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A Business Model-LCA of air purifiers

Comparing sales and rental business model in Sweden

Master's thesis in Industrial Ecology

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Abstract

This study investigates the potential of decoupling economic growth from environmental impact through innovative business models, using the case of an air purifier company. The company is exploring a rental model as an alternative to traditional sales, aiming to enhance sustainability by ensuring product longevity, increased recycling, and efficient resource use. The study compared the environmental performance of these two models using the Business Model Life Cycle Assessment (BM-LCA) methodology, which connects profitability with environmental impact.

Results showed that the rental model has a lower impact normalized per amount of generated profit, when compared to the sales model in almost all impact categories. For instance, there is a potential reduction of 10% for the rental compared to the sales model for the climate change impact. Also, the contribution of the air purifier's life cycle stages to various impact categories differs between the models. The product assembly has the larger contribution to almost all impact categories for the sales model, while for the rental model the filter assembly become more relevant. The reason for this is that the different models require different flows of air purifiers and filters to achieve the same profit margin.

A sensitivity analysis showed that a change of energy mix would have a large influence on the results, increasing the importance of energy efficiency measures if the rental service would expand into other markets than Sweden. The analysis also identified the subscription fee and technical lifetime of the purifier as factors that could influence the impact of the results.

To conclude, the study showed that a rental model can have an overall better environmental performance than a sales model while still providing the same profit for the company. Analysis based on the results revealed that the geographical location of the service, technical lifetime and subscription fee had great impact on the overall environmental impact. Recommended future work for the company would be to improve the lifetime of the filters, since they are the biggest contributing process to the environmental impact over time. The calculation model created for the comparison of the business models, can be used for an expanded sensitivity analysis where more parameters can be studied, e.g., the filter replacement rate or broadening the scope, assessing other markets outside of Sweden.

Keywords: BM-LCA, life cycle assessment, circular business models, consumption, sharing economy, product service system, environmental assessment of business models

CONTENT PAGES

| | |
|---|----|
| 1. Introduction | 1 |
| 1.1. The case: Comparing environmental performance of a sales and rental business model using BM-LCA..... | 1 |
| 1.2. The product: Air purifier | 2 |
| 1.3. Aim | 2 |
| 1.4. Limitations | 2 |
| 1.5. Research questions..... | 3 |
| 2. Background..... | 4 |
| 2.1. Sustainable Development Goals (SDG)..... | 4 |
| 2.2. Decoupling..... | 5 |
| 2.3. Circular economy..... | 5 |
| 2.4. Sustainable business models..... | 6 |
| 2.5. Product service system/Product as a service..... | 7 |
| 2.6. Life cycle assessment..... | 7 |
| 2.7. BM-LCA..... | 8 |
| 2.8. User behaviour | 8 |
| 2.9. Conclusion of background | 8 |
| 3. Method..... | 10 |
| 3.1. Literature review | 10 |
| 3.2. BM-LCA..... | 10 |
| 4. Results..... | 13 |
| 4.1. Goal and scope: Descriptive phase | 13 |
| 4.1.1. Linear model description | 14 |
| 4.1.2. Rental model description..... | 16 |
| 4.1.3. Impact categories..... | 18 |
| 4.2. Goal and scope: Coupling phase..... | 19 |
| 4.3. Material flow results..... | 25 |
| 4.4. Life cycle inventory | 26 |
| 4.4.1. Allocation | 29 |
| 4.5. Life cycle impact assessment | 29 |
| 5. Sensitivity analysis..... | 34 |
| 5.1. Product..... | 34 |
| 5.1.1. Changing product technical lifetime | 35 |
| 5.1.2. Changing material..... | 35 |
| 5.2. Economic..... | 36 |

| | | |
|--------|--|----|
| 5.2.1. | Changing rental price..... | 36 |
| 5.2.2. | Changing sales product price..... | 38 |
| 5.3. | Consumer behaviour | 38 |
| 5.3.1. | Changing sales % consumers buying new filters..... | 38 |
| 5.3.2. | Changing the energy mix | 39 |
| 6. | Discussion | 41 |
| 6.1. | Validity of results | 41 |
| 6.2. | Use of the results..... | 42 |
| 6.2.1. | Can a rental business model reduce environmental impact while maintaining economic performance compared to sales business model? | 42 |
| 6.2.2. | What are the economic and environmental hotspots in the different business models? | 42 |
| 6.2.3. | How could the circular business model be improved? | 43 |
| 6.3. | Improvements and future research | 43 |
| 6.3.1. | Improvements and future research for the project | 43 |
| 6.3.2. | Improvements and future research for BM-LCA | 45 |
| 7. | Conclusions | 46 |
| | Sources..... | 48 |

1. Introduction

This chapter introduces the reasoning for conducting this study along with the concepts and strategies it will touch upon and its goals.

During the last century the world population has quadrupled, and the global GDP has grown more than 20-fold (Krausmann et al., 2009). Since industrial metabolism is a major driver for environmental change (Krausmann et al., 2009) increased consumption has led to today's situation, with global warming and other serious environmental challenges. Decoupling has been proposed as a means to remove/reduce the link between economic growth and environmental impacts on a societal level (Böckin et al., 2022). However, to accomplish decoupling on a societal level, companies need to contribute to decoupling by providing not only more environmentally friendly product portfolios but also in their business models, meaning the way they offer their products. Böckin et al. (2022) pointed out the absence of tools to assess the connection between economic performance and environmental impacts in business models. To address this gap, they introduced the business model life cycle assessment (BM-LCA) methodology. The BMLCA methodology assists companies in evaluating their business models and could lead to finding ways to optimize them or change to completely different ones where profits could be sustained while decreasing their environmental impact.

1.1. The case: Comparing environmental performance of a sales and rental business model using BM-LCA

The case company has launched a pilot subscription model for its products that recently introduced some of the company's well-being products, including some of their air purifiers. These air purifiers are long lived but requires different filters depending on their use, and these filters needs to be replaced several times depending on the use. The pilot introduced a closed-loop, service-oriented business model that offers a subscription solution for consumers as an alternative to the traditional linear sales model, where consumers buy their products of the shelf. For a monthly subscription cost, the air purifier is transported to the consumer with a requested filter, a new requested filter is then sent each year. If the product requires repairs the product will be sent to the in-house repair service, which uses mostly harvested parts from previous defect products and then returned to the consumer. If the consumers choose to end the subscription the products are returned to the company and refurbished, then the product can be offered for a reduced subscription cost to another consumer. Hence, increasing the utilisation of the air purifier. When the product is rendered defect beyond repair, it is harvested for usable parts and then sent for recycling.

The pilot rental business model aims to decouple economic performance from environmental impact compared to their traditional linear sales business model. It aims to do this by applying circular business strategies such as reducing the number of products required to achieve a set profit, reusing products and parts and refurbishing used products so they can be used by more users.

1.2. The product: Air purifier

The product in focus of this project is an air purifier. The goal of an air purifier is to improve indoor air quality and to do so several air purification methods can be used. The most common one is HEPA-filters which is great to capture larger particles and allergens. Another method is activated carbon filters which are mainly used to remove odors and smaller particles. Lastly, ionization which sends out charge ions to attach to particles and make them fall to surfaces. All these methods have different benefits and are often applied to perform a specific task. The product studied in this report uses a combination of a HEPA filter, activated carbon filter and ionization to fulfill several tasks.

To put it simple, the product uses a fan and other electronics to move air through the filter. Hence, trapping captured particles in the filter and letting purified air back into the room. However, over time the filter gets filled up with captured particles which will affect the performance of the purification. Therefore, the filter regularly must be replaced, and the used filter be discarded.

1.3. Aim

In this report a comparison will be made on how the climate impact of an air purifier might depend on the business model that is applied. The two business models that will be compared are a rental and sales models. The rental model is a circular model through renting and the provider has the ownership of the product throughout the product lifetime. The sales model is a traditional linear model where the consumer gets ownership of the product. This comparison will be conducted with a BMLCA and the assessment will be cradle-to-grave. The purpose of this analysis is to compare and see how environmental performance differs and how the results change for different scenarios by doing a sensitivity analysis.

1.4. Limitations

The study will only be concerning the two previously mentioned business models for the product. The study also had to be limited into looking at a sales model were the company producing the product also sells it to the consumer by a web store, however the selling part of the company buys it from the producing part, hence, the producing part will be considered a supplier. The reason for this is that we have access to better data and can avoid some confidential data, such as the profit margin the producing company puts on its product for retail stores.

1.5. Research questions

- Can a rental business model reduce environmental impact while maintaining economic performance compared to a sales business model?
- What are the economic and environmental hotspots in the different business models?
- How could the circular business model be improved?

2. Background

Our planet stands before major challenges in the future. One of the most prominent challenges is the one facing the environment. Global warming and littering are two problems that can be linked to unsustainable consumption. As an answer to the issue of unsustainable consumption, methods such as circular economy has blossomed. Circular economy focuses on closing the loop between resources and consumption, returning the resource into the economy after consumption. By using means such as reuse, remanufacture, repurpose, recycling etc. Hence, it's possible to decouple increased demand and resource use. To calculate the environmental impact of a product, the life cycle assessment (LCA) method is often used. However, a conventional LCA, is not directly applicable to compare the environmental impacts of business models and instead focuses on comparing products. However, to assess the environmental impact of business models, a BMLCA could be used. By doing a BMLCA the environmental performance of fundamentally different business models could be assessed and improvements be found.

2.1. Sustainable Development Goals (SDG)

The United Nations (UN) has listed 17 goals for sustainable development that world leaders have agreed to achieve by the year 2030. Some of these will directly be linked to this project and the ones in question are:

- SDG 3 – Good health and well-being
- SDG 12 – Responsible consumption and production
- SDG 13 - Climate action

SDG 3 describes goals for health improvements, one of which calls for significant reductions of deaths and illnesses linked to chemicals and air, water and soil pollution and contamination (UN, 2024). The production of new electronic products contributes to more electronic waste which customers potentially could dispose of in nature and therefore contributes to pollution to the afore-mentioned areas in nature. Lead is one of the common substances emanating from e-waste, polluting, and causing harm to living creatures (WHO, 2023). If the numbers of units produced and sold can be reduced while still meeting customer needs, less e-waste will be able to cause pollution and illnesses. Air purifiers with bacterial filters, PECO-process or traditional UV-light can also help mitigate the spread of diseases in homes and workplaces through their ability to eliminate air born viruses (Acharya et al., 2023). This could aid in slowing the spread of e.g. pandemics and viral diseases (Clarke et al., 2023).

SDG 12 has several sub goals that, among others, describe a desire to establish efficient use of natural resources, reduce waste generation and to encourage more companies to adopt sustainable business practices (UN, 2024). This report will investigate the use of a rental program for an air purifier compared to a traditional sales model and what environmental benefits a closed loop system (e.g. rental program) will bring. The use of the

rental model should reduce the total number of produced units compared to a sales model and therefore help achieve a more efficient use of natural resources. The nature of the closed loop system will also lead to higher recycling rates since the renting company can ensure most units reach recycling facilities instead of being wrongly discarded (Ragossnig & Schneider, 2019).

SDG 13 highlights the importance of environmental action on all levels of society, meaning both large companies to each individual. Having the circular business model of a rental program enables both the company and each customer to choose a more sustainable way of interacting with products.

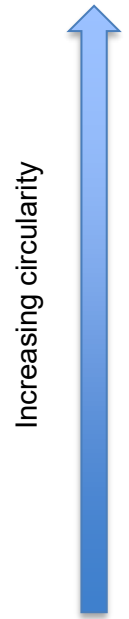
2.2. Decoupling

Decoupling has been identified as a critical concept in the realm of sustainability (UNEP, 2011). It refers to the ultimate effort of separating or disconnecting economic growth from the harmful environmental impacts traditionally associated with them (UNEP, 2011). Decoupling strives towards the scenario where economic development can continue to occur without increasing resource consumption and pollution (UNEP, 2011). To achieve decoupling, behaviours in consumption and manufacturing must change by introducing circular economy models and using more sustainable energy etc. (Tere Vadén et al., 2020).

2.3. Circular economy

A Circular Economy is a system that view products, materials and even waste as a resource. It focuses on closing the loop and reducing the amount of materials that ends up in landfills along with increasing the efficiency of the products, making better use of what we have (Ragossnig & Schneider, 2019). To achieve a Circular Economy the 4R framework was developed which focuses on the principles of “Reduce”, “Reuse”, “Recycle” and “Recover” (Kirchherr et al., 2017). Since then, further expansion of the framework has been proposed. Such as the 9R framework seen in Table 1.

Table 1 – The 9R framework, adapted from (Potting et al., 2017).

| Circular economy | Strategies | | |
|---|--|---|--|
|  Increasing circularity | Smarter product use and manufacture | R0: Refuse | Make product redundant by abandoning its function or by offering the same function with radically different product. |
| | | R1: Rethink | Make product use more intensive (e.g. sharing) |
| | | R2: Reduce | Increase efficiency in product manufacture or use by consuming fewer natural resources and material. |
| | Extended lifespan of product and its parts | R3: Re-use | Reuse by another consumer of discarded product which is still in good condition and fulfils its original function. |
| | | R4: Repair | Repair and maintenance of defective product so it can be used with its original function |
| | | R5: Refurbish | Restore an old product and bring it up to date |
| | | R6: Remanufacture | Use parts of discarded product in a new product with the same function |
| | Useful application of materials | R7: Repurpose | Use discarded product or its parts in a new product with a different function |
| | | R8: Recycle | Process materials to obtain the same (high grade) or lower (low grade) quality |
| Linear economy | R9: Recover | Incineration of material with energy recovery | |

The 9R framework expands the framework introducing more radical principles such as “Refuse” which questions the necessity of the product. It also incorporates a circularity axis, where the system gets increasingly circular.

2.4. Sustainable business models

Sustainable business models are approaches to conducting business that prioritize environmental, social, and economic sustainability (Bocken, 2023). These models aim to meet the needs of the present without compromising the ability of future generations to meet their own needs (IISD, 2023). Sustainable business models often follow the triple bottom line framework that builds on the principles of profit, people, and the planet (HBSO, 2020). As opposed to the single bottom line referring to only focusing on generating profit. Some key features and examples of sustainable business models are green and clean technologies, ethical sourcing and supply chains, circular economy practises, stakeholder engagement, sharing economy and product-service systems. Sustainable business models are not only driven by a sense of responsibility but are increasingly recognized as essential for long-term business success. Adopting sustainable practices can lead to several advantages for a company such as enhanced brand reputation, competitive edge on the market, cost savings and employee engagement (Lindgardt et al., 2015).

2.5. Product service system/Product as a service

A product-service system (PSS), also known as Product as a service (PaaS), is a business model that shifts the focus from selling physical products to providing a package deal for the customer including product and service. In this model, instead of selling products outright, companies offer a service-oriented solution where customers pay for the utility, functionality, or performance of a product without necessarily owning it (Moro et al., 2022). This business model aims at creating profitability and competitiveness while also contributing to sustainability (Bocken et al., 2014). A PSS is often based on a subscription or a usage-based pricing for the ownership/use. By offering a product through one of these payment options, the risk and responsibility of the performance of the product is transferred from the customer to the service provider. It also encourages the service provider to implement continuous improvement to ensure customer satisfaction and competitiveness.

PSSs can be categorized into three main types (Tukker, 2004). *Product-oriented*, *use-oriented*, and *result-oriented*. In the first category *product-oriented*, the focus of the BM is aimed towards the sales of products but with some extra services. In the *use-oriented* category, the provider stays in ownership of the product and either offers the service of the product as a *lease*, *subscription*, *renting* or *pooling*. These services differ mainly in the length of the contract, where *renting* usually has a contract length of a few hours to 3 months, *subscription* from 3 months to 24 months and *lease* from 24 months up to a few years. Pooling can differ more since more consumers have access to the product but here the contracts are usually short, such as a few hours. In the *result-oriented* category, the provider and client agree on a result that should be met and there is no direct focus on the product itself, this could be a *pay per service* offer.

PSSs aligns with the idea of circular economy where resources are used more efficiently, and waste is minimized. This happens when the companies renting out the products, extend their life span through continuous repairs and services which in turn can yield more uses per product compared to normal linear sales plan where the customer is the owner of the product (Evans et al., 2017).

2.6. Life cycle assessment

Life cycle assessment (LCA) is a methodology defined by ISO 14040 and 14044 standards and is used to analyse environmental impacts of products (Klöpffer, 2014). In the assessment the product is analysed with a life cycle perspective. Furthermore, there are two main ideas of scope for a LCA, with the main idea being the *cradle-to-grave* model. There the product and its subsequent emissions are analysed from the cradle, meaning the raw material extraction phase to the grave, meaning the product ending up on a landfill or disposed of. The other idea being the *cradle-to-gate* model. This assessment incorporates a partial product life cycle, analysing the subsequent emissions from raw material extraction to the product leaving the factory gate.

2.7. BM-LCA

A “business model life cycle assessment” refers to the concept of evaluating the environmental performance of different business models, as opposed to a “life cycle assessment” where the goal is to evaluate the environmental performance of a product system (Böckin et al., 2022). The Business Model Life Cycle Assessment (BMLCA) distinguishes itself from a typical LCA primarily through the definition of the functional unit. In contrast to the conventional LCA, where the functional unit is typically defined to facilitate comparisons between product systems based on their function, the BMLCA's functional unit is tied to the financial aspect of a business model, specifically, the profit generated by the business model. Consequently, the BMLCA's functional unit provides a connection between the profitability of a business model and the associated environmental performance, a departure from the conventional LCA approach where considerations of profit are often overlooked (Goffetti et al., 2022).

2.8. User behaviour

User behaviour can significantly affect the environmental performance a product system, an example of this could be the use-phase of an appliance that consumes electricity. Depending on how the consumer uses the product the energy consumption may vary. The user behaviour also affects a product-service system (PSS) in several ways. Changes in consumer behaviour presents a challenge when designing sustainable products and services, this can be seen in the *Rebound effect* which is a well-documented phenomena where consumers increase their total usage of a product when the energy efficiency/consumption goes down. Hence, sometimes increasing their environmental impact due to behavioural changes (Greening et al., 2000). In a similar way changes in consumer behaviour can be seen as a risk when implementing a PaaS, since consumers might not be as careful with rented products compared to products, they themselves own, lowering the lifetime of the product.

2.9. Conclusion of background

As mentioned previously, there is a large virgin resource usage linked to product consumption worldwide. This has led to a desire for economic decoupling which refers to a continued economic growth that doesn't entail an equal material resource use. This decoupling can be achieved by implementing circular economy strategies.

The 9R framework has been developed to highlight and give an overview of those linked to circular economy. Some of these are reuse, remanufacturing, and recycling. The high resource usage and emissions linked to production and transports have also called for more sustainable business models. These are often based on the triple bottom line framework that builds on the principles of profit, people, and the planet.

Examples of sustainable business models are circular economy, sharing economy and product-service systems. PSS/PaaS are business models that let a customer use a product without necessarily owning it outright. Instead, they e.g. rent the product and therefore each product could potentially see more use per person and therefore lead to less produced units while still providing revenues for the companies. PSSs aligns with the idea of circular economy where resources are used more efficiently, and waste is minimized.

To compare a PSS with a traditional sales model from an environmental performance standpoint, a method called BMLCA is a suitable choice. While LCA is an excellent tool for analysing product systems, it is outside of a conventional LCA's scope to directly compare business models. This spawned the concept of BMLCA, which uses an economical functional unit as opposed to a functional unit based on the function of a product system as is done in an LCA. The purpose of this report will be to evaluate two different business models related to selling an air purifier by using the BMLCA methodology.

3. Method

In this chapter an overview of the methodology applied in the project is presented in *Figure 1*. The specific methods are then described in further detail in each section.

The BM-LCA method is applied through a comparative case study of two business models used in the case company. The BM-LCA results aims to answer the first research question, the second and third research questions are then answered by conducting and reviewing the results from a sensitivity analysis.

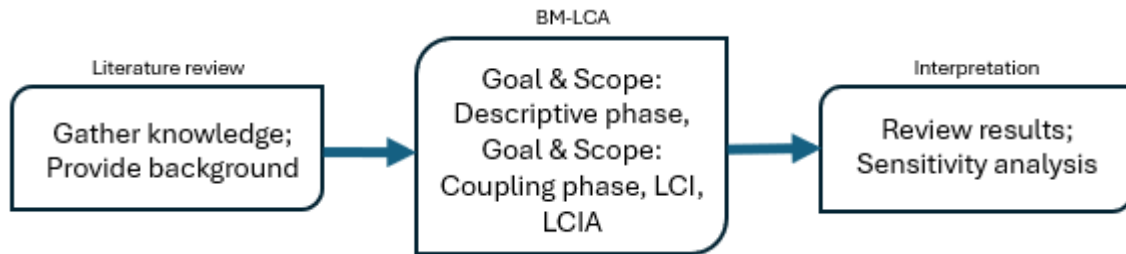


Figure 1 – Descriptive overview of the applied methodology.

3.1. Literature review

To get an insight on the current available information on performing environmental assessments on business models, a literature review was performed. This review provided familiarity to the relevant theories and knowledge within the subjects related to this study which are listed below. The information gathered from the literature review provided the background for the project. Searches were performed on Chalmers lib, Google Scholar, Scencedirect as well as Web of Science. Using keywords such as BM-LCA, LCA, LCC, Product level LCA, organizational LCA and consumer LCA, different search strings could be created. With a “building blocks approach”, search strings could be created, based on keywords with Boolean, proximity-operators. Multiple search strings were crated, and the following categories were reviewed and published literature were gathered:

- Decoupling
- Circular economy
- Sustainable business models
- Product as a Service (PaaS)
- Life Cycle Assessment (LCA)
- Business Model Life Cycle Assessment (BM-LCA)
- User behaviour

3.2. BM-LCA

The methodology used in the assessment were based on the article “Business model life cycle assessment: A method for analysing the environmental performance of business” by

Böckin et al. (2022). The steps of the method presented in Böckins article are presented in *Table 2*.

Table 2 – Step-by-step description of Business Model Life Cycle Assessment Methodology.

| Phase | Description |
|-----------------------------------|---|
| Goal and Scope: Descriptive phase | <p>Step 1: Detail the business models and describe them in relation to the product systems using actor analysis. Identify and connect cost and revenue streams for these actors (in and outside the company). This simplifies the identification of relevant economic parameters later. Also state a time period from where to get data.</p> |
| | <p>Step 2: Define system boundaries and the impact categories that will be studied.</p> |
| Goal and Scope: Coupling phase | <p>Step 3: Define the connection between transactions, t, and production, q, for each business model. Then determine the Functional Unit as the profit level, π, that will act as target for both business models.</p> |
| | <p>Step 4: From the actor analysis, identify costs and revenue streams for each business model. Find coupling equations, relationships between q and t so costs and revenues can be expressed with transactions, t. Set up an equation for the Functional Unit (profit), π, as revenues – costs:</p> $\pi = \sum Revenues_r * t_r - \sum Costs_r * t_r$ |
| | <p>Step 5: Solve the equation and find the transactions, t_r needed to reach the Functional Unit. From t_r, derive the required production, q_r. Do this for both business models.</p> |

| | |
|------------------------------|---|
| Life Cycle Inventory | Construct flow model, collect data for flows e.g. (raw materials, emissions, waste, recycled goods). Calculate product flows and scale to Functional Unit. |
| Life Cycle Impact Assessment | Translates the LCI data to environmental impact categories using emission factors. |
| Interpretation | Analyse the results from the LCIA and test the calculations sensitivity by conducting a sensitivity analysis. Perform Environmental Hotspot identification. |

4. Results

In this chapter the results of the various parts of the BM-LCA will be presented. Firstly, the goal and scope, where the descriptive and coupling phases are described. Then moving on to the life cycle inventory where data from a previous product LCA conducted by the company will be used, this data are then connected to all material flows and will be presented. Thereafter, the life cycle impact assessment will be presented, where the environmental impacts will be calculated. Finally, an interpretation of the results including a sensitivity analysis will be presented, to find sensitive variables and environmental hotspots in the system.

In the BMLCA analysis, the functional unit of 1 500 000 SEK over a time period of three years will be used for both the rental and sales model. This was decided through dialog with the company and is used as a basis for the analysis.

4.1. Goal and scope: Descriptive phase

In this chapter the business models will be detailed and described in relation to the product systems using actor analysis. The business models will be presented with flowcharts where all cost (Cx) and revenue streams (Rx) between processes (in and outside the company) are mapped, see *Figure 2* and *Figure 3*. All processes will also be described in further detail, to get an understanding of the system.

In both cases the product is produced in China where the production of the air purifier takes place. All the suppliers of raw materials needed for the product are also located in China and the transports of raw materials are done by lorry. It is the same scenario for the filter production. From China the products and filters meant for the European market are sent by ship to Poland and then the products and filters meant for the Nordic market are sent by lorry to Mariestad Sweden. All the costs associated with the product from production to the transport to Mariestad are summed up in the product and filter procurement costs, see *Figure 2* and *Figure 3*. From there the product flow differs between the two cases, which are presented in the sections below.

The same product is used in both business models. It is an air purifier from the company, it uses a HEPA filter to purify the air. The service offers four different types of HEPA filters that specialises on different tasks, such as capturing pollen, bacteria, or odours. The lifetime of the filters varies depending on their compositions. In the sales model, one filter is included in the purchase and more can be purchased separately such as the filters for different use cases. For the rental model, 1-2 filters are included during each year of rental.

4.1.1. Linear model description

The linear model (Direct to customer, DTC) differentiates itself from the rental model once the air purifiers have reached the central warehouse in Sweden. In the sales model the products are shipped directly to customers from the central warehouse. In *Figure 2* below, the flowchart of the costs and revenues linked to the sales model, are displayed. The first blue box, named “Central warehouse”, is the main storage location of the air purifier and filters for the company in Sweden. From here, products are sent both to retailers and to customers that have purchased the air purifier from the company’s webstore. As stated in the chapter “Limitations”, retail stores were excluded from the analysis which is why only the central warehouse is visible in the flowchart since it includes the webstore. Products bought from the webstore are then transported to customers and enter the “Use” box. From the “Use” box there are then arrows to transport that leads to “Repair service” and then the end-of-life processes “Recycling purifier” and “Incineration purifier”. The repair service handles mainly warranty repairs of the air purifier. When the air purifier is ready to be disposed of by the customer it will most likely be either recycled or incinerated.

The costs in the flowchart are marked as “C” and mainly follows the material flows. From the two production facilities there are costs called “product procurement costs” which represents the costs of producing the air purifier and the filter (C1, C2) and all other costs before the products get to the warehouse, including transportation there. There is then a cost in “Central warehouse” marked as C3, which represents the total cost of the storage in the central warehouse. The central warehouse also contains an admin cost marked as C4. When a customer places an order in the company’s webstore, a revenue is created for the air purifier and a potential revenue for extra filters (R1, R2). These are marked in the flow chart as exiting from the “Use” box and then entering the company system marked in blue. There are also two costs called C5 and C6 which are the costs of distribution of the air purifier and extra filters to customers. The costs C7 and C8 are linked to the repair service since they correspond to the costs of spare parts and the labour linked to the repairs. C9 is the cost of transporting the warranty claimed products. Finally, C10 is the cost of having the air purifier recycled at an electronics waste facility, which is covered by producing company for each air purifier they produce, due to producer responsibility.

In the sales flowchart, q_s and q_{fs} refers to the product flows of the air purifier and filter. The number of sales transactions during a set period T is marked as t_s .

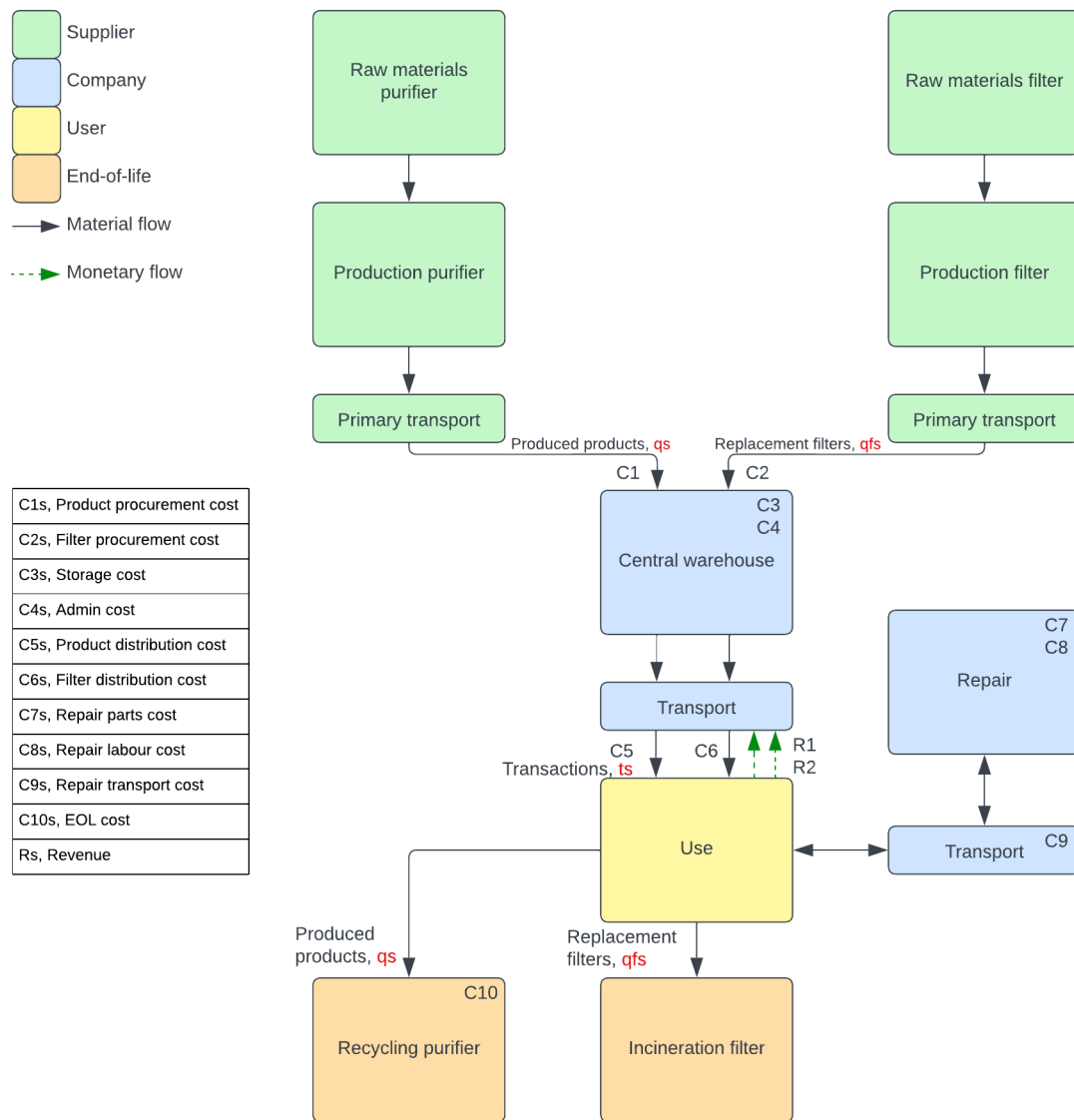


Figure 2 – Flowchart of the linear sales model.

During the creation of both the flowchart for the sales and rental model, a couple of assumptions and clarifications were made:

- There should be a transport cost from warehouse to repair service for spare parts etc. However, these costs will not be accounted for since we believe the allocated cost to be insignificant due to batch deliveries.
- Transports between production and warehouse is accounted for in the procurement cost for both products and filters. Therefore, there is not extra transport cost in that flow.
- There is a small flow of defect products into the repair service, which is estimated, and all defects are considered a cost for the company and will be repaired, which includes a cost for spare parts, but also labour cost.

- The transport to the repair service (C9) will only be a cost for those products that are mailed there. Since some of the defect products comes into service shops by the consumers themselves, this will not be a cost for all defects.

4.1.2. Rental model description

The flowchart of the rental model, as shown in *Figure 3* below, contains the same first steps as the sales model which is the production of the filters and the air purifier along with transport to the central warehouse. However, in this model the “central warehouse storage” was put outside the company system boundary since the rental model uses its own “PaaS storage” and is therefore of higher interest when analysing the rental model. From the “PaaS storage” there are product flows to both a “Refurbishment” service and a “Repair” service. There is also a flow to the process “Recycling purifier” since the company has full control of the air purifier unit and can either send all of them to recycling or use some for spare parts which they currently do. From the “PaaS storage” there is a product flow to the customers in the “Use”-phase. From this phase there is also a flow to “Incineration filter” since the customers are free to do as they please with the old filters they accumulate during their use of the air purifier. So, there is a chance they discard them at a waste collection station where the filters most likely will become incinerated.

C1, C2 and C4 represent the costs of both productions along with a warehouse transport cost. C3 is the “storage buildup cost” which represents the cost of continuously paying off the build-up of inventory. From the “PaaS storage” there is a value and product exchange in the form of “Refurbishment” service and “Repair” service. The three costs associated with these services are C9, C10 and C11, which also include the cost of spare parts. The “PaaS warehouse storage” has two costs on its own which are a storage cost and a credit check cost emanating from new rentals (C5 and C6). The flows between the “PaaS storage” and the customers in the “Use”-phase are the distribution costs and the revenue from the rental transactions (C7, C8, Rr). The final cost C12, covers the cost of recycling the air purifier.

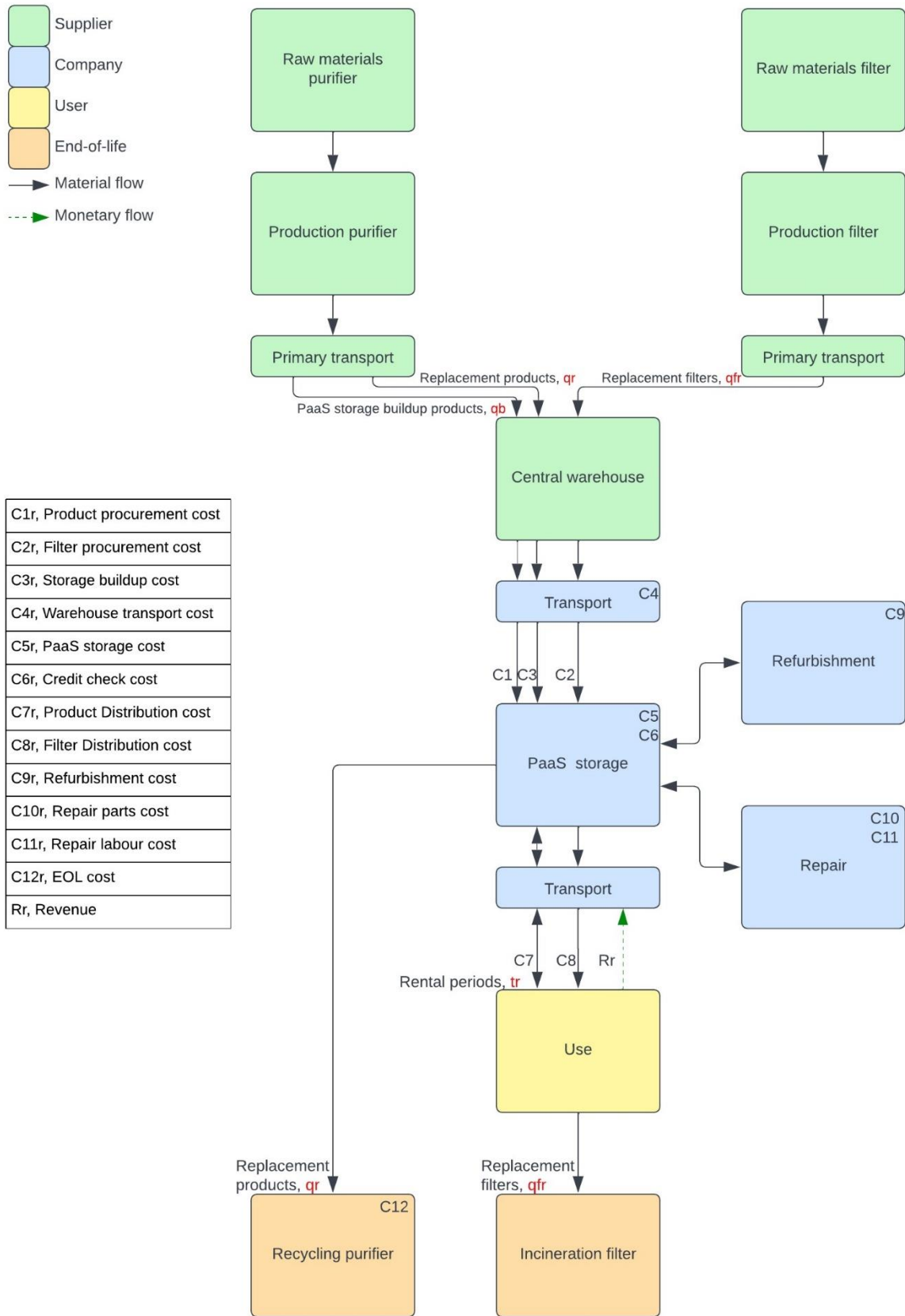


Figure 3 - Flowchart of the Circular rental model.

During the creation of the flowchart for the rental model, a couple of assumptions and clarifications were made:

- There should be a transport cost from warehouse to repair service for spare parts etc. However, these costs will not be accounted for since we believe the allocated cost to be insignificant due to batch deliveries.
- Transports between production and central warehouse is accounted for in the procurement cost for both products and filters. Therefore, there is no extra transport cost in that flow.
- There are distribution costs for the products being transported to and from consumers and the PaaS warehouse, these are accounted for, and the number of transports depend on the rental periods and number of filters being sent during the rental periods.
- At the end of all rental periods, the products need to be refurbished and prepared for new consumers, this cost is associated with a cost for the refurbishment and is accounted for.
- Some rental products will be defective, and these are accounted for by using a Defect rate which represents the percentage of products in circulation that gets a defect during the time period T
- It is assumed that there is no need to pay for storage for all the products in circulation for the rental model. Instead, there is a rental efficiency factor (Q_r) that says that during a stable rental period, Q_r % products are being rented at any given time, that leaves $(1-Q_r)$ products in storage at any given time. This amount is used for the storage cost.

4.1.3. Impact categories

The impact categories for this study are the ones calculated in the ReCiPe 2016 v1.03, midpoint (H). The result of these impact categories will be studied in the project and later analysed. However, only the impact categories with the biggest impacts will be studied in more detail. A previous LCA study had been conducted by the company. Due to implications with the use of different life cycle assessment databases between the school and the company, other categories were chosen for this project which are listed in *Table 3* below.

Table 3 – Environmental indicators (impact categories) chosen for this project.

| Environmental indicators | Unit | Method |
|---|------------------------|---------------------------------|
| Acidification: terrestrial | kg SO ₂ -Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Climate change | kg CO ₂ -Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Ecotoxicity: freshwater | kg 1,4-DCB-Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Ecotoxicity: marine | kg 1,4-DCB-Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Ecotoxicity: terrestrial | kg 1,4-DCB-Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Energy resources: non-renewable, fossil | kg oil-Eq | ReCiPe 2016 v1.03, midpoint (H) |

| | | |
|---|---------------------------|--|
| Eutrophication: freshwater | kg P-Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Eutrophication: marine | kg N-Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Human toxicity: carcinogenic | kg 1,4-DCB-Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Human toxicity: non-carcinogenic | kg 1,4-DCB-Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Ionising radiation | kBq Co-60-Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Land use | m ² *a crop-Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Material resources: metals/minerals | kg Cu-Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Ozone depletion | kg CFC-11-Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Particulate matter formation | kg PM2.5-Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Photochemical oxidant formation: human health | kg NOx-Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Photochemical oxidant formation: terrestrial ecosystems | kg NOx-Eq | ReCiPe 2016 v1.03, midpoint (H) |
| Water use | m ³ | ReCiPe 2016 v1.03, midpoint (H) |
| Waste mass, total, placed in landfill | kg | ReCiPe 2016 v1.03, midpoint (H) - Inventory data |

4.2. Goal and scope: Coupling phase

In this chapter, the previously mentioned monetary and material flows gets connected through coupling equations, presented in Table 5,

Table 6 and Table 7. The BMLCA method is based on using a profit level as the functional unit. By first calculating the profit level for the sales model π_s , the functional unit is calculated by:

$$\text{Profit level } \pi = \text{Revenue} - \sum \text{Costs}$$

When the same profit level has been set for both the rental model and the sales model, the number of rental transactions needed to fulfil the same revenue as the sales model, can be calculated.

Table 4 – Table showing the variables used in the coupling equations.

| Symbol | Description | Unit |
|--------|---------------|-------------|
| T | Time period | Months |
| k1s | Purifier cost | SEK/product |
| k2s | Filter cost | SEK/product |
| k3s | Storage cost | SEK/product |

| | | |
|-------|---|-------------------|
| k4s | Admin cost | SEK/product |
| k5s | Distribution cost | SEK/transport |
| k6s | Repair parts cost | SEK/transport |
| k7s | Repair labour cost | SEK/repair |
| k8s | Repair transport cost | SEK/repair |
| k9s | Weeee cost | SEK/transport |
| r1 | Revenue from selling a product | SEK/product |
| r2 | Revenue from selling a filter | SEK/product |
| k1r | Product production cost | SEK/product |
| k2r | Filter production cost | SEK/product |
| k3r | Warehouse transport cost | SEK/product |
| k4r | Storage cost | SEK/product |
| k5r | Credit check cost | SEK/Transaction |
| k6r | Distribution cost | SEK/transport |
| k7r | Refurbishment Cost | SEK/refurbishment |
| k8r | Repair parts cost | SEK/repair |
| k9r | Repair labour cost | SEK/repair |
| k10r | Weeee cost | SEK/product |
| r3 | Revenue from subscription | SEK/month |
| ts | Sales transactions during T | Transactions |
| tr | Nr of rental periods during T | Transactions |
| qr | Number of products produced for the rental model during T | Products |
| qs | Number of products produced for the sales model during T | Products |
| qf | Replacement filters | Products |
| f1 | % of consumers that buys spare filter | % |
| f2 | Customer hand-in/shipping to service point | % |
| Dr=Ds | Defect rate | % |
| Qs | Storage ratio | % |
| Qr | Rental efficiency | % |
| Q | Number of products in circulation | Products |
| Ur | Average rental period | Months |
| Rr | Average rate of replacement during T | % |
| fr | Filter replacement rate | Months |
| NUr1 | Share of 1 Rental period per costumer | % rental periods |
| NUr2 | Share of 2 Rental period per costumer | % rental periods |
| NUr3 | Share of 3 Rental period per costumer | % rental periods |
| Yb | Months to reach storage buildup | Months |
| Π | Profit during T | SEK/T |

Below in *Table 5* and

Table 6, the costs and revenues for both business models are presented, in the first column the cost/revenue name can be seen, in the second column the cost in connection with either transactions tr/ts or products produced qr/qs are presented, finally in the third column the same connection is presented in equation form using variables defined in *Table 4*.

Table 5 – Table showing the costs and revenues for the sales model, EOL - (End-of-life).

| <u>Revenues and costs - Sales model - DTC</u> | | |
|---|---|------------------------------------|
| Revenue or cost category | Connection to rental transactions or products produced | Connection in equation form |
| $C1_s$, Product procurement cost | Purifier cost SEK/product * number of products produced during time period T | $k1s * qs$ |
| $C2_s$, Filter procurement cost | Filter cost SEK/product * (number of products produced during time period T * number of replacement filters produced during time period T) | $k2s * (qs * qfs)$ |
| $C3_s$, Storage cost | Storage SEK/product * number of products produced during time period T * Storage ratio | $k3s * qs * Qs$ |
| $C4_s$, Admin cost | Admin cost SEK/product * number of products produced during time period T | $k4s * qs$ |
| $C5_s$, Product Distribution cost | Transport cost SEK/product * number of products produced during time period | $k5s * qs$ |
| $C6_s$, Filter Distribution cost | Transport cost SEK/product * number of replacement filters produced during time period T | $k5s * qfs$ |
| $C7_s$, Repair parts cost | Repair parts cost SEK/product * number of products produced during time period T * defect rate | $k6s * qs * Ds$ |
| $C8_s$, Repair labour cost | Repair labour cost SEK/product * number of products produced during time period T * defect rate | $k7s * qs * Ds$ |
| $C9_s$, Repair transport cost | Transport cost SEK/product * number of products produced during time period T * defect rate * customer hand-in/shipping to service point | $k8s * qs * Ds * f2$ |
| $C10_s$, EOL cost | Weee cost SEK/product * number of products produced during time period T | $k9s * qs$ |
| R_s , Revenue | (Product price SEK/product * number of products produced during time period T + Filter price SEK/product * number of replacement filters produced during time period T) | $(r1 * qs + r2 * qfs)$ |
| π_s | Profit level | Revenue- \sum Costs |

Equation 1 – Calculation of profit level for the sales model.

$$\pi_s = R_s - (C1_s + C2_s + C3_s + C4_s + C5_s + C6_s + C7_s + C8_s + C9_s + C10_s)$$

Table 6 – Table showing the costs and revenues for the rental model.

| <u>Revenues and costs - Rental model</u> | | |
|--|--|------------------------------------|
| Revenue or cost category | Connection to rental transactions or products produced | Connection in equation form |
| $C1_r$, Product procurement cost | Purifier cost SEK/product * (number of products produced during time period T) | $k1r * qr$ |

| | | |
|------------------------------------|--|---|
| $C2_r$, Filter procurement cost | Filter cost SEK/product * (number of replacement filters produced during time period T) | $k2r * qfr$ |
| $C3_r$, Storage buildup cost | Purifier cost SEK/product * Storage buildup amount) | $k1r * qb$ |
| $C4_r$, Warehouse transport cost | Warehouse transport cost SEK/product * (number of products produced during time period T + storage buildup amount + 0,45 * number of replacement filters produced during time period T) | $k3r * (qr + qb + 0,45qfr)$ |
| $C5_r$, PaaS storage cost | Storage SEK/product * Products required by BM * (1 - Rental efficiency) | $k4r * Q * (1 - Qr)$ |
| $C6_r$, Credit check costs | Credit check costs SEK/transaction * number of rental periods during time period T | $k5r * tr$ |
| $C7_r$, Product distribution cost | Transport cost SEK/product * 2 * Number of rental periods * (Share of consumers renting 1 period + Share of consumers renting 2 periods + Share of consumers renting 3 periods) | $k6r * 2 * tr * (NUR_1 + \frac{NUR_2}{2} + \frac{NUR_3}{3})$ |
| $C8_r$, Filter distribution cost | Transport cost SEK/product * Number of rental periods * (Share of consumers renting 2 periods * allocation towards T + Share of consumers renting 3 periods * allocation towards T) * Number of filters per renting period | $k6r * tr * \left(NUR_2 * \frac{T}{4Ur} + 2 * NUR_3 * \frac{T}{6Ur} \right) * \frac{Ur}{fr}$ |
| $C9_r$, Refurbishment cost | Refurbishment cost * Number of rental periods * (Share of consumers renting 1 period * allocation towards T + Share of consumers renting 2 periods * allocation towards T + Share of consumers renting 3 periods * allocation towards T) | $k7r * tr * \left(NUR_1 * \frac{T}{2Ur} + NUR_2 * \frac{T}{4Ur} + NUR_3 * \frac{T}{6Ur} \right)$ |
| $C10_r$, Repair parts cost | Repair parts cost SEK/product * Products required by BM * defect rate * (1 - Reused parts %) | $k8r * Q * Dr * (1 - Rp)$ |
| 11, Repair labour cost | Repair labour cost SEK/product * products required by BM * defect rate | $k9r * Q * Dr$ |
| $C12_r$, EOL cost | Weee cost * (number of products produced during time period T + storage buildup amount) | $k10r * (qr + qb)$ |
| R_r , Revenue | Subscription cost SEK/month * number of rental periods during time period T * Average rental period | $r3 * tr * Ur$ |
| π_r | Profit level | Revenue- \sum Costs |

Since the BM-LCA framework uses the profit level π as the functional unit, the profit level for the rental model π_r needs to be equal to the profit level for the sales model π_s .

Equation 2 – Defines the profit levels of both business model as equal.

$$\pi_r = \pi_s$$

The next step is to calculate t_r and q_r . However, since the equations for the rental model in *Table 6* depends on both t_r and q_r which are unknown, they need to be rewritten with the help of Equation 3 and Equation 4, presented below. This produces the equations presented in *Table 7* below, where q_r has been replaced with expressions containing t_r , which in turn led to one less unknown factor and made the system solvable.

There is a need to describe the number of products constantly in circulation between repairs, warehouse and rental customers, this total amount of product flow can be named “Q”. There will also be an amount of products that need to be added each time period T to the product flow since there will be products that need to be replaced as a result of e.g. irreparable damage. This number of products can be described as “ q_r ”. To calculate q_r , there is a need to know what portion of the Q-stock that need to be replaced, this is called “ R_r ”, replacement rate (%). So, to calculate q_r , Q can be multiplied with R_r , as shown in Equation 4. This is the first part of Equation 4 and gives the number of products that need to be replaced each time period T to keep up the stock needed to fulfil the rental transactions. The replacement rate has been estimated with the help of the company.

The next part of Equation 4, also equates to q_r , but is based on t_r as shown in Equation 3. As previously explained, this will help in solving the coupling equation system since expressions of q_r will be replaced with ones containing t_r and therefore eliminating a variable. Equation 3 describes the total stock (both being rented and in storage) needed to suffice the rental model. For the next part of the equation, the replacement rate (R_r) is multiplied with the average rental period for each transaction (U_r), divided by the rental efficiency (Q_r), multiplied with the time period (T) and finally multiplied with the rental transactions during T (t_r).

Equation 3 – Calculates the total required number of products to sustain the business model.

$$Q = \frac{(U_r * t_r)}{(Q_r * T)}$$

Equation 4 – Calculates the number of products produced each time period T, by calculating the number of products that are replaced in the system each T.

$$q_r = R_r * Q = \frac{(R_r * U_r)}{(Q_r * T)} * t_r$$

Equation 5 - Number of filters that needs to be replaced during period T.

$$q_{fr} = t_r * \left(\frac{U_r}{f_r}\right)$$

Equation 5 determines how many filters that are replaced each rental period by dividing the average length of rental period with the set filter replacement rate (amount of time before a filter has to be replaced) and then multiplying that fraction with the number of rental periods.

Equation 6 - Storage buildup amount during T.

$$q_b = T * \frac{Q}{Y_b}$$

Q are the total number of products required to sustain the BM. Y_b can be viewed as the monthly payment plan for the storage buildup. The equation describes the required number of products to sustain the BM during time period T, where Q/Y_b is the total required number of products divided by the number of months in the payment plan and then multiplied with the time period T. This gives q_b , the allocated number of products for the storage buildup.

Table 7 – Rental model costs expressed as tr instead of qr.

| Revenue or cost category | Equation expressed as tr |
|--------------------------------|--|
| C1r, Product procurement cost | $k1r * tr * \frac{Rr * Ur}{Qr * T}$ |
| C2r, Filter procurement cost | $k2r * tr * \frac{Ur}{fr}$ |
| C3r, Storage buildup cost | $k1r * \frac{Ur * tr}{Qr * Yb}$ |
| C4r, Warehouse transport cost | $k3r * \left(\frac{tr * Rr * Ur}{Qr * T} + \frac{Ur * tr}{Qr * Yb} + 0,45 * \frac{tr * Ur}{fr} \right)$ |
| C5r, PaaS storage cost | $k4r * \frac{Ur * tr}{Qr * T} * (1 - Qr)$ |
| C6r, Credit check costs | $k5r * tr$ |
| C7r, Product Distribution cost | $k6r * 2 * tr * \left(NUr1 + \frac{NUr2}{2} + \frac{NUr3}{3} \right)$ |
| C8r, Filter Distribution cost | $k6r * tr * \left(\frac{NUr2 * T}{4Ur} + \frac{2 * NUr3 * T}{6Ur} \right) * \frac{Ur}{fr}$ |
| C9r, Refurbishment cost | $k7r * tr * \left(\frac{NUr1 * T}{2Ur} + \frac{NUr2 * T}{4Ur} + \frac{NUr3 * T}{6Ur} \right)$ |
| C10r, Repair parts cost | $k8r * \frac{Ur * tr}{Qr * T} * Dr * (1 - Rp)$ |
| C11r, Repair labour cost | $k9r * \frac{Ur * tr * Dr}{Qr * T}$ |
| C12r, EOL cost | $k10r * \left(\frac{tr * Rr * Ur}{(Qr * T)} + \frac{Ur * tr}{Qr * Yb} \right)$ |
| Rr, Revenue | $r3 * tr * Ur$ |

When the equations in *Table 7* are put into the $\pi = \text{Revenue} - \sum \text{Costs}$ equation, that leads to Equation 7 below.

Equation 7 – Calculation of the profit level using the equations presented in Table 7.

$$\begin{aligned} \pi &= r3 * tr * Ur \\ &- \left(k1r * tr * \frac{Rr * Ur}{Qr * T} + k2r * tr * \frac{Ur}{fr} + k1r * \frac{Ur * tr}{Qr * Yb} + k3r \right. \\ &* \left(\frac{tr * Rr * Ur}{Qr * T} + \frac{Ur * tr}{Qr * Yb} + 0,45 * \frac{tr * Ur}{fr} \right) + k4r * \frac{Ur * tr}{Qr * T} * (1 - Qr) + k5r \\ &* tr + k6r * 2 * tr * \left(NUr1 + \frac{NUr2}{2} + \frac{NUr3}{3} \right) + k6r * tr \\ &* \left(\frac{NUr2 * T}{4Ur} + \frac{2 * NUr3 * T}{6Ur} \right) * \frac{Ur}{fr} + k7r * tr \\ &* \left(\frac{NUr1 * T}{2Ur} + \frac{NUr2 * T}{4Ur} + \frac{NUr3 * T}{6Ur} \right) + k8r * \frac{Ur * tr}{Qr * T} * Dr * (1 - Rp) + k9r \\ &* \frac{Ur * tr * Dr}{Qr * T} + k10r * \left(\frac{(tr * Rr * Ur)}{(Qr * T)} + \frac{Ur * tr}{Qr * Yb} \right) \end{aligned}$$

This equation describes the relationship between the sales model and the rental model. If both models are set to the same revenue, then the e.g. the number of rental transactions (tr) needed for the rental model to meet the same revenue as the sales model, can be derived.

With an equation of this complexity, it is beneficial to use a mathematical software to quickly be able to extract tr . If the equation is too complex for the software, it is possible to guess the right value of tr by changing the input value of tr until the profit of both equations are equal.

4.3. Material flow results

The number of products and filters required by the BM's were calculated and can be seen in this subsection. When Equation 7 was solved for tr , the subsequent variables could also be solved. The results can be seen below in *Table 8*.

Table 8 – Showing the resulting material flows for the rental model.

| Material flow rental | | |
|------------------------------|--------|---------------------------------|
| Variable | Pcs | Unit |
| tr | 1011.2 | Rental periods |
| qr | 10.5 | Replaced products |
| qb | 210.7 | Amount products bought during T |
| qfr | 1011.2 | Amount replacement filters |
| <i>In storage</i> | 84.3 | Pcs products in storage |
| Rented out at any given time | 337.1 | Pcs products in use |
| Q | 421.3 | Products required by BM |

In *Table 8*, the number of rental periods tr can be seen, each rental period is 12 months. Then qr , the number of replaced products, due to defects can be seen, in addition to qb the number of products bought during the time period T to reach the required number of products needed in the BM. The number of replacement filters qfr is also displayed. Then the number of products in storage and rented out at any given time can be seen, these are a product of the factor Qr , seen in *Table 4*. Lastly the number of products required by the BM Q can be seen.

Table 9 – Showing the resulting material flows for the sales model.

| Material flow sales | | |
|----------------------------|------------|----------------------------|
| Variable | Pcs | Unit |
| ts | 414 | Transactions |
| qs | 414 | Produced products |
| qfs | 248.52 | Amount replacement filters |
| <i>In storage</i> | 124 | Pcs products in storage |

The resulting material flows for the sales model can be seen above in *Table 9*. Here the number of transactions ts which is equal to the number of produced products qs for the sales model. The amount of replacement filters required by the business model qfs can also be seen and the results here compared to the rental model is much lower. This is because not all consumers buy new filters, this is simulated by the factor $f1$ seen in *Table 4*. Lastly the number of products in storage can be seen. When comparing *Table 8* and *Table 9*, a clear difference is the total amount of products produced for the two models. The total number of produced products in the rental model is $211+11=222$ and for the sales model it's 414 .

4.4. Life cycle inventory

In *Table 10* below, the modules of the air purifier along with filter and packaging are listed. These are also the main spare parts assemblies that are sometimes replaced as whole if there is a fault.

Table 10 - Modules of the air purifier including filter and packaging (data provided by company).

| Air Purifier | |
|------------------------|--------------------|
| Modules | Weight (kg) |
| Accessories | 0,21 |
| Base Body | 2,21 |
| Base body top Assembly | 1,48 |
| Blower Assembly | 1,53 |
| Fan Motor Assembly | 0,82 |
| Filter | 1,19 |
| Internal Packaging | 0,60 |
| Packaging | 1,76 |
| Sensor Assembly | 0,41 |

| | |
|--------------------|--------------|
| UI | 0,14 |
| Sum | 10,35 |
| Sum (no packaging) | 7,99 |

The complete list of materials used in the air purifier including filter and packaging are listed in *Table 11* below. The “Materials” column contains the main material categories, and the “Notes” column contains the materials.

Table 11 - Materials of the air purifier including filter and packaging (data provided by company).

| Air Purifier | | |
|----------------------------------|--|--------------------|
| Materials | Notes | Weight (kg) |
| PP | PP | 0,453 |
| PET (Polyethylene Terephthalate) | PET | 0,001 |
| PE | PE, LDPE, HDPE, PE film, twist tie wire (only LDPE part) | 0,283 |
| Paper | Paper | 0,213 |
| Mix plastics | PVC, ABS, acrylic, nylon 6, PA6+GF, PC, PC+ABS, PU, rubber, TPE | 4,048 |
| Metals (Steel) | Galvanized steel, low alloyed steel, inox steel, magnetite, twist tie wire (only steel part) | 2,076 |
| Metals (non-ferrous) | Brass, copper | 0,133 |
| Electronics | PCB, cable, switch, fan + motor, motor + cable, electronic + cable | 0,623 |
| Cardboard | Cardboard, corrugated board | 2,065 |
| Carbon | Carbon pellet | 0,326 |
| Aluminium | Aluminium | 0,015 |
| Adhesive | Glue | 0,115 |
| Sum | | 10,350 |

Table 12 display the total data related to the transports of the air purifiers and filters from China to consumers in Sweden. Some of the transports had already been calculated by the company in their LCA and was therefore used in this study as well since there had been no changes to the routes or transport methods. The two distances between Berlin and Mariestad and Mariestad to Stockholm had to be estimated with google maps. The primary transports show the deliveries to the warehouse in Mariestad and Stockholm for both the rental model and the sales model. EURO 6 was chosen as the measuring standard of the emission from the lorry transports since this is the latest standard issued by the European union (icct, 2016). Raw material transports for the product and filter are incorporated into the Ecoinvent v.3.10 market datasets used in the LCA.

Table 12 – Table of all transport steps and their types and distances.

| |
|-------------------|
| Transports |
|-------------------|

| Transport step | Locations | Transport type | Sales distance (km) | Rental distance (km) | Source |
|---|--|--|---------------------|----------------------|-------------|
| Primary transport 1 (China to Mariestad) | Ningbo Taller Electrical Appliance Co LTD - Port of Ningbo | freight, lorry 32 metric ton, EURO 6 | 117 | 117 | Company |
| | Port of Ningbo - Port of Sassnitz | transport, freight, sea, container ship” | 20135 | 20135 | Company |
| | Port of Sassnitz - Berlin | freight, lorry 32 metric ton, EURO 6 | 312 | 312 | Company |
| | Berlin - Mariestad | freight, lorry 32 metric ton, EURO 6 | 875 | 875 | Google maps |
| Primary transport 2 rental (Mariestad to Stockholm) | Mariestad - Stockholm | freight, lorry 32 metric ton, EURO 6 | | 301 | Google maps |
| Primary sum lorry | Multiple | freight, lorry 32 metric ton, EURO 6 | 1304 | 1605 | Multiple |
| Primary sum ship | Multiple | transport, freight, sea, container ship” | 20135 | 20135 | Multiple |
| Distribution | Stockholm/Mariestad - consumer | freight, lorry 32 metric ton, EURO 6 | 200 | 200 | Assumption |

Firstly, the production of the air purifier and filters are separated due to them being affected by different flows. There is then a transport activity called “primary transport”, this is the combined transports of the products and filters required by each business model and is a product of their combined total weight. Since a products lifetime can be longer than the timeframe of the analysis, the two activities (Production purifier and Primary transport) which only occur once per product, need to have their respective emissions allocated to the timeframe of the analysis. After that, there is a storage activity which incorporates the emissions from the storage of products in each business model, this is based on emissions data for storage facilities from the Swedish building agency Boverket proposition (BFS 2007:4 and BFS 2007:14), an assumption of the possibility to store 1,5 products/sqm have been assumed. Then there’s two more transport activities for the products and filters called Product distribution and Filter distribution, these activities sum the total emissions during the time period for the products and filters for each business model. The calculations depend on the business model since the sales model only have one transport per product and the rental model can have multiple due to cancellation of subscriptions.

There is then a Use-phase activity which includes the emissions from energy usage from the product during the time period. This is calculated by the average energy consumption

provided by the company and the quantity of products being used by each business model and the length of the time period. There is also a Repair activity which combines the emissions for producing repair parts and the transport to the service shop. However, this activity differs for the business models since the repair service of the rental model harvests parts from defect products and uses these for repairs and the repair service of the sales model only uses new repair parts. Therefore, the rental repair service requires less new repair parts per repair. The repair service for the rental model is also located at the same place as the PaaS storage, therefore the transports for the repairs are included in the Product distribution activity instead. Lastly there are two more activities for the end-of-life processes for the purifier and filter called EOL purifier and EOL filter, these activities sum up the emissions incineration of the filters and recycling of the purifiers.

Table 13 – Table showing the recycling rates for the material types used in the product and filter.

| Source | Waste type | Waste treatment method | | |
|------------|---------------------------|------------------------|--------------|-----------|
| | | Landfill | Incineration | Recycling |
| EUROSTAT | Plastic waste + adhesive | 5,0% | 21,4% | 73,6% |
| | Metal waste (steel) | 0,1% | 0,1% | 99,8% |
| | Metal waste (non-ferrous) | 0,1% | 0,0% | 99,9% |
| | Paper + cardboard | 0,0% | 1,3% | 98,7% |
| | Filter | 45,7% | 54,3% | 0,0% |
| EL-Kretsen | Electronics | 3,0% | 28,0% | 69,0% |

In Table 13 the recycling rates for the material types used in the product and filter can be seen. The recycling rates have been collected from the previous LCA conducted by the company and uses data from EUROSTAT (EUROSTAT, 2018) and EL-Kretsen (EL-Kretsen, 2023).

4.4.1. Allocation

Since the air purifier has a technical lifetime of 12 years, it would be unfair to account for all emissions linked to its whole lifecycle, since the timespan of the analysis is only 3 years. To adapt the analysis for this, emissions that occur once per product such as the production of the purifier, primary transport and EOL of the Purifier were allocated only to the time period that was considered. Meaning that a factor of 3/12 years was used on the total emission for these processes. The Use phase emissions were only calculated for the time period of the 3 years the model look at.

4.5. Life cycle impact assessment

The result of the life cycle impact assessment LCIA can be seen in this section of the report. The assessment is the result of the inventory data in the previous section. Both the sales and rental business model impacts were calculated according to the ReCiPe 2016 v1.03, midpoint (H) method using Ecoinvent v3.10 datasets through OpenLCA software. The

results can be seen in appendix A - LCIA results according to ReCiPe 2016 midpoint (h) for all impact categories and normalized to sales model. The results are classified according to the 18 impact categories included in the ReCiPe method in addition to Waste mass, total, placed in landfill which is a separate flow studied in the LCA. Furthermore, the results are shown for both sales and rental for each impact category. The results are normalized to the sales model and color-coded for the processes included in the LCA. After the results had been calculated, a decision was made to limit the project into looking at the impact categories with the highest impacts in addition to the total waste mass placed in landfill. The resulting diagram can be seen below in *Figure 4*.

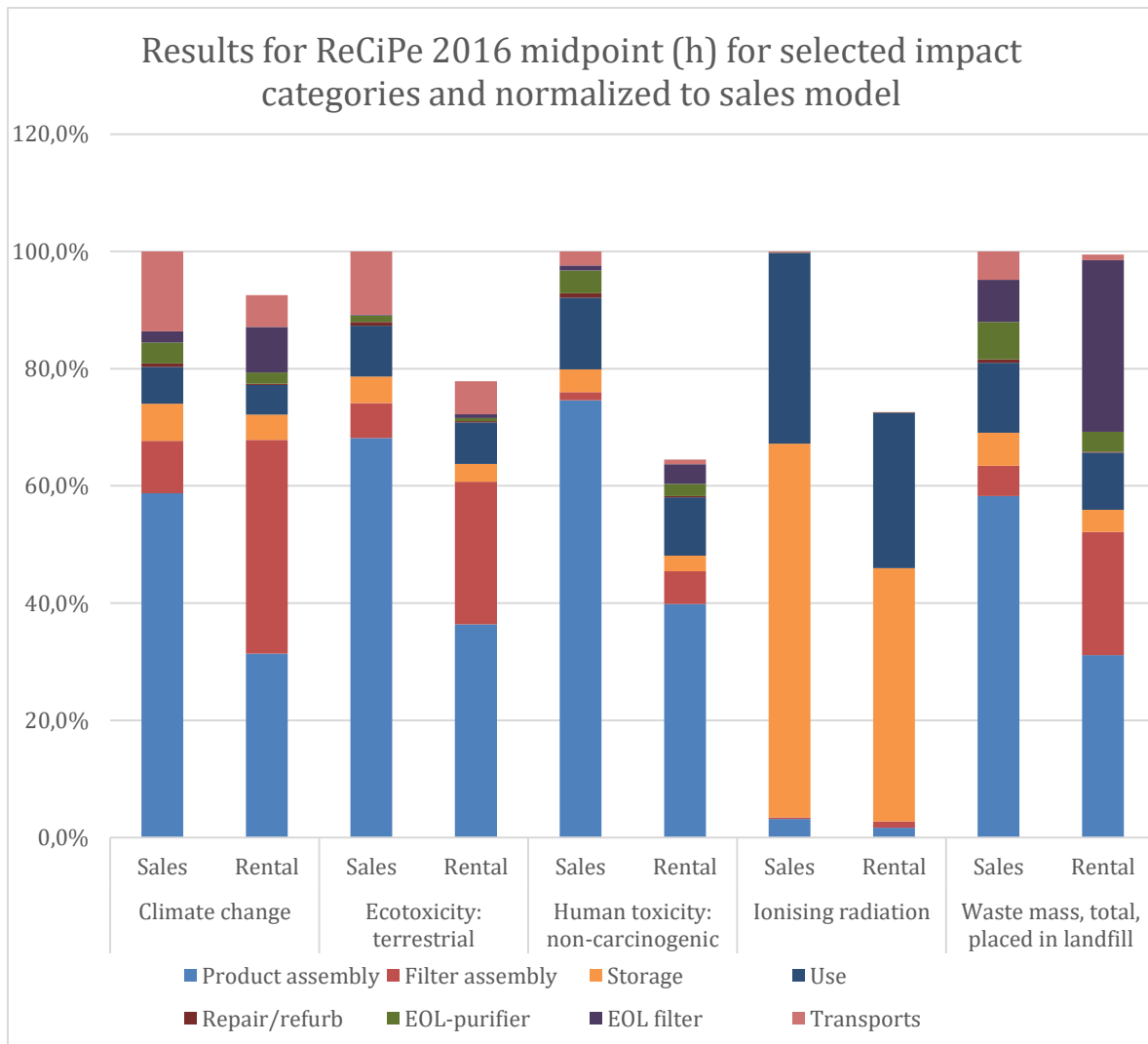


Figure 4 - Results for ReCiPe 2016 midpoint (h) for selected impact categories and normalized to sales model.

In *Figure 4*, the impacts per functional unit (normalized to the sales model) for both business models and in which life cycle process impacts appear can be seen. The rental model impact performance per amount of generated profit resulted in an overall reduction compared to the sales model in most categories. There is a reduction of 10% for the rental compared to the sales model when looking at climate change (GWP) impact. When looking at the graph there is a big difference in the “Product assembly” and “Filter assembly” processes, which can be seen in *Figure 4*. The reason for this is simply the fact that the

different models require different flows of products to achieve the set profit margin. The sales model requires far more products and the rental model requires far more filters. Another process that differs between the business models are transports, it can be seen in the figure that the impact is more than twice the size on the sales model compared to the rental model. However, for most impact categories studied in *Figure 4*, the total impact “Transports” has is less than 15%. For the Ecotoxicity: terrestrial category it can be seen that the “Product assembly” process stands for a higher percentage of the total impact, this leads to an increased difference between the two BM’s where the rental model has a 22% reduction in impact. Similarly, for the Human toxicity: non-carcinogenic category also has an increased susceptibility to the “Product assembly” process, but also a lowered susceptibility to “Filter assembly” which leads to a decreased impact of 35% for the rental model. Another learning from the results is that storage and use have the biggest impact on ionising radiation, this is because these are the main processes using electricity which have a high impact on this category. In the Ionising radiation category, it can also be seen that the “Storage” emissions are lower for the rental option. This is due to the fact that the rental BM has a smaller safety stock and higher rental efficiency compared to the sales model and therefore less products in storage. The rental option in the “Use” stage is a little bit higher for the sales model since more products are in circulation, leading to an increased energy usage. Lastly on the category waste mass, total, placed in landfill apart from the Purifier and Filter production processes, the EOL process have a great impact of 15-30%. However, the total impact of the two BM’s are very similar for this category.

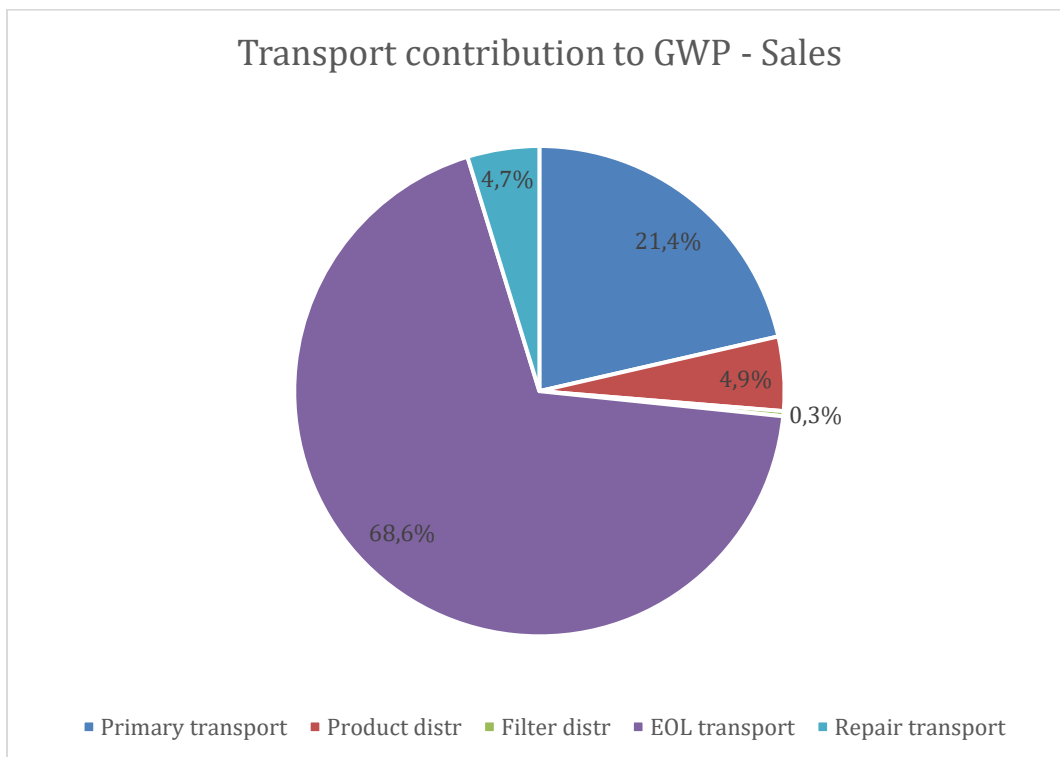


Figure 5 – Showing the contribution of GWP results for the different transports in the product flow to the combined transport emissions for the Sales model.

In regard to the calculations of the transport emissions, the calculations for ship and truck were done through tonnes/km but for the EOL transports by car, only the distance was used.

The datasets used in the analysis of the transports by car, didn't consider the extra weight carried in the car but only the distance transported.

EOL transport is the largest contributor when it comes to the transport since in the sales model, the customers transport the air purifier and the filters themselves by car to the recycling stations, this way of transportation has a much larger impact compared to transporting them by truck of EURO 6 standard which is predominantly used by the company. Primary transport accounts for the second largest emission because it is the longest transport distance and, in the sales case, transports do not occur more than once apart from filter transports which happen once a year. The rest of the transports have lower impacts as a consequence of low volumes and short transports distances.

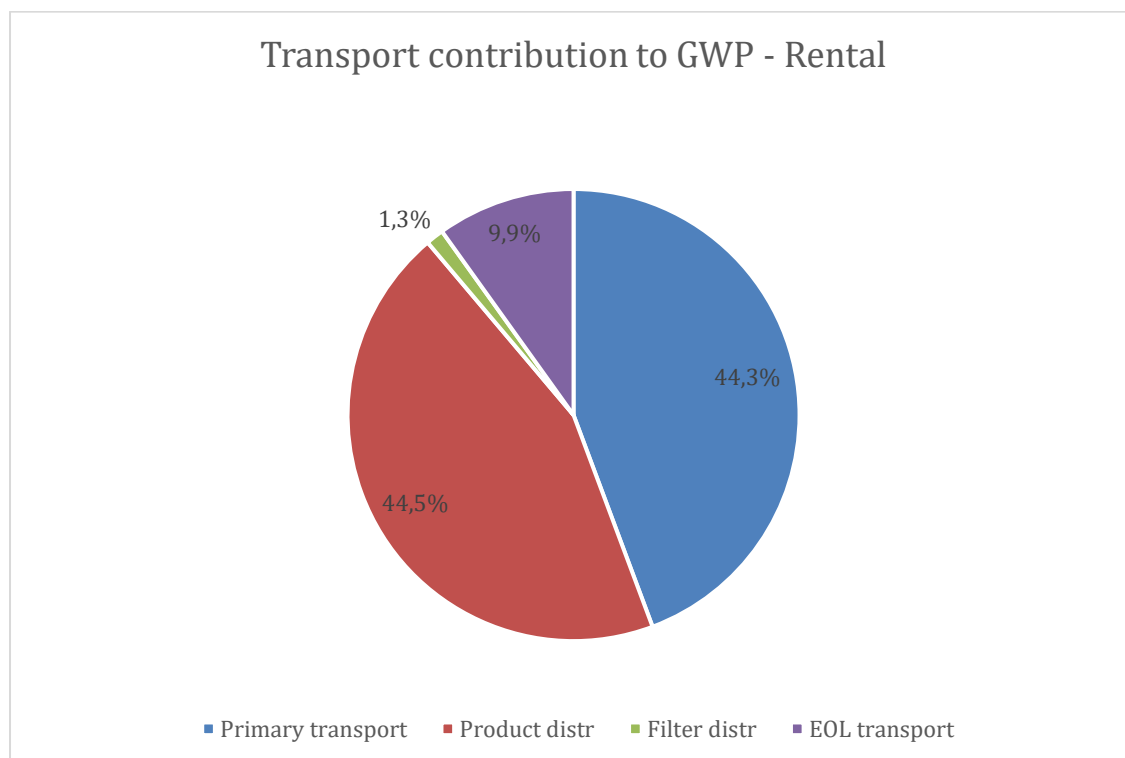


Figure 6 - Showing the contribution of GWP results for the different transports in the product flow to the combined transport emissions for the Rental model.

In the rental case, "Product distribution" has the second largest effect on GWP, this is because the purifiers in the rental model is transported back and forth from customer along with filter shipments during their lifetime, due to cancelled subscriptions or other reasons. The primary transports have the second largest impact on the total emissions. Just as in the sales model, the reason for this large impact is because of its long transport distance from China to Sweden with both ship and trucks. EOL transports doesn't have as big of an impact as it does in sales BM since the shipments to the recycling centre are done in bulk with trucks instead of single transports with personal cars. It is assumed that there is no additional repair transport in the rental case, instead the transports that occur when a product out for renting becomes defect is seen as a product distribution since the consumer gets a new product and the defect product gets returned to the company. Thereby the repair transports for the rental model are included in the product distribution. The contribution of the Filter distribution is small since many of the filters are replaced every time the air purifier is

returned because of an ended subscription period. Hence, the need of an additional filter transport is nullified.

5. Sensitivity analysis

To understand how the business models react to different inputs and to find environmental hotspots in the BMLCA, a sensitivity analysis was conducted. In this analysis, parameters used in the coupling equations and environmental impact equations were altered. Using the functional unit of SEK 1 500 000 under a period of 3 years as a basis for comparison.

Several parameters were altered in the analysis to get a good understanding of the system, including product related parameters such as product lifetime, economic related parameters such as price for renting as well as uncertain data related to consumer behaviour such as the number of consumers buying filters in the sales model.

The parameters used in the sensitivity analysis are categorised into the following categories:

- Product
- Economic
- Consumer behaviour

The results of the sensitivity analysis are summarised in *Table 14* below.

Table 14 - Sensitivity analysis of the two business models related to GWP (Kg CO₂ eq/F.U).

| Sensitivity category | Parameter that was changed (default value) | How the parameter was changed | % change sales | % change rental |
|----------------------|--|---------------------------------|----------------|-----------------|
| Product | Product technical lifetime (TI = 12 years) | tl - 3 years | 22% | 13% |
| | | tl + 3 years | -13% | -8% |
| | Material change | PLA instead of ABS | -5% | -6% |
| Economic | Revenue from subscription | r3 - 25% | 0% | 77% |
| | | r3 + 25% | 0% | -30% |
| | Revenue from product sales | r1 - 25% | 65% | 0% |
| | | r1 + 25% | -26% | 0% |
| Uncertain | Changing % consumers buying new filter | F1 = 0% | 0,1% | 0% |
| | | F1 = 100% | -0,3% | 0% |
| | Change of energy mix | Europe energy mix instead of SE | 80% | 65% |

5.1. Product

In this section of the sensitivity analysis the result of product related parameters will be presented.

5.1.1. Changing product technical lifetime

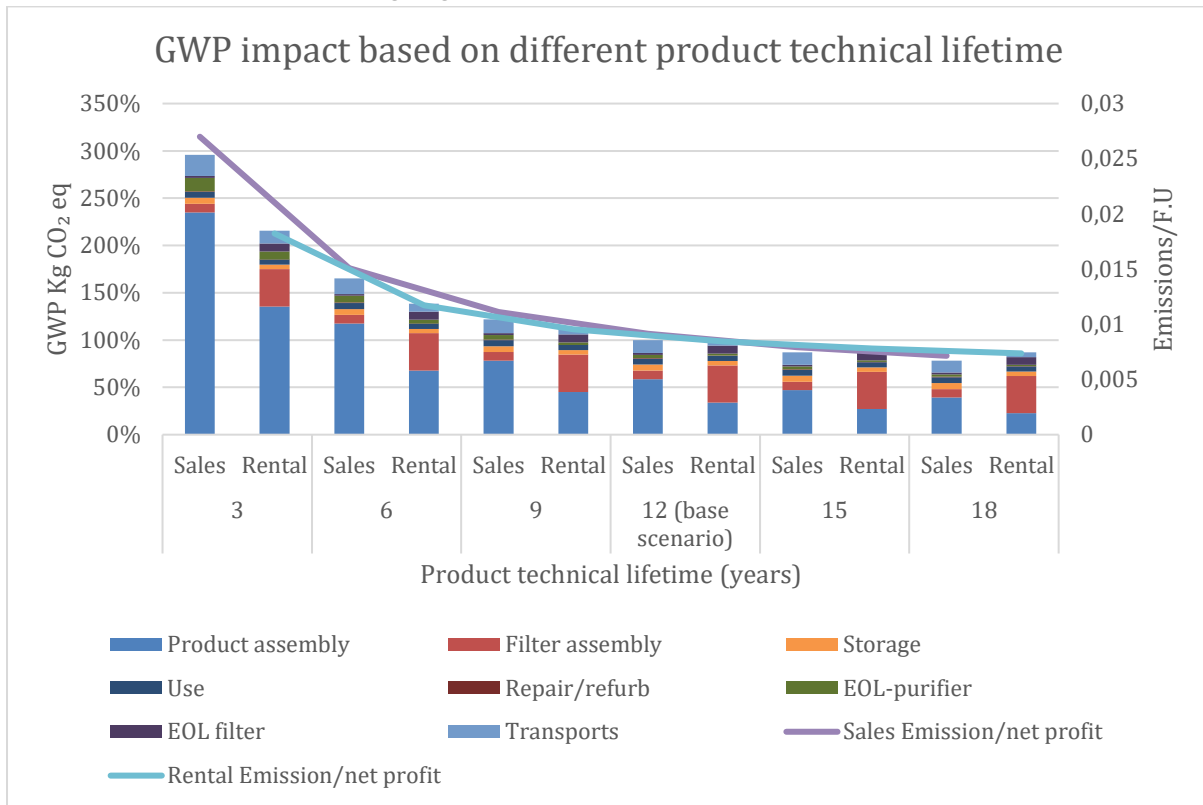


Figure 7 – Sensitivity analysis based on different technical lifetime for the product and then normalised to the sales base scenario of 12 years technical lifetime.

This graph illustrates the change in GWP impact as the Product technical lifetime parameter is changed. What can be seen in *Figure 7*, is that for both the sales and rental models the GWP impact is heavily affected by the technical lifetime of the product. When an extreme case of only 3 years is looked at, the GWP impact for the sales model is close to 300% compared to the base scenario of 12 years, for the rental model the same scenario leads to a 200% increase. When the product lifetime instead is increased, the GWP impact gets reduced. When looking at a lifetime of 18 years, the sales model emissions are reduced by 22% and 13% respectively for the rental model. Another point taken from the graph is that as the lifetime of the product increase the emissions from “Filter assembly” becomes the most impactful process. Therefore, if the product lifetime of the product can be increased by other design choices in the future, more emphasis should be placed on the filter design as well.

5.1.2. Changing material

The purifier and filter design are composed of several materials. However, the material contributing to GWP impact the most are ABS plastics, which stands for approximately 30% of the GWP impact when looking at only materials. Therefore, it would be interesting to see if this portion of the GWP impact could be lowered by substituting with another material. The choice of substitute material for the analysis landed on PLA plastic which has some similar properties as ABS but are lacking when it comes to durability which could make it unsuitable in practice. The results can be seen below in *Figure 8*.

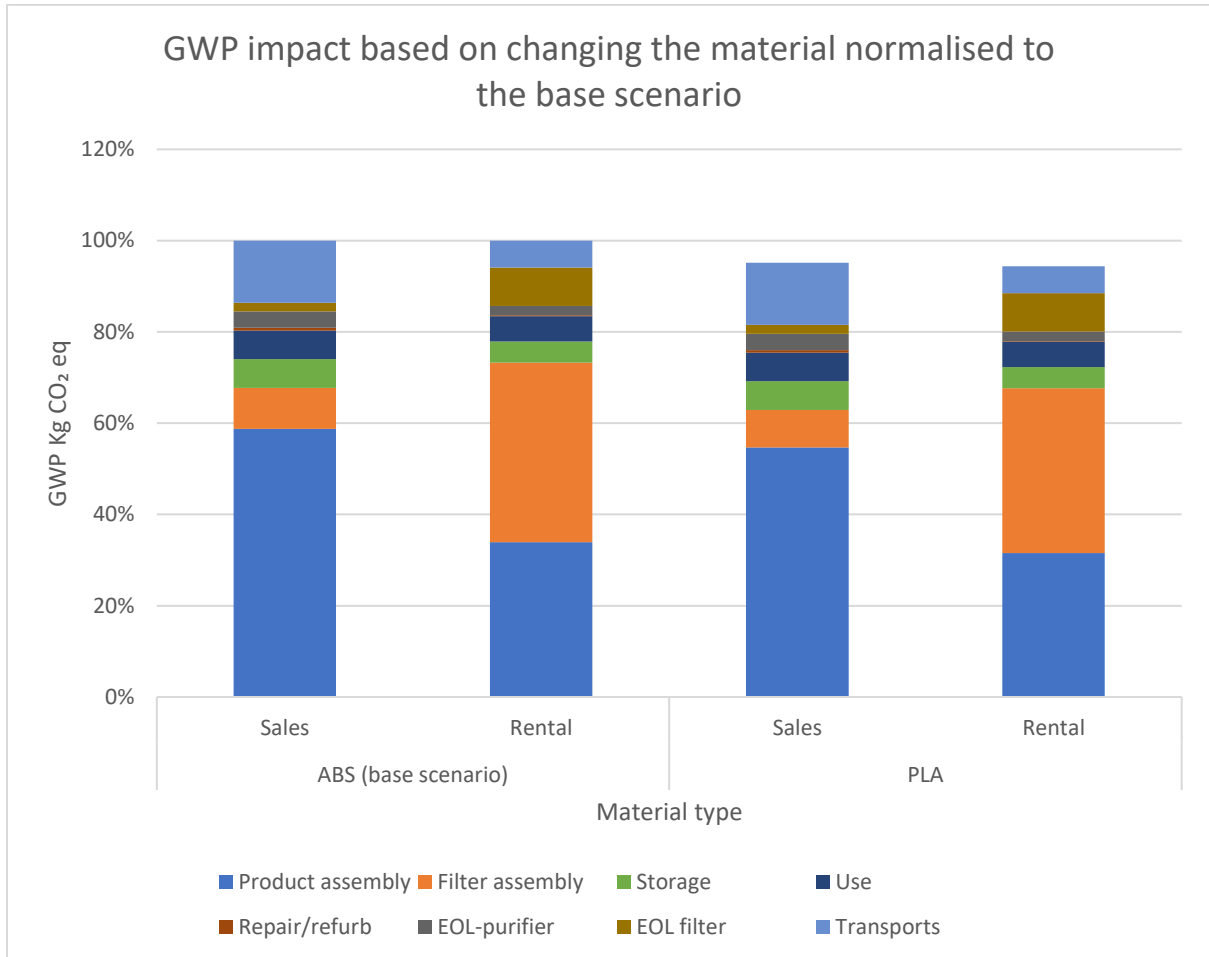


Figure 8 – Sensitivity analysis of changing from the use of ABS plastic to PLA plastic, within the purifier and filter assembly.

As can be seen in Figure 8, a reduction in GWP impact happens due to the change to PLA plastic. The biggest difference is in Product assembly, where most of the ABS plastics were used.

5.2. Economic

In this section of the sensitivity analysis the result of economic related parameters will be presented.

5.2.1. Changing rental price

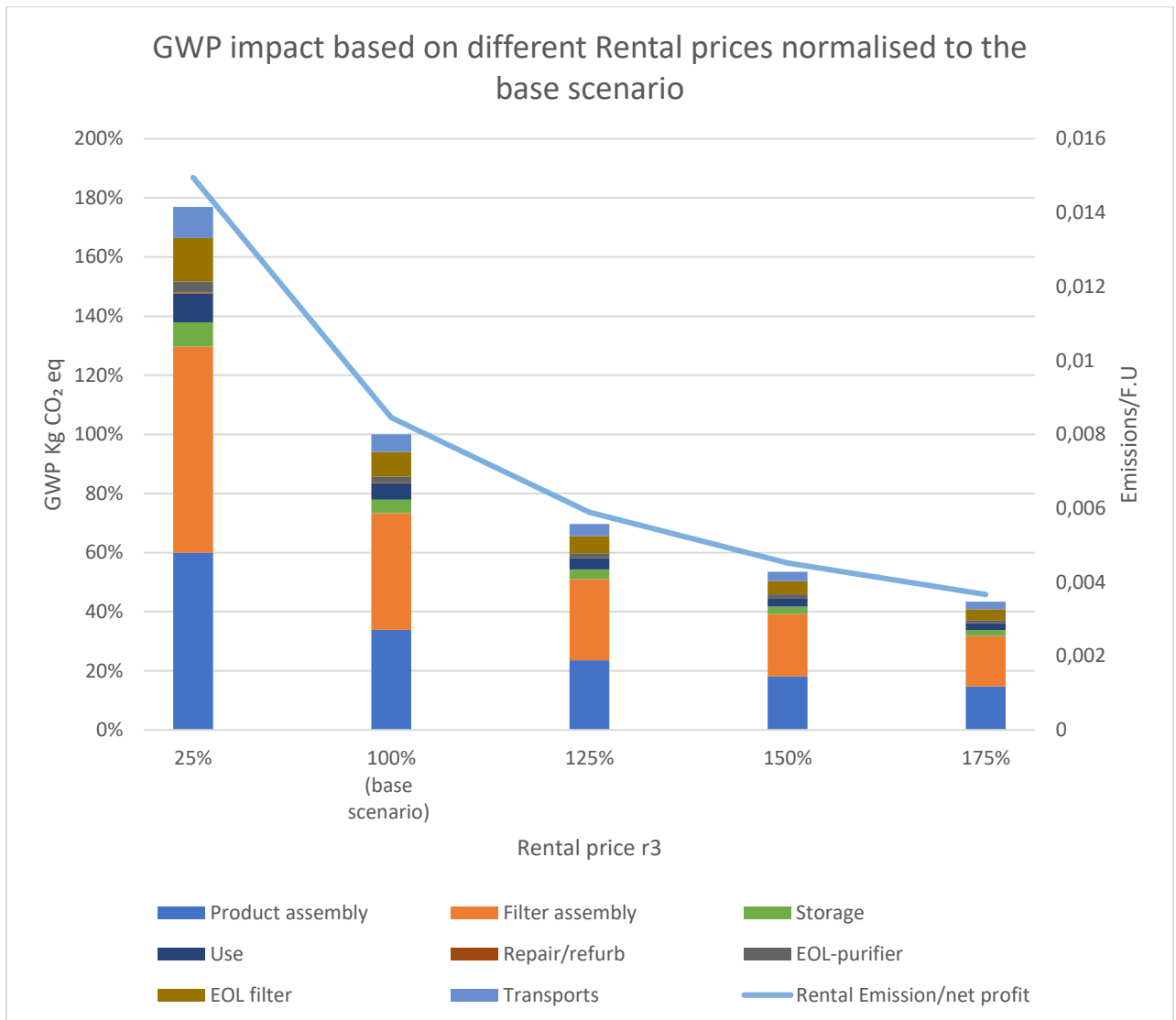


Figure 9 – Showing the GWP impact when changing the rental price.

This graph shows the change in GWP impact as the rental price r3 change. As can be seen in Figure 9, the GWP impact is reduced as the rental price is increased. This is because the rental BM generates more revenue from the same cost when the price is increased, resulting in an increased profit, which then results in a reduced number of products and therefore also filters when the results are normalised to the same F.U. However, something worth noting is that this change in price might have an impact on the service attractiveness since the price plays a big role there.

5.2.2. Changing sales product price

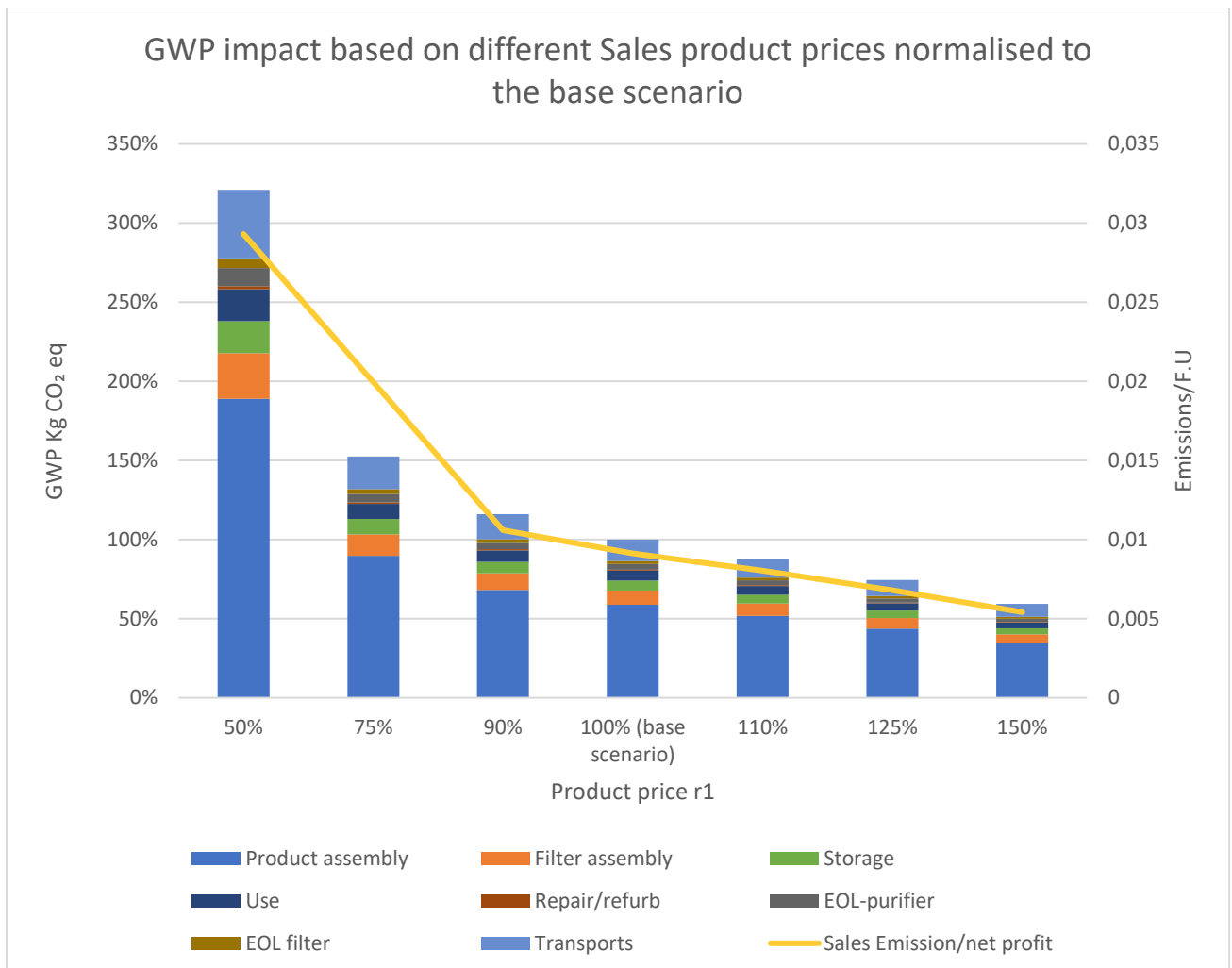


Figure 10 - Showing the GWP impact when changing the product price, the results are normalised to the product price set in the base scenario.

This graph shows the change in GWP impact as the sales product price change. This is a similar graph to the one seen in Figure 9, as can be seen in Figure 10, as the product price increases the emissions are reduced. Furthermore, as the price of the product is reduced the emissions increase. One thing to note is that when the price of the product is reduced more than 90% then the emissions increase exponentially ending up with 300% increased emissions when the product price is reduced by 50%.

5.3. Consumer behaviour

In this section of the sensitivity analysis the result of consumer behaviour related parameters will be presented.

5.3.1. Changing sales % consumers buying new filters

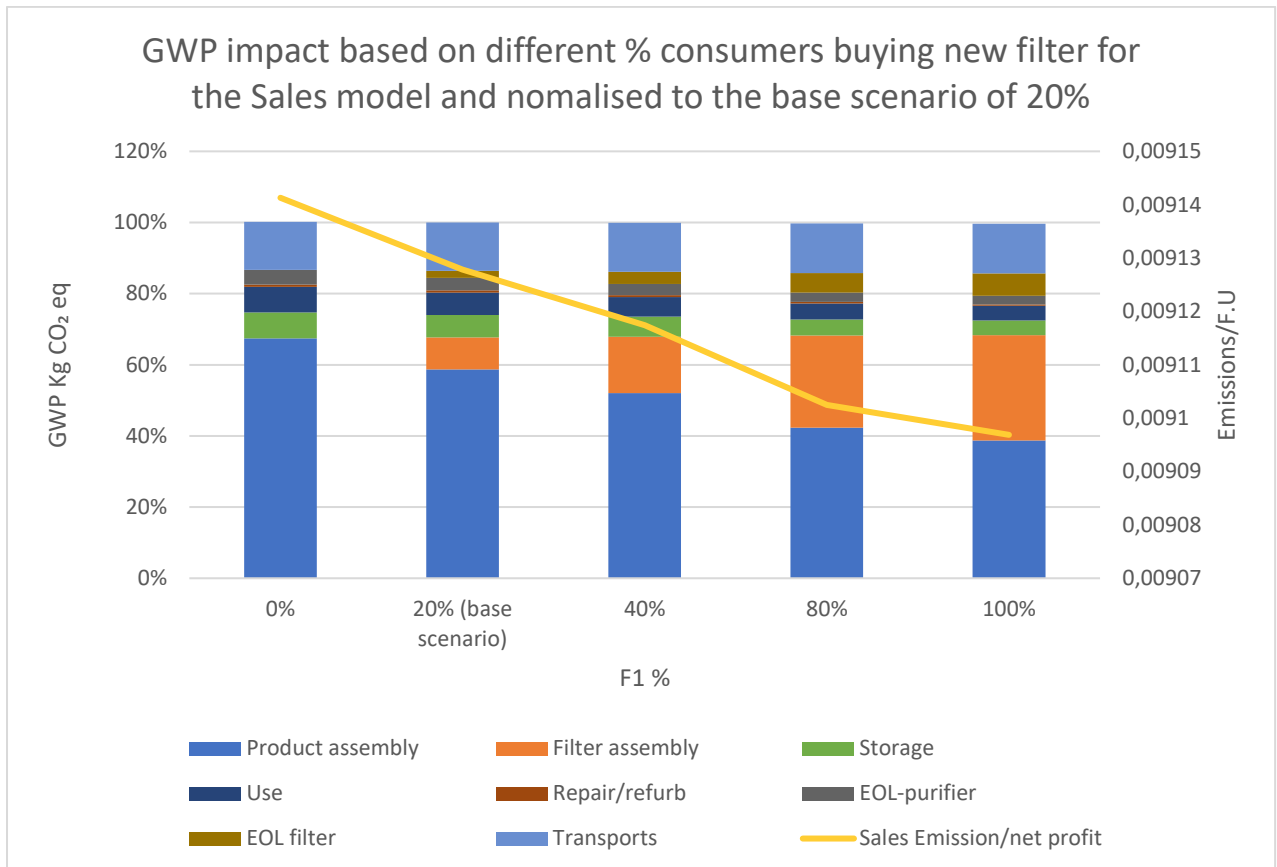


Figure 11 - Showing the GWP impact when % of consumers buying new filter changes from 0% to 100%.

This graph illustrates the GWP impact of the purchase pattern of new filters that the consumers in the sales model have. Each percentage of the filter replacement factor F1, is the amount of the customers that will buy a new filter after the supplied filter as reach its EOL which is on average 12 months. As can be seen in *Figure 10*, the total GWP impact does not change much when the number of consumers buying new filters change for the sales model. However, as seen in the line in the figure, the emissions/F.U is reduced as the number of consumers buying a filter increases. This lowering of emissions, however, is very low which can be seen at the right shoulder heading. Another interesting aspect from the figure, is that as the number of consumers buying new filter increases, then number of products produced gets reduced. This is because both of these flows act as revenue flows for the sales model and in order to achieve the set F.U one flow has to be replaced by another. What can be said is that for the sales business model the volume of this flow does not really matter when wanting to lower the total GWP impact. As the “Filter assembly” emissions increase as the f1% parameter is increased, the “EOL filter” process is also increased.

5.3.2. Changing the energy mix

In the base scenario, the Use-phase and Storage process did not have a great overall impact on the results. This is because the base scenario looked at a Swedish energy mix, which has one of the lowest GWP impacts in Europe. Since the rental service could be expanded into other markets outside of Sweden, the energy mix will be different and

therefore it is interesting to see how the results might change. In *Figure 12* below, the energy mix has been changed to a European energy mix for both the low voltage used by consumers and medium voltage used by the storage facility.

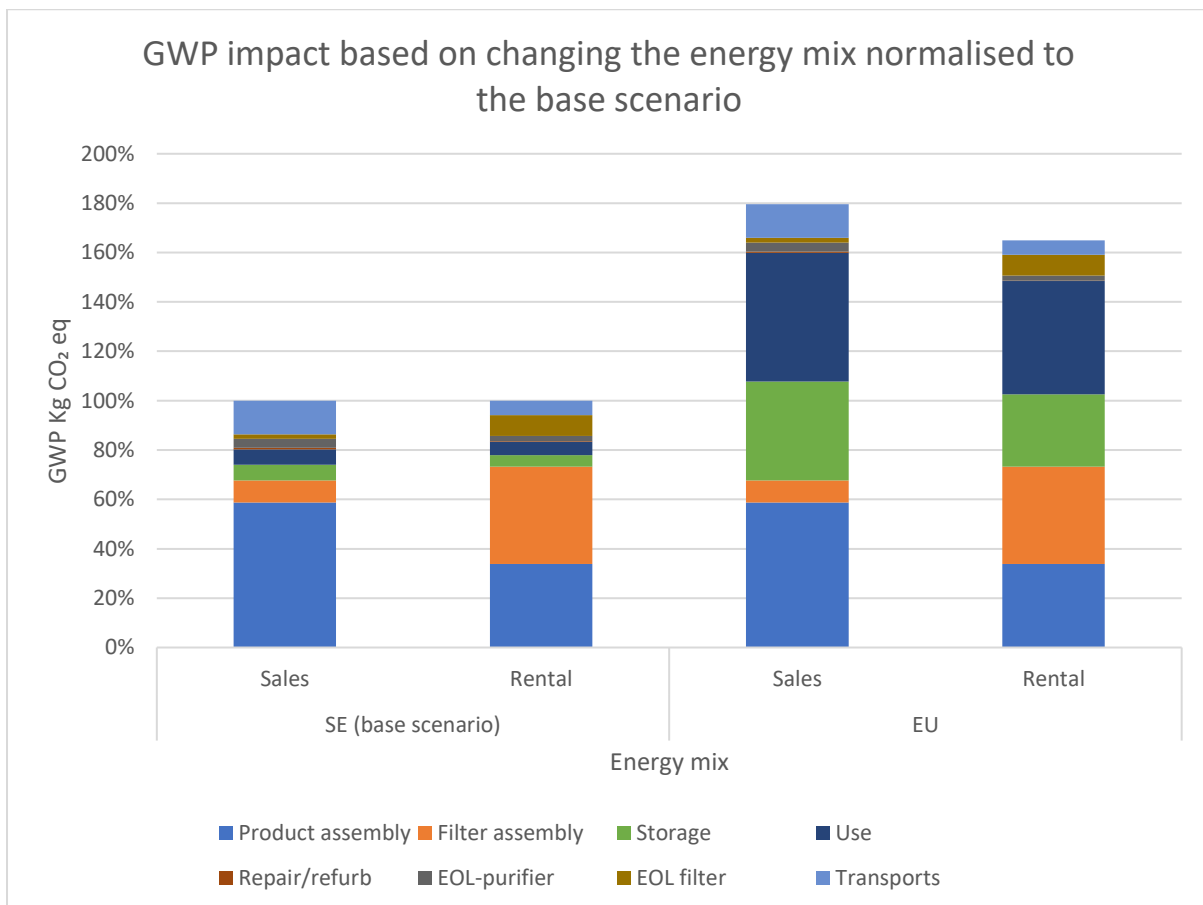


Figure 12 – Sensitivity analysis of changing the energy mix used by the consumers and the storage facility.

As can be seen in the figure, the GWP impact increases by 80% for the sales model and 64% for the rental model, the difference here is only due to the different number of products required by the BM. When the service uses a European energy mix most of the impact now comes from Use-phase and Storage process in the sales model and nearly the majority for the rental model. Therefore, it would be beneficial to focus on energy efficiency measures and to buy renewable energy for storage facilities if the rental service is expanded outside of Sweden.

6. Discussion

In this chapter, the project will be discussed in terms of validity, improvements for the product and future research for the project.

6.1. Validity of results

The data used for the previous LCA of the product supplied by the company uses secondary data on material and energy flows from the Ecoinvent v3.8 database (2021). However, the LCA processes added or changed in the BM-LCA, such as transport to consumer and use-phase uses more updated secondary data from Ecoinvent v3.10 database (2023). Some of the datasets in the Ecoinvent database that was used by the company, were no longer available in the newer version of the database. An example of this could be the recycling process of a certain material. In these instances, a similar material was chosen instead. This was done to save time since finding the impacts for all the chosen impact categories for the study, for a single material, proved to be too time consuming considering the time frame of the project. In an optimal scenario, these should be investigated further to make the impacts even more exact.

Another problem with translating the already existing LCA from the company to the replica one produced for this study in excel, was that some of the data lost quality. For example, the company LCA had more in-depth data on the raw material transports in China to the factories. Because of difficulties with translating the LCA, some more generic datasets had to be chosen for these processes.

In talks with the company, some of the input values for the economic model were estimated. An instance of this was the safety stock for the sales and the rental model. It was determined that for the sales model it was 30% and for the rental model 20%. These safety stock levels, along with the needed number of products for the business models during the set time period T , affect the total stock levels which impacts the emissions. The emissions are tied to the electricity needed to support the storage of the products per square meter and is therefore directly tied to the number of products in storage. This is an example of how estimations easily affect the end results tied to the economic model and the emissions.

Other inputs that had to be estimated were some of the prices related to spare parts. The company were able to provide prices for some parts while for the project, some parts had to be assigned a price depending on similar parts prices found for sale or average cost of the parts prices the company provided. Another cost that was estimated was the warehouse transports cost. It was based on an invoice cost that was obtained for one of the transports where the shipping company responsible for the transport had billed the case company for two pallets. From this invoice, the price per pallet was calculated. Off course, using this price per pallet to scale the cost of larger shipments does not represent a real-world case where the shipping company might do price reductions if the transports contain more pallets from the case company. In similar fashion, the storage cost is based on the current number of products, but the price could scale differently depending on the storage used to house the products if they outgrow their current storage or have to scale down. All these estimated

economic inputs could be improved to help make the results more accurate. This would require a more in-depth investigation into the company resources and conversations with more stakeholders.

6.2. Use of the results

Here the research questions will be answered, and the use of the results are discussed.

6.2.1. Can a rental business model reduce environmental impact while maintaining economic performance compared to sales business model?

In this study, the circular business model showed an overall reduction in the environmental impact compared to the sales model. However, as was shown in the sensitivity analysis, different factors can change the results to where the sales model performs better than the rental model. The impact category where the largest change could be observed was the “human toxicity” impact category where the rental option had a decreased impact of 35% compared to the sales model. The level of difference in impact between the two BM in falling order was then: “Ionising radiation”, “ecotoxicity: terrestrial”, and “climate change” (GWP).

From the analysis, it was concluded that the factors with the largest influence on the results were the technical lifetime of the air purifier and the filter, the pricing of the products and service and the energy mix used during the use of the air purifier. This mean that an increase in the pricing and the technical lifetime would benefit the rental service further. However, if the service is moved to a country or region with an energy mix that utilizes more fossil fuels, then the sales model has potential to have a better environmental performance than the rental model.

6.2.2. What are the economic and environmental hotspots in the different business models?

It was identified that the economic hotspot was located with the procurement of the product and filters and had the greatest impact of all costs for both business models. For the rental model the cost for procuring filters was also significant, due to the higher consumption modelled in the analysis. It was also noted that the price for the product/filter and the price for the rental service heavily affected the GWP impact as seen in *Figure 9* and *Figure 10*. This was especially true for the rental model, since the subscription price was the only revenue stream compared to the two revenue streams of product and filter price for the sales model.

For environmental hotspots, product assembly and transports were identified for the sales model. There was a larger number of products needed in the sales model, which increased

the impact from product assembly and the EOL transports for the sales model included car transportation, which increased the transport impact. For the rental model, the filter assembly stood for the greatest impact. This was because the rental model offered a replacement filter every 12 months, which led to a higher flow of filters than in the sales model. The product assembly also stood for a large impact in the rental model, but not as large as in the sales model, as can be seen in *Figure 4*.

6.2.3. How could the circular business model be improved?

As seen from the results, filter assembly stood for the largest impact for the rental model. To decrease this impact, a service improvement in this sense could be to use sensors within the product to sense when the filter is about to be full and thereafter send out an offer to get a new filter for the rental service. In this way the company probably could reduce the number of filters being sent out in the rental service by only sending out replacement filters if the ones being used are full. This could also lead to reduced energy consumption for the consumers since the purifier will never be used with a full filter for a long time, thereby, reducing the energy consumption.

A factor that goes hand in hand with maximizing the use of the air purifier is to increase its technical lifetime. As was calculated in the sensitivity analysis, the emissions are reduced the more years the air purifiers are in service. However, with longer use, comes a higher filter consumption, which could pose as a problem because of their environmental load. To mitigate this, further study could be put into the design of the filter, more sustainable materials could be used in the construction of the filter that will reduce its impact on mainly GWP, which was the impact category that filters had the biggest impact on. Further development of the filter design could also be put to redesigning the filter to last longer, which would lead to reduced emissions, especially for the rental model.

In the study by Böckin et al., (2022a), it was concluded that offering to sell a rented product to a customer in second hand at any time after a rental period leads to significant negative results for the rental model. This stems from the product losing more rental opportunities and therefore use-time, since the maximum use time of a product in the rental BM results in the lowest emissions. This effect is also applicable to the rental scenario of the air purifier, where maximizing the use time of a product is essential since having to produce new products to replace sold ones, directly affect the largest emissions factor which is the assembly processes.

6.3. Improvements and future research

In this chapter, the possible improvement and areas for further research related to the project and BM-LCA in general will be discussed.

6.3.1. Improvements and future research for the project

During the project some parameters were altered in the sensitivity analysis, which provided a good picture of what parameters had a potential to affect the results if varied. However,

several interesting parameters were not looked at, due to a limitation of time. Here, some parameters prepared in the model which could be interesting to look at for further research are presented.

Replacement rate filters (fr) – first, the replacement rate for filters could be interesting to look at, since it was seen in the rental model that the filter assembly had the greatest impact in many impact categories, such as GWP. If the replacement rate for the filters would become shorter, it would be a qualified prediction that more filters need to be produced, increasing the impact of filter assembly. However, if the lifetime of the filters could be increased, hence, making the replacement rate of the filters longer, then the impact would probably decrease.

It is estimated by the company that with average usage, a filter lasts for about a year before needing replacement. However, company data showed that some customers may not buy a new filter even if the air purifier has given a warning that the filter is full. This provides a dilemma for the analysis since a full filter would affect the electricity efficiency of the air purifier. Making the sales and rental model use-phase not directly comparable. Therefore, this could be an interesting factor for further analysis. However, this is not estimated to play a big role for the scope of this study since the energy usage from the Use-phase were relatively low. However, if the service were to be expanded outside of Sweden and use an energy mix of lower quality the impact would increase making this more interesting for further study (Analytics OMG, 2021).

In the analysis, it is assumed that the air purifier and filter is used the same amount for every consumer for simplifying reasons. However, the amount of use per consumer would differ. Some customers might only use their air purifier at limited times, as an example, during spring when there is pollen in the air or when a pet allergic person has a pet visiting. If this is the extent of the customers usage during the year, the filter could last longer than the set 12 months meaning that they don't have to buy a new filter as often which will reduce the impact on GWP from producing new filters. In this sense the model presented in this paper is a bit stiff and does not take these factors into account and could be a further researched.

Length of the rental periods, both ($NUrx$ and Ur) – Other interesting factors to consider for further analysis, would be the length of the rental period (Ur) and number of rental periods in a row for a customer ($NUrx$). These factors affect the number of distribution transports to consumer for both the purifiers and filters, making it interesting to study.

Other transport scenarios, placement of storage in other locations – In the study, the geographical scope was limited to Sweden and the company's existing logistic solutions. However, it could be interesting to look at how the results may vary if the storage facilities would be located elsewhere. This would affect the length of transports and could potentially be adapted to fit the continuous distribution to and from consumers more efficiently, in the rental model.

If looking at a different geographical location (other country) – It could also be interesting to broaden the scope and look at the impact of providing the rental service in other countries. What could be seen from the sensitivity analysis was that when the energy mix was changed to an EU energy mix, then the impact increased by 64% alone. However, here other parameters that also would change if the rental service were to be launched in another

country were not changed. Such as the recycling rates for materials used in the product, which may vary depending on the country. Also, the logistical aspect, transport lengths would change and the type of transport, changing the impact from the transport processes. Also, the different costs/revenues could change, ultimately affecting the number of products needed to reach the F.U.

Defect rates (Dr) – Lastly it would be interesting to look at how the defect rate used in the project could be interesting to look at. The defect rate used in the project were derived from guarantee matters for the linear sales model. However, it is not uncommon that the consumer behaviour changes when the product is rented. Hence, the defect rate could differ from the one used in the project.

6.3.2. Improvements and future research for BM-LCA

As a recommendation for future projects doing BM-LCA studies, when conducting a BMLCA with a company, it is important to derive information from the involved stakeholders as early as possible to map the product flows within the company. It is also beneficial to gather information and data on any previous LCA work within the company already in the beginning of the project since this can take time to convert to e.g. excel or any other software of preference.

As can be seen in this project, small changes in the economic model can have large impacts on the life cycle impact assessment. Therefore, it is crucial to map the costs as accurately as possible along with the coupling equations and to incorporate consumer behaviour variables in the coupling equations to strengthen the sensitivity analysis. Making a robust economic model gives much more freedom and accuracy when doing the sensitivity analysis.

7. Conclusions

To conclude, the study compared the environmental performance of a rental and sales business model using the Business Model Life Cycle Assessment (BM-LCA) methodology, which connects profitability with environmental impact. Before this study was conducted, it was unknown whether the rental model would have a lower or higher environmental impact compared to the already used sales model. However, with the results from this study, it was seen that the rental BM does perform better overall than the sales model while still providing the same revenue for the company.

The results of the study showed that the largest impacting life cycle for the sales model was the product assembly process whereas in the rental model, the filter assembly process often had a larger impact. A sensitivity analysis also showed that the energy mix used heavily influenced the results, meaning that the geographical location of the service would affect the results. However, the same results also showed that impact of the sales model would increase more than the rental model if a worse energy mix would be used, enhancing the benefits of the circular business model. The analysis also showed that the subscription fee and technical lifetime of the product also influenced the results.

Future improvements the company can act on to reduce the environmental impact of the rental model further is to increase the technical lifetime of the filter but also the air purifier since a longer lifetime means that a product can be used longer and less new products need to be produced, reducing emissions from manufacturing new units. An increased subscription fee would also help reduce emissions by reducing the number of products needed to reach the same profit level. If the service would be offered in another country with a worse energy mix, energy efficiency measures for the usage of the product would be beneficial. As for improvements to the results of the study, more depth could be added to the economic model by adding more complexity to the costs which will contribute to results that are even more accurate to reality.

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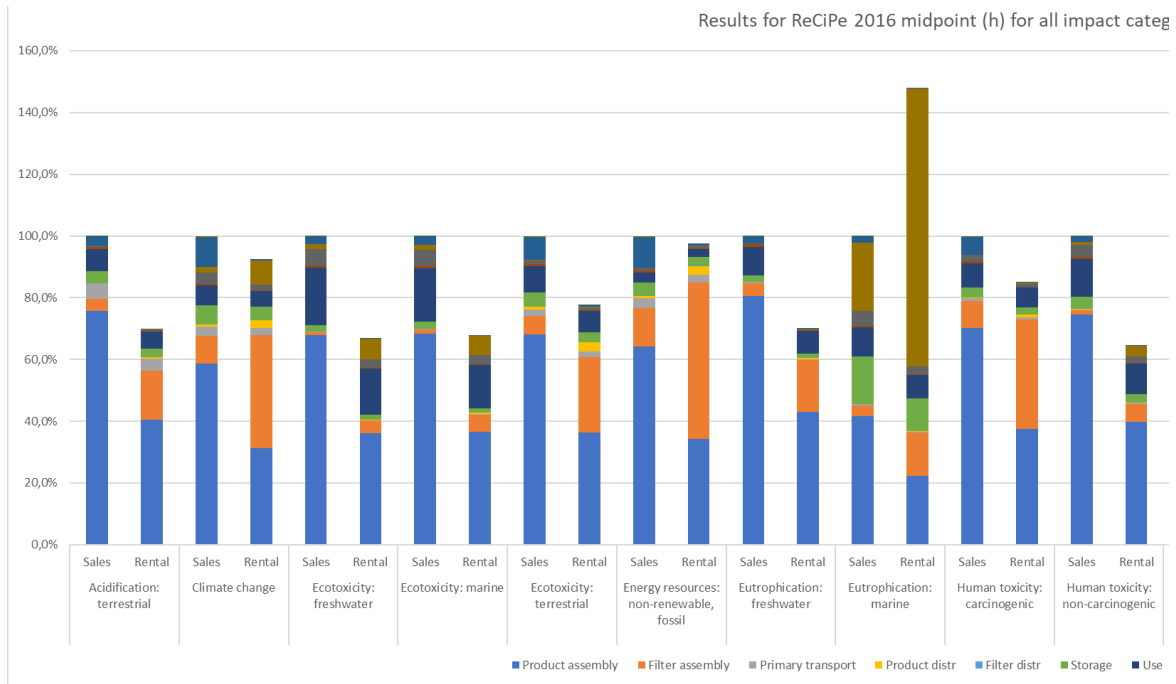
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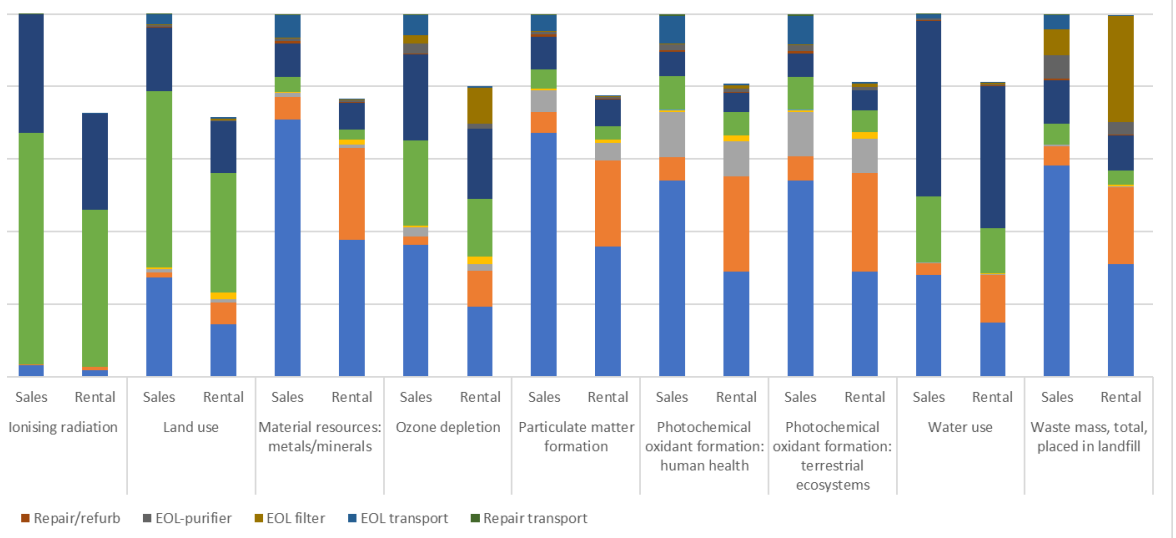
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Appendix A – LCIA results according to ReCiPe 2018 midpoint (h) for all impact categories and normalized to sales model



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