next pages. The vertical axes contain the needed tests and other resources categories, next to the common Market, Product and Technology categories. This is the Strategic planning type of roadmap that focuses on the development of a future vision for these categories and comparing this to the current position (Phaal et al, 2004). In this way, gaps can be identified and options can be explored to bridge these gaps. The Market category contains trends in the market that can have an influence on the planning or future vision, next to the launches of the created proposition parts in different steps. The yellow dots indicate milestones of the 4 propositions. The detailed propositions and their explanation can be read in the previous chapters.


Past (2019)
1 year (2020)
Market
Released mask select software
Released headgear with arms
Implement mask select software at DME
Adjust clean and problem tips in app
Test
Comfort testing
Product
Headgear
Test and industrialize knitted headgear
Mask
Change mask attachment
Dreammapper app
Develop App functions
Implement Mask select software in app
Technology
Research TPE as silicone substitute
Design and develop 3d print masks
Optimize 3d scan technology
Develop recycled yarn
Other resources
Partner with Yarn recycler
Partnerships
Build DME partnership
Infrastructure
Partner with silicone recycler in EU
Skills
Partner with 3d printing company


3 year (Strategy)
Release of new Iphone with 3d camera
Launch order through app
Launch new mask and headgear
Launch other materials in design
Bio-compatibility testing of new materials
Implement new materials in headgear
Implement custom 3d mask cushions
Build order-through-app platform
Develop custom 3d print mask platform
Partner with reverse logistics company
Set up local recycling facilities


10 year (Radar)
Vision
2025: municipal textile collection+ recycling EU
Launch premium customized masks
Launch customized masks and headgear as standard
Implement new materials in headgear
Make 3d printed masks suitable for mass production
Develop custom headgear size platform

SECTION 7
Conclusion

Chapter

20

CONCLUSIONS

19.1 LCA conclusions

The LCA method is used during the different stages of this project to analyse the current product life cycle and new concept and designs to find out how the environmental impact could be lowered. The initial product system and use scenario is used as a bench mark, as explained in chapter 7. The positive impact of a circular business model and other designs are discussed in chapter 11. Furthermore, the total report and data sheets, including the analyses of different cleaning scenarios can be found in detail in Confidential Appendix 3 and 4.

Data & Results

On the next pages, a simplified product life cycle is displayed of the current product system, based on the extensive Product Life Cycle poster in Confidential Appendix 2. The changes in this over time, based on the 4 new design and proposition steps, are displayed underneath. The change in environmental impact is shown in the graphs next to these. The detailed Lify Cycle Analysis approach and used data can be found in the Confidential Appendix 4. In the LCA results graphs on the next page, the use phase is only displayed in the top one. This phase is removed in the next graphs as it stays the same over time for the new design and is too big compared to the other phases. Now the differences between the other phases can be read more easily. A bigger version of the graphs is displayed in Confidential Appendix 4.
In the current scenario, a wash cycle of weekly warm hand washing is taken into account. The use phase impact will be higher, for the users that wash more regularly. Furthermore, the package including 3 mask sizes is calculated, to show the difference with the other scenarios.
As was discussed in chapter 15, the water saving of washing in the machine compared to hand washing is estimated on 91% (Ceced, 2017). This is calculated in the first part of the new proposition. In the new procurement model, the second part, the longer lifetime of the products is now taken has 24 months instead of 12. This is done because the current products are tested inside Philips to twice its lifetime. Except for the mask cushion as this is a critical part for the performance and expected to be replaced more often than the other. Though, the actual average longer lifetime is still dependent on the user and can only be determined in a pilot test. In the last scenario, the transport scenario is changed to a more local on- demand production site. There was too little data available to estimate what this would mean for the production phase, so this was out of range for this project.

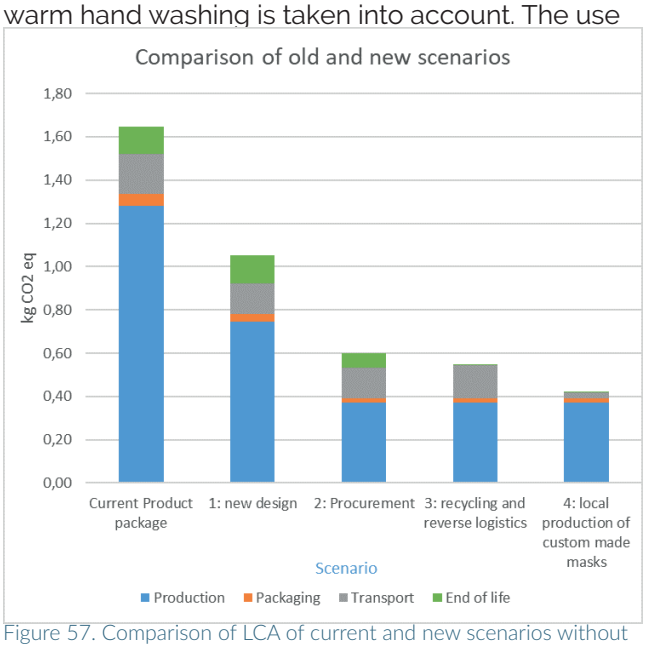


Figure 57. Comparison of LCA of current and new scenarios without use phase

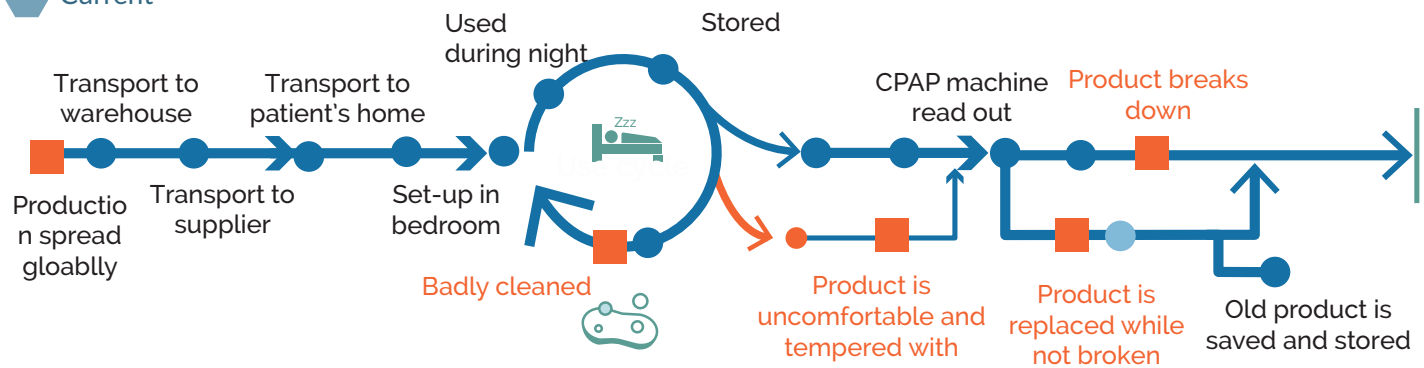
Conclusion

A change in the washing cycle has the highest positive impact on the total environmental impact of the product system, as was already concluded in chapter 7 and Appendix L. Next to the use phase, the new proposition parts have a positive effect on the other phases of the product life cycle, as can be seen in figure 57. The new design reduces the production impact. Furthermore, the procurement model saves the use the extra cushion sizes and can prolong the lifetime of the products.

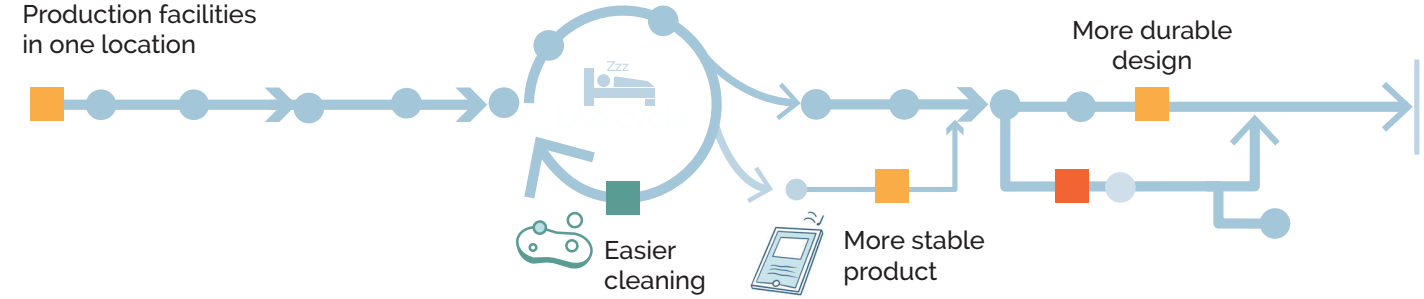
Discussion

The results of this LCA should be seen as a rough estimation that indicates a positive effect instead of exact numbers. Because the approach that is used in this project is mostly the fast track LCA analysis to easy and fast compare different scenarios. When more production and finishing details are added to the production phase of the different scenarios, the numbers for these phases will be higher. Furthermore, the reduction of the impact by the change in cleaning scenario and product lifetime highly depends on the current and new behaviour of the patients, which needs to be further researched. Next to this, the CO2 impact of the expanding of the Dreammapper app in terms of energy from data storage and online communication is not taken into account.

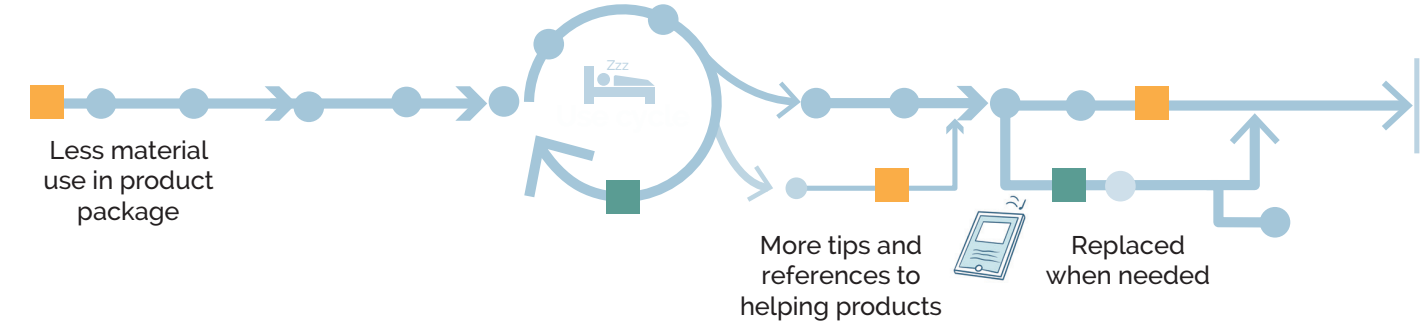
Current



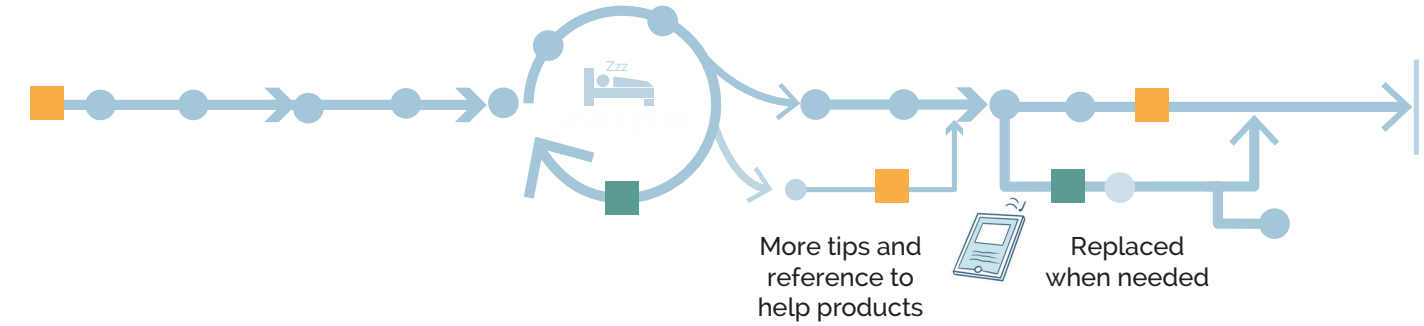
New product + extra app features



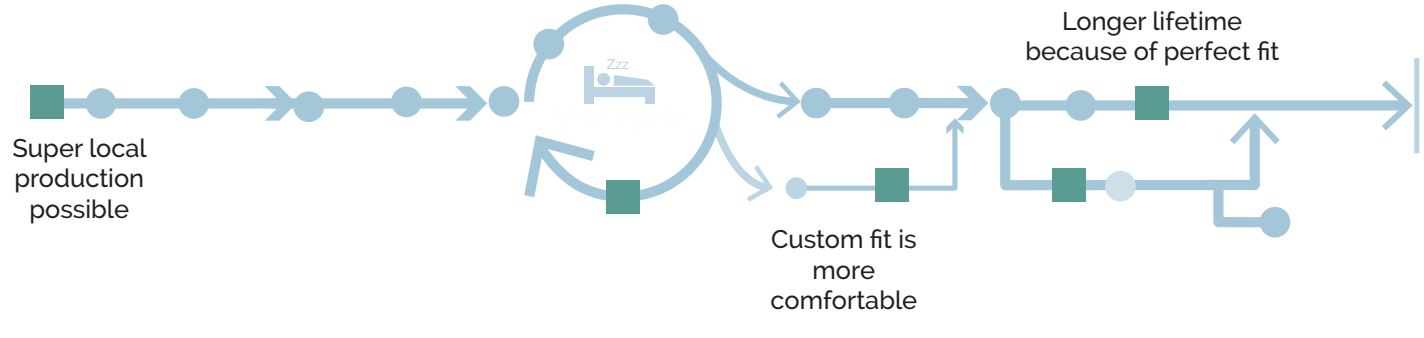
Implement other procurement scenario and extra app features

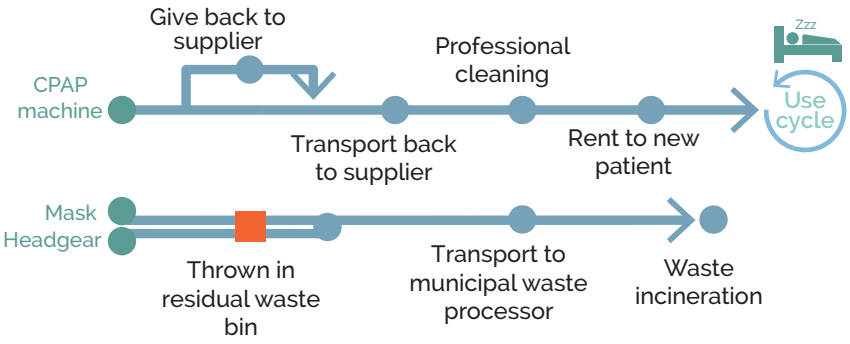


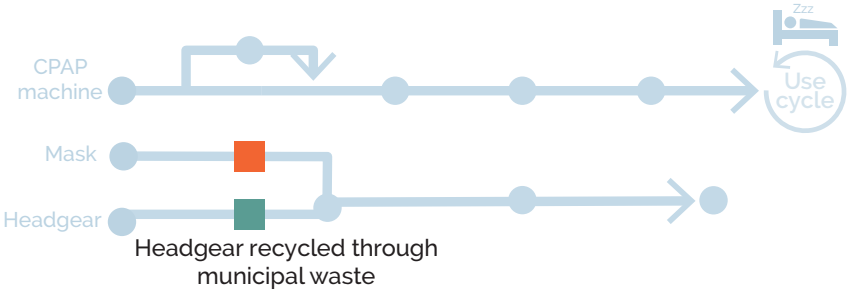
Recycling scenario & reverse logistics

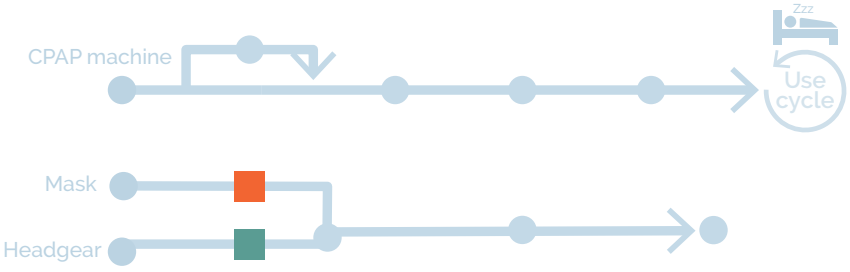


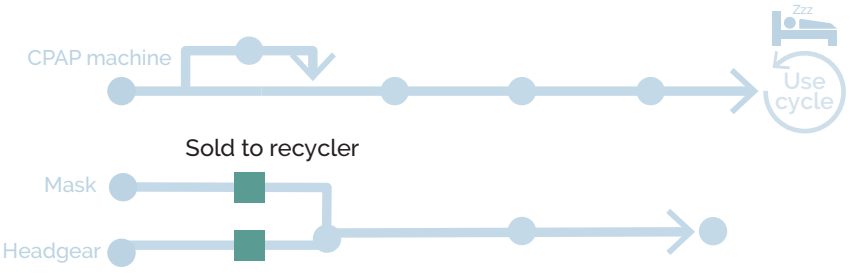
Custom masks + headgear with local production

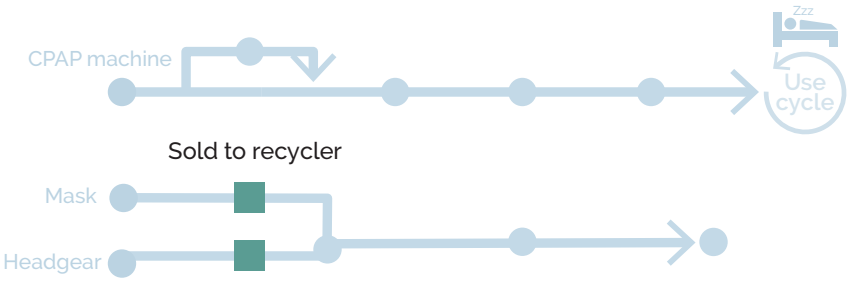


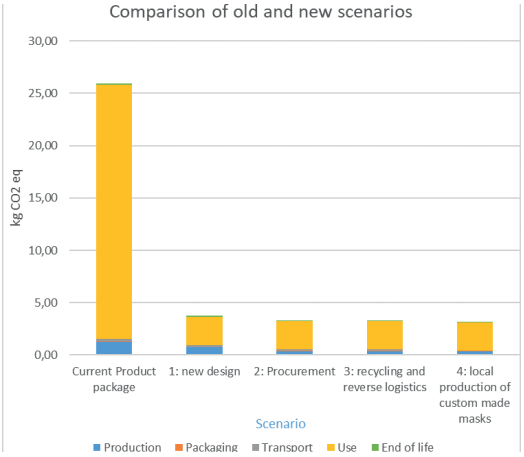

Give back to supplier
Professional cleaning
CPAP machine
Transport back to supplier
Rent to new patient
Use cycle
Mask
Headgear
Thrown in residual waste bin
Transport to municipal waste processor
Waste incineration

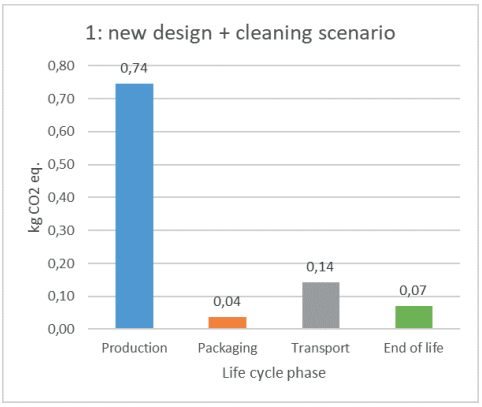

CPAP machine
Use cycle
Mask
Headgear
Headgear recycled through municipal waste

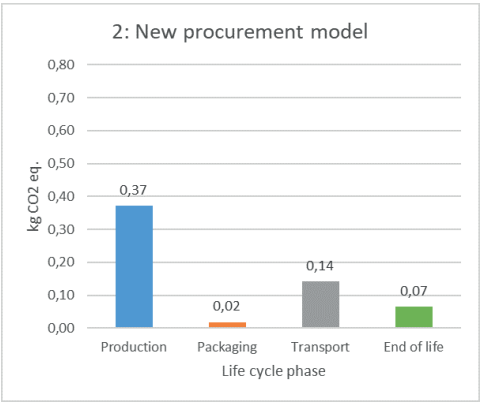

CPAP machine
Use cycle
Mask
Headgear

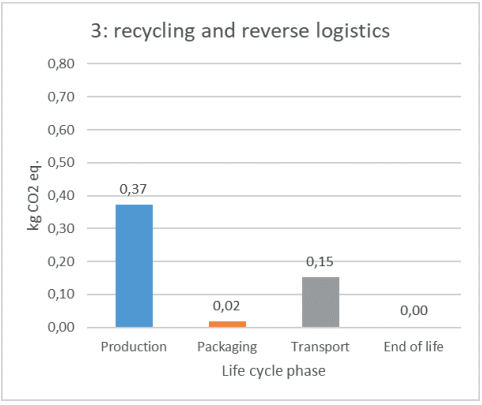

CPAP machine
Use cycle
Sold to recycler
Mask
Headgear

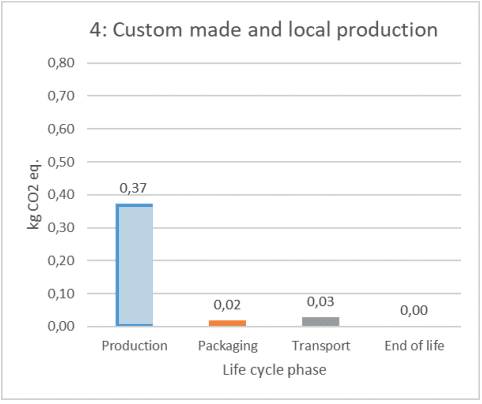

CPAP machine
Use cycle
Sold to recycler
Mask
Headgear

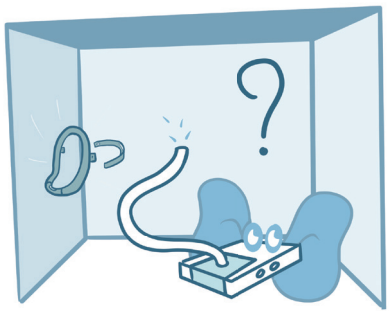

Comparison of old and new scenarios
kg CO2 eq
30,00
25,00
20,00
15,00
10,00
5,00
0,00
Current Product package
1: new design
2: Procurement
3: recycling and reverse logistics
4: local production of custom made masks
Scenario
Production
Packaging
Transport
Use
End of life


1: new design + cleaning scenario
kg CO2 eq.
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
0,74
0,04
0,14
0,07
Production
Packaging
Transport
End of life
Life cycle phase


2: New procurement model
kg CO2 eq.
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
0,37
0,02
0,14
0,07
Production
Packaging
Transport
End of life
Life cycle phase


3: recycling and reverse logistics
kg CO2 eq.
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
0,37
0,02
0,15
0,00
Production
Packaging
Transport
End of life
Life cycle phase


4: Custom made and local production
kg CO2 eq.
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
0,37
0,02
0,03
0,00
Production
Packaging
Transport
End of life
Life cycle phase



What about the CPAP machine?

This project started with a focus on the headgear, but after the research and LCA analyses the scope was broadened to include the mask and product package as well. This was done as the headgear was only responsible for a small part of the total environmental impact of this product system. Furthermore, the product life time and resupply of these products are connected to each other. The CPAP machine was not taken into account in this project as it has a different resupply model and it would result in a too big design scope. Though, it is good to stay critical towards the positive impact of a proposition and the relation to its system. A fast track life cycle assessment is done to estimate the environmental impact of the CPAP machine and its use over time. The conclusion is a rough estimation, as can be read in Confidential Appendix 4, part 11. The results are displayed in figure 58. The CPAP machine has a lifetime of at least 5 years, which is taken into account to compare it to the 1 year replacement of the product package. From this can be concluded that the CPAP machine has the highest impact in the product system. Though, the electricity that the CPAP machine uses to provide the therapy is also essential for the function of the total product system. When this energy is not taken into account, the proportion of the material impact of the CPAP supplies on a yearly basis in this total system becomes clear, as can be seen in figure 59. Which is even higher in the American reimbursement schedule. Therefore, it can be concluded that reduction of the environmental impact of the CPAP supplies has a significant positive effect on the impact of the entire product system.

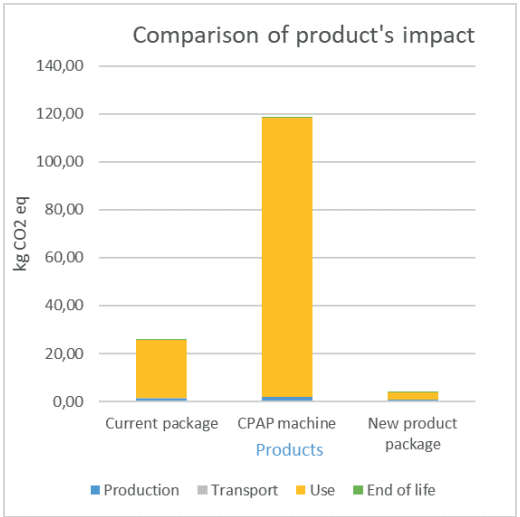


Figure 58. Comparison of the impact of different product packages to the CPAP machine

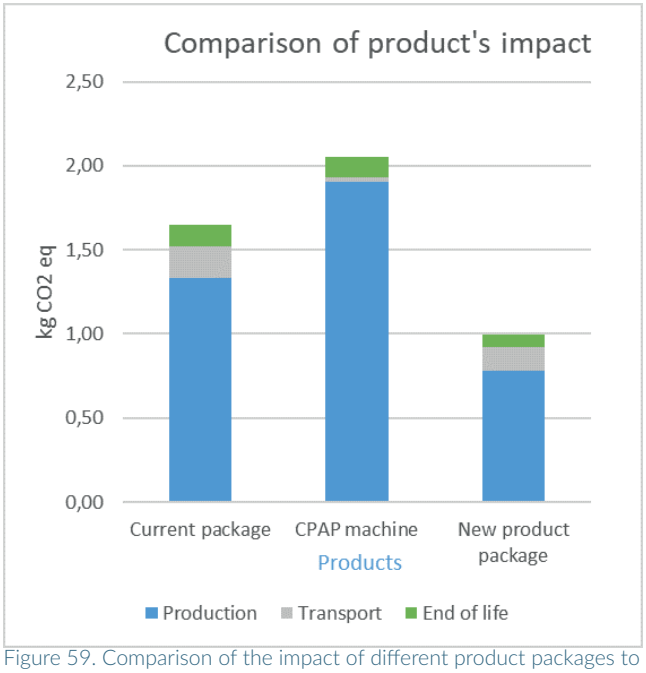


Figure 59. Comparison of the impact of different product packages to the CPAP machine over 1 year, without use phase.

Discussion on micro plastics

Every time synthetic clothes are washed, millions of microfibres are spread into the water. These can not be filtered in the municipal water filtering system which means they end up in nature. There, they cause harm to fish and other living organisms. As this environmental problem is gigantic, multiple solutions are developed. Guppy friend is a washing bag with fine mesh that traps the microfibres that are released during washing inside the bag (Guppyfriend, 2019).

Next to this, microfibres filters are developed to attach to current washing machines and washing machine producers are working on microfibres filters that are built in. In 2020, the first washing machine with a built-in filter which blocks 90% of the microfibres will come to market (Hussain, 2019). The headgear is a small piece of clothing compared to all the synthetic clothing people possess. Because of this and the innovations regarding micro filters, it is still chosen to use nylon Spandex or a future new synthetic development in the headgear.

Figure 60. Guppy friend washing bag reprinted from Guppyfriend, 2019

19.2 Contributing to Philips Circular revenue

Philips' Circular Revenue Targets

As explained in the Project Introduction chapter, Philips has targets that define the percentage of revenue that should be from circular products and services, which is set for 15% in 2020. One of the goals for this project, was to see how the CPAP supplies (before: headgear) could contribute to circular revenue.
In the Circular Design Playbook from Philips Design, like described in paragraph 3.2, are multiple circular revenue categories defined that resemble a certain business model. This can be found in Confidential Appendix 1. These categories and their benefits, risks and requirements are listed there.

Performance and access based

The new procurement model that will be link replacement to the mask fit, while ownership of the products remains with Philips or the DME, contributes to the performance and access based business model.

Recycled content

When the recycled nylon yarn is tested and implemented in the headgear, the product can contribute to the recycled content category.

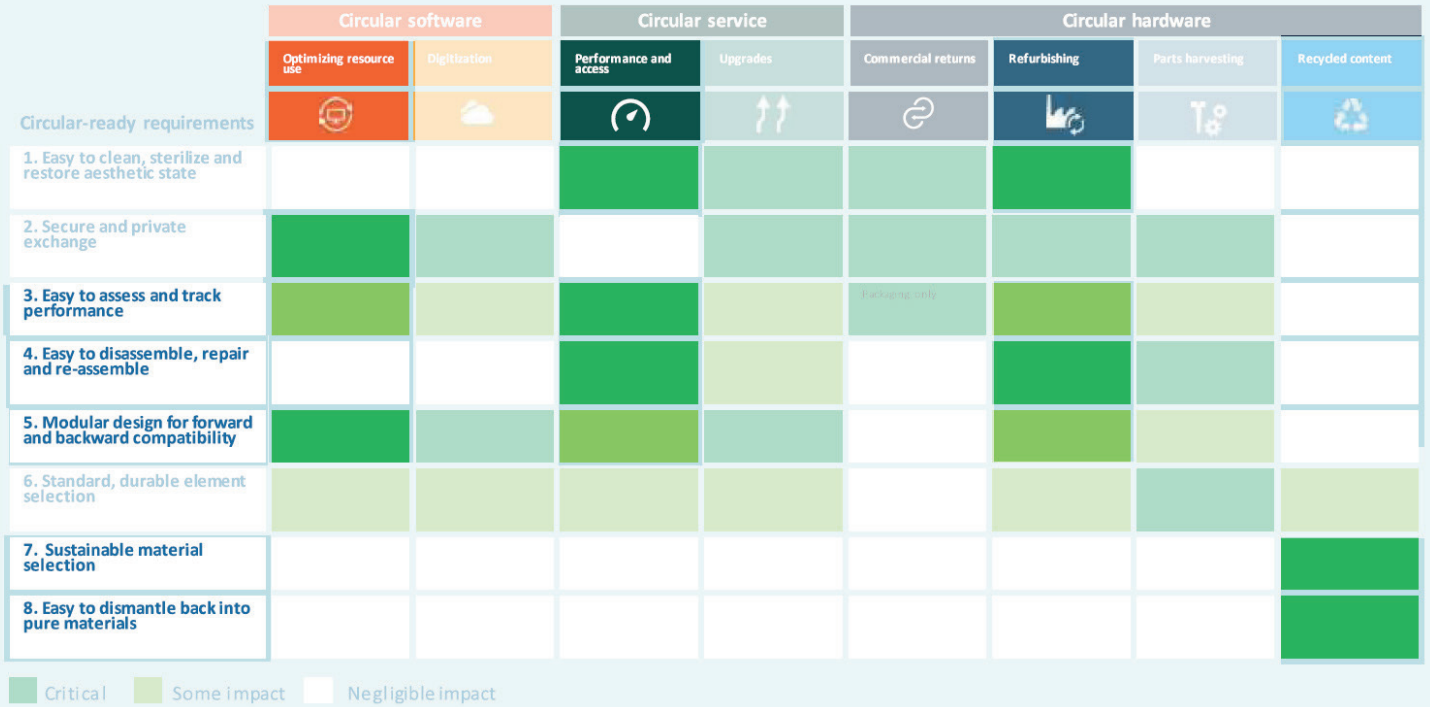
Refurbishing

The CPAP machine of Philips is by some DMEs already taken back after 5 years, professionally cleaned, potentially refurbished and re-rented. Sometimes, this is done by Philips. By extending this practise, this circular revenue category can grow.

Optimizing resource use

The new product service system can contribute to the **circular revenue category of Software**. The current fitting package has multiple sizes of nasal cushions, of which the user needs only one. If the chosen new performance based business model is combined with a digital solution whereby the fitting of the right mask cushion is done differently than just sending every one, this software will then replace the need for this hardware. This is not yet the definition of the "digitization" circular revenue category (Philips Design, 2019), but it is a recommendation to include it in the future circular revenue description. If this is reached, the new product service system could contribute to the **circular revenue category of "Recycled Content"**.

Circular revenue models and business requirements



19.4 Conclusion: Answer to research question

Looking back

How can circular design principles help prevent the headgear from ending up in landfill whilst creating value for user and business?

This research question was formulated at the beginning of this project and was extended to a broader scope including the mask and the context. This was done because out of the literature research, LCA calculations and defining of circular barriers was concluded that an holistic design approach is needed to design truly sustainable products. Therefore, at the end of the research phase the following design vision was formulated:

Design Vision

"..improve the motivation to work towards a circular solution with an holistic design approach and showing that such a circular proposition is of advantage for SRC; by increasing contact with patients and gaining control over mask decision process, while increasing the control over material flow.."

Herein, four things were defined to are needed to stimulate SRC to make the transition to the circular economy:
1. Show that it is possible to create a circular solution
2. Show the advantages of such a circular solution for SRC
3. Create a structured overview; to break down the complex system and overload of requirements.
4. Show that a truly circular proposition is in need for an holistic solution and not just a quick fix by changing some materials.

Answering the research question

I now know, that the main research question does not have one simple answer, as circularity is a large concept and there is often not one single perfect solution. In this project, multiple circular business models were evaluated, multiple reverse logistics scenarios were researched and multiple design strategies were applied and tested to the headgear. This resulted in various overview schemes that among others can be found in the design brief and appendix ...

To answer the research question, actually multiple circular design principles have been applied in this project (Bocken et al, 2016) :

Design for durability; The headgear arms are optimized for a long durability of the knitted fabric and the eliminating of the Velcro ensures a longer lifetime in combination with an easier cleaning ritual.

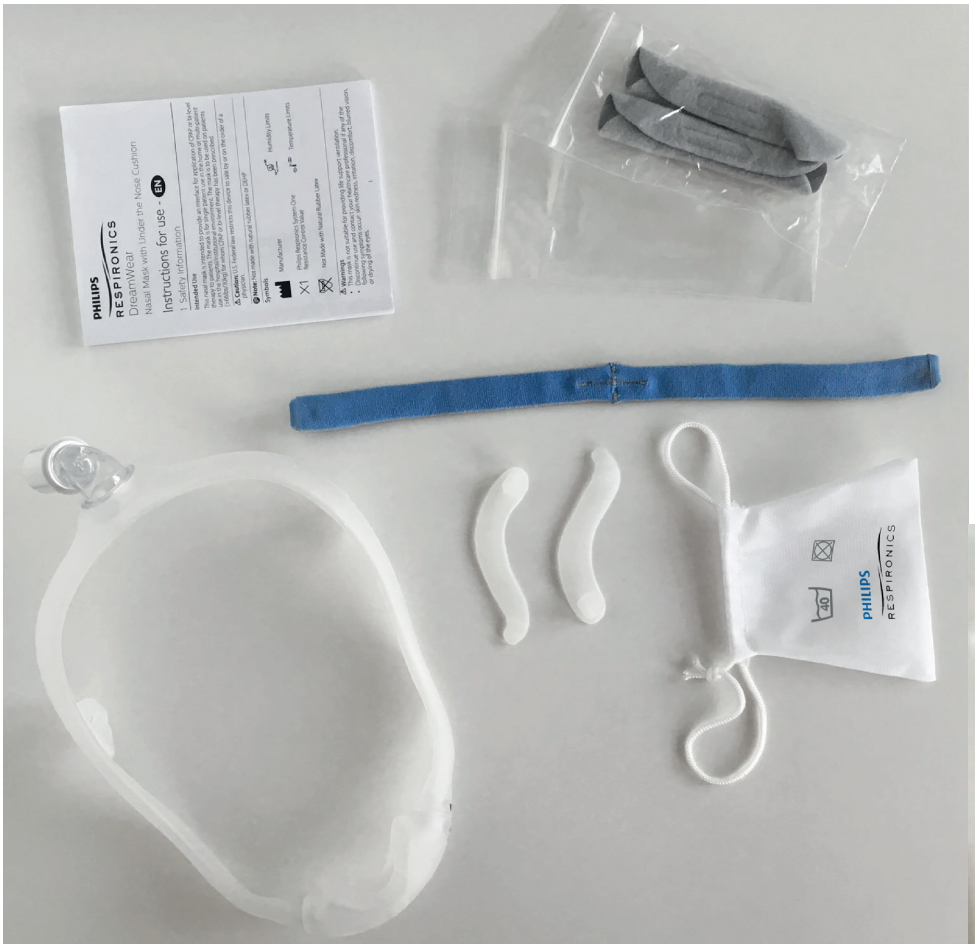
Design for recycling; The materials have been chosen as such, that they can be recycled in the future. A lot of material research is done to compare the characteristics and sustainability of these materials. Though, the techniques and research are evolving fast, thus the conclusions could change over time. The main recommendation is to start developing the products with materials that last long, and continue to investigate the recycling possibilities and partners for these and relative materials.

Design for disassembling: The headgear fabric and arms are made as such, that they are not permanently attached to each other. The

Design for upgradability and adaptability: The Dreamwear mask frame is already designed in such a way that different cushions fit on the mask and parts can be replaced in different time span. For these reasons, this has been kept the same in this project. Furthermore, the knitting production technique and this modularity enable the easy implementation of custom made mask and headgear in the future.

As the main research question includes creating value for user and business and during the research phase was found that a circular business model is needed, not only circular design principles are applied and explored. To answer the bigger underlying research question: "How can the headgear become circular?"; by applying the four proposition steps that initiate a system change instead of only change the design of the product.

Current total Dreamwear nasal package



New designed total Dreamwear nasal package

Chapter

21

EVALUATION

20.1 Discussion of project results

Feasibility

In the design brief were already several requirements stated that should have been met in this project, to make the product circular. The main objective, that is defined in chapter 1, is to inspire SRC to make the transition to the Circular Economy. This is all about the feasibility of the new proposition. Therefore, the whole product system and context was taken into account to identify current infrastructures and opportunities that can be used for this new proposition. Furthermore, the design of the headgear is based on a current design of the headgear with arms, which is already tested on comfort. The procurement scenarios can be implemented in the already existing app, and use the current supply chain and stakeholders. For all these reasons and by keeping in mind the feasibility requirement during this project, the results are highly feasible on multiple levels. To make this even higher, one project requirement of the design brief was to create structured overviews for clear communication towards the business. Therefore, the roadmap and the other overviews are made, which helps Philips SRC to continue on the project and set the next steps.

Costs

Furthermore, the implementation of the new proposition is expected to be financially feasible because of the use of existing resources and infrastructure. The supply chain can stay the same for now (though local production is preferred for less CO2 emissions), and the new headgear can be produced in China close to the mask production site. The costs and investment of the new headgear product is not expected to be very high, as the design is very close to the current one. The arms can be made of the same material, but a new injection mould is needed. Furthermore, the slots that are a part of the mask frame need to be changed. Therefore, this mould also needs to be replaced.
The production costs of the knitted fabric piece need to be further researched. In interviews within Philips was mentioned that in earlier projects the costs were estimated higher than the current headgear. As can be seen in Confidential Appendix 6 Production costs, only 35% of the production costs are from machine costs and materials and 18% is from manual labour. As the manual labour and the transport costs will decrease and the knitted design is straightforward and not complex, it is estimated that the production costs are not higher and even lower than the current headgear. Furthermore, all the hot finishing and welding equipment is not needed anymore. Next to this, the competitor already has a comparable product on the market with a knitted headgear. Therefore, it is expected that the production of the headgear is also financially feasible. This should be further validated.

Desirability

Next to the feasibility requirement, another key project requirement as defined in the design brief was "show the advantages of such a circular solution for SRC" to create the right motivation to implement circularity. Therefore, the four different steps are developed and designed with business advantages for Philips SRC and the other involved stakeholders. Furthermore, this project is relevant for Philips in terms of the methods that were used and created. The LCA tool helps choosing the right solutions in the future and the iterative use of these calculations show the way to make eco-design decisions dúring the ideation and concept phase of a design project instead of at the end to only evaluate or make small changes.
Furthermore, the design directions and decisions are discussed with Philips SRC during the project, and therefore the design could be iteratively evaluated and improved. The final presentation of the circular strategies, 4 propositions, the roadmap and the new design resulted in very positive reactions and questions that resembled the interest and motivation to know more and continue the project. The results were also positively received because it touched all aspects of circular innovation and a large scope, which was mentioned as something they haven't done before. Therefore it can be concluded that "inspiring" the SRC business is achieved. Furthermore, the discussion and aligning of the created roadmap will be continued.

Viability

The roadmap that is created gives a good representation of the different steps, resources and knowledge that is needed on the long term. The roadmap is achieved by looking at technology trends and implementing this in the future vision of the product service system, whereby the current design is already designed in such a way that this future envisioned proposition can be implemented later. This ensures the viability for Philips to work towards a future sustainable solution.

20.2 Recommendations

Product design

The product design is created through the evolution of many prototypes that are tested during the design process. These prototypes were created with fabric and 3d printed pieces. Only the final prototype was made out of an existed knitted product. Furthermore, the slot has been quickly evaluated through a tensile test.

The roadmap that was created, already gives a good overview of the general next steps and the plan for the future.

The first next steps are to create knitted prototypes and injection moulded arm parts, to test with patients for comfort and easy assembling. The assembling of the headgear should be compared to the current design, as it does not have to be way easier but should not get way worse. Furthermore, the different sizes of the headgear need to be established by testing multiple sizes on patients. In this test, the needed number of sizes for a good comfort on the largest group of patients can be established.

The designed washing cycle enables the washing of the headgear in the washing machine and still recommends to clean the mask in the dishwasher. Though, it would be even easier if both products could be washed in the same machine. Therefore, tests should be conducted on washing the mask in the washing machine and the effect f the movement on the durability of the parts. The material can already withstand the heat and water. Furthermore, a technique of washing the headgear and arms in the dishwasher should be explored. The challenge with this is that the parts are small and should not be caught in the movement of the dishwasher parts. The washing bag could be used to tie the package on the dishwasher rack so it does not move during the cycle.

Furthermore, the new slot should be tested on fatigue over time now the position is turned. With the tensile strength test, the strength and durability of the slot is already estimated to be well.

The products are designed for easy cleaning and durability. The durability of the headgear and mask needs to be tested well, to confirm that the products can last longer than the current reimbursement schedule. Out of researched was concluded that the mask is often replaced before it is actually broken. To test this insight and to have a good indication for the profit of the service model, the actual possible lifetime of the mask should be further researched. These products are already tested for twice the lifetime and maybe they can even last longer.

At last, in the material research was defined that a yarn made from recycled material should be developed for the use in the headgear. For this, a partnership with a yarn production company is needed.

DreamMapper app

The implementation of the procurement model and the feasibility needs to be further researched. For this, the partnership with the DMEs are crucial. Therefore, after developing the concept further and creating a well defined business proposal, this should be well discussed, evaluated and further developed with the DMEs.
The interfaces that are shown in the different chapters are merely examples of how the functions could be integrated and need to be further developed and tested on usability with the patients. Furthermore, it needs to be tested how the new procurement model is perceived by the patients on clarity and service. From pilot tests with this whole system, can be concluded if patients really order and use less products over time or if an extra incentive is needed in the form of positive stimulation or a costs advantage. This question is large enough for a whole different design project where user behaviour and motivation is taken into account.

20.3 Personal reflection

In the Project Brief, see appendix ..., I defined several learning goals in the form of knowledge and skills that I wanted to develop during this graduation project. I chose this project and the approaches that were used in it, to really be able to do things I have never done before, to gain experience and just exploit the last phase of my study to learn as much as possible, instead of doing the things that I knew I already could.
The main personal goal of choosing this graduation project was to deepen my knowledge about sustainability in terms of circular and eco- design and the approach of such a project. This was my first project in which the main focus was on sustainability and I learned A LOT. The main insights in the beginning of the project were that circular design and eco design are truly different approaches and that 'circularity' is not only about closing resource loops. This opened my eyes to many possible solutions, designs and business models and this is what made the design process more complex than I had expected in the beginning of the project. But, which I also stated in the design brief, I love puzzles. Therefore, the complexity of the project and the context was a perfect and fun challenge for me. The large exploration area, possible design directions and many prototypes resulted in an inspiring and fun design process.

'Information visualisation' was another wished improvement skill during my project. Before I started, I thought about infographics and the use of schemes. This is what I implemented in the research phase by creating the product life cycle and patient journey poster. But during this project I stumbled on a total different and very valuable skill: Visual thinking. Therefore, I bought a book and practised during my summer break. It feels like I unlocked a part of my brain that was always there, but just did not know how it should let itself hear. After this holiday, all my ideas, overviews and scenarios kept getting captured in simple and easy to understand drawings that were fast and fun to create and now are spread all over this report. These drawings capture the essential of pieces of text and visualize hard to understand concepts. Next to this, drawing helps to order my own thoughts. This is a skill that is now very valuable to me and I will keep developing it in the future.

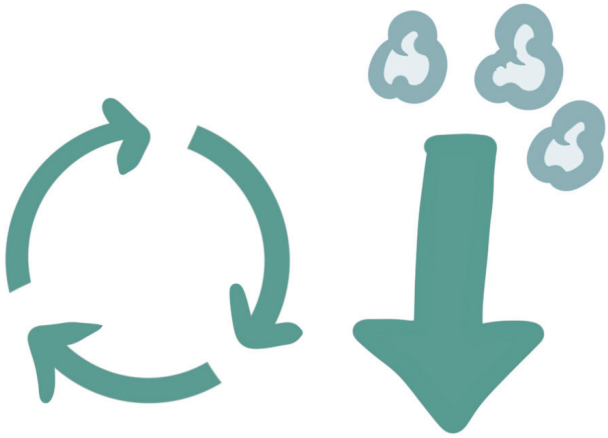
Another one that I mentioned in the project brief is 'Knowledge on design and production techniques of polymers and fabrics'. In this project, I learned to use the sewing machine and experienced what should be taken into account when designing with fabrics, for example the amount of stretch, the different material types and the finishing techniques. Furthermore, I found it very interesting to dive in the knitting production technique and visit the studio of a knitting expert. Which was good to know more about the subject for my project, but was also a fun experience now I had the chance.

The last is 'making substantiated choices + argument them'. During this project I learned about the Pyramid Principle and to ask the question Why? and How? instead of "What". This resulted in a project approach that next to the design of the headgear, was focuses on the LCA analyses, strategic and business model explorations and the roadmap. Whereby, the detailed design of app screens has a lower priority. Furthermore, I learned to apply these questions and the Pyramid Principles in the many presentations that I gave during this project, which became better and better over time. These presentations were among others; to communicate the results of the research to the different stakeholders, the midterm presentation, a small pitch before a creative session inside Philips, concept presentation for SRC and the final design presentation for SRC which was followed by an evaluation session.
These insights and experienced improved this skill, but I can still learn a lot. Making choices is still not my best skill and my perfectionism and ambitions can get in the way. For the future, I now know that helps to create matrices from the information, visualize the ideas and keep talking to different stakeholders for evaluation. This helps determining what is important and what is not. During this project I experienced that evaluating ideas and designs with different stakeholders keeps giving new insights and perspectives, and can help to find the right way when you have stared blind on a specific problem. Explaining my ideas to others and answering questions, has often made me see that I already knew more than I thought and often already knew the right direction.

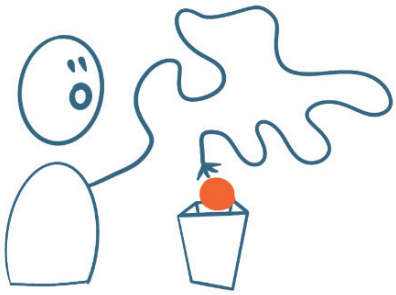
Now, I am just super proud that I learned so much during this project and got the chance to inspire people. I have done this project with great joy and a continuous curiosity to more knowledge. The process was not always easy, especially as I was recovering from my shoulder surgery, but hé: I made it!!

My vision on sustainable design

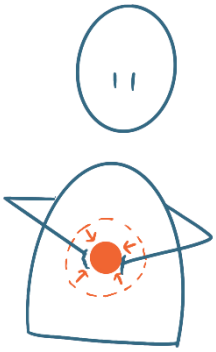
An ' holistic' design approach is needed to create truly sustainable products. A combination of circular design principles and eco design is needed. Therefore, the whole system needs to be taken into account. Circular design is not only about closing resource loops, but also about slowing them and efficient material use. While, Eco design helps to lower the environmental impact of a product or service by choosing the right materials and lower the impact of the total life cycle. To be able to define the best strategy for a circular proposition and sustainable solution, an iterative approach should be applied. Therefore, one Life Cycle Analysis means nothing; the LCAs should be used through the whole design phase to continuously evaluate options and design decisions.



"The final theme, 'whole system solutions', acknowledges the fact that surrounding every product or service there is an extremely complex, far-reaching system. Solutions cannot be designed in isolation, but rather need to be designed with the entire system in mind. The entire product lifecycle and all stakeholders need to be considered."
(Kuzmina et al, 2019)

Slowing  resource loops

Closing  resource loops

Material  efficiency

Lower CO2  emissions

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Appendices

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Confidential Appendices

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