

Circular economy:

Sustainability assessment of circular business models based on material flow analysis.

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Abstract

This study has contributed to the developing concepts of circular economy by assessing circular business models and to test different approaches for circularity in a measurable way. In our current era of time, we stand against environment challenges with a warming planet and resources scarcity. To mitigate the effect of greenhouse gas emissions and to find new more circular solutions to material demand. The developing concept of circular economy is aligned with these goals.

In this study the climate impact and profitability of circular business models are investigated using material flow analysis. The result is an assessment of these parameters from a sustainability perspective for product organizations and show that longer lifetime and use period a product has the lower the yearly global warming potential. For profitability the assessment is dependent on more parameters such as current business models, gross margin, raw material, logistics and distribution cost an increased profit is not as strongly connected to lifetime or use. When an increased circularity can be accomplished as a complement to current business (without significant cost increase) there is a possible profit.

The study suggests an analysis model for investigate circular strategies in the *Assessment model for circular business models*. The study contributed to the practical adaptation of circular economy principles providing a suggested analysis framework. By applying circular economy principles and this assessment model it is possible to contribute to a more sustainable future for the system of planet Earth.

Keywords

Circular economy, Circular business models, Product-Service-System, Profitability, Climate impact, Material Flow Analysis

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Table of Contents

1 INTRODUCTION	1
1.1 PURPOSE.....	2
1.2 OBJECTIVES	2
1.3 CIRCULAR ECONOMY	2
1.3.1 <i>The R-10 Framework and the Value Hill</i>	4
1.3.2 <i>Circular business model (CBM)</i>	5
1.3.3 <i>Circular economy assessment</i>	6
1.4 MATERIAL FLOW ANALYSIS	6
2 METHOD	6
2.1 CONCEPTUALIZATION OF MFA BY CIRCULAR STRATEGIES	7
2.1.1 <i>Linear flow (baseline) (MF_{lin})</i>	7
2.1.2 <i>Recycle flow (MF_{rec})</i>	7
2.1.3 <i>Reuse flow (MF_{reu})</i>	8
2.2 MODELING AND CALCULATIONS.....	9
2.3 CIRCULAR STRATEGIES AND BUSINESS MODELS.....	10
2.3.1 <i>Limitations</i>	11
2.4 DATA	11
2.4.1 <i>Case 1</i>	12
2.4.2 <i>Case 2</i>	12
2.4.3 <i>Common parameters, variables, and assumptions</i>	12
3 RESULT	13
3.1 CASE 1	14
3.1.1 <i>Climate impact per product</i>	14
3.1.2 <i>Climate impact per business model</i>	14
3.1.3 <i>Profitability per product</i>	16
3.1.4 <i>Profitability per business model</i>	16
3.2 CASE 2	18
3.2.1 <i>Climate impact per product</i>	18
3.2.2 <i>Climate impact per business model</i>	18
3.2.3 <i>Profitability per product</i>	20
3.2.4 <i>Profitability per business model</i>	20
3.3 RESULT ANALYSIS	22
3.3.1 <i>Assessment of circular business models</i>	22
4 DISCUSSION	24
4.1 METHOD DISCUSSION.....	24
4.1.1 <i>Data Collection</i>	24
4.1.2 <i>Method improvements</i>	24
4.1.3 <i>Scope</i>	25
4.2 RESULT DISCUSSION	25
4.2.1 <i>Recycling (product)</i>	26
4.2.2 <i>Recycling (Business model)</i>	26
4.2.2 <i>Reuse (product)</i>	26
4.2.3 <i>Reuse (Business model)</i>	26
4.3 ANALYSIS DISCUSSION	27
4.3.1 <i>Climate impact business model(s)</i>	27
4.3.2 <i>Profitability of business model(s)</i>	27
4.3.3 <i>Assessment model of circular business models</i>	28

5 CONCLUSION.....	29
6 FURTHER RESEARCH	30
REFERENCES	31
APPENDIX A - DATA CALCULATIONS GLOBAL WARMING POTENTIAL.....	34
APPENDIX B - DATA CALCULATIONS PROFITABILITY POTENTIAL	38

Definitions and abbreviations

CE – Circular economy

CS – Circular Strategies

CBM – Circular Business Model

PPS – Product Service System

CO₂ eqv. – Carbon dioxide equivalent

MFA – Material flow analysis

1 Introduction

As a system, planet Earth can be considered a closed system where the flows of material and energy remain within. The available resources available to humanity are finite, and the amount of material humans can produce and consume is therefore limited. For many resources, we are approaching this limit of availability. This is manifested as a resource scarcity for human society. Especially for resources originating from the earth's crust and only available after extraction and manufacturing (Bianchi and Cordella, 2023). Besides the natural resources, the societal boundaries including the economy are eventually also affected negatively as the planetary boundaries are challenged and stressed. Depletion of natural resources and climate change will ultimately threaten the existence of human life on planet Earth (Steffen *et al.*, 2015). Doughnut economics addresses the holistic perspective of the connection between planetary boundaries and human societies' economic way of living (Raworth, 2021). Where the economics is in most cases seen as the driving force development (growth) therefore it must be not only considered but integrated into achieving a sustainable paradigm (IPCC, 2022).

As from a sustainable perspective Circular Economy (CE) recognized the limitations mentioned in the planetary boundaries and the Doughnut economy. There is also possible to see CE as a Malthusian viewpoint. Malthus predicted in *An Essay on the Principle of Population* (1798), that the resources wouldn't be enough for the growing population. Malthus was not right when recognized the limits to growth, but he wasn't entirely wrong either. The traditional linear economy and material flow can be illustrated as a cornucopia. Where the resources of planet earth are a never-ending source of material and enabling eternal economic growth.

In general, Circular Economy addressed the current and emerging resource scarcity. The general backbone of CE is to bend the linear material regime towards a circular flow providing solutions for environmental issues, resource dependencies, emissions, waste, etc. by closing, slowing down, and reducing the loops of materials (Ellen MacArthur Foundation, 2019). By applying CE principles, the environmental pressure can be decreased by a reduced demand of virgin raw material. Material loops circulating the products at their highest value decreases the negative climate impact compared to extraction of virgin material (Achterberg, Hinfelaar and Bocken, 2016). CE holds a promising solution to it all as an applied sustainable practice. This report uses a system perspective of the current developing definition(s) of the circular economy with the potential economic and environmental benefits to be achieved.

Before going any further, it must be concluded that the concept of circular economy (CE) is not universally defined or standardized. The concept of CE is reviewed as many studies show deficiency in the area (Ghisellini, Cialani and Ulgiati, 2016, 2020; Harris, Martin and Diener, 2021; Brändström and Eriksson, 2022). However, many have tried and investigated this and critically review Circular economy as a concepts and definitions in literature studies (Kirchherr, Reike and Hekkert, 2017; Korhonen et al., 2018; Korhonen, Honkasalo and Seppälä, 2018).

1.1 Purpose

This study aims to contribute to the circular economy concept development by assessing circular business models and to test different approaches for circularity in a measurable and practical way. The purpose is to evaluate what effects circular strategies have on financial aspect and climate impact for a producing organization and to investigate MFA as a method to assess implementation of Circular economy in a business.

1.2 Objectives

The objective of the study is to:

- assess circular strategies in material flow analysis from climate impact and financial aspects.

1.3 Circular economy

In the shift towards a more sustainable world, the concepts of circular economy offer principles that can concretize necessary activities on the sustainability trajectory. Circular economy has strong connections to sustainability. In this study two of the pillars from the triple bottom line perspective is used; economic and ecological (Elkington, 1997). As an enabler for sustainable development, the CE aims to reduce the use of resources and the ecological impact on the biosphere while the current economic mechanisms remain (Ellen MacArthur Foundation, 2018). CE is used and referred to with increased frequency by authorities, corporates, and academia. For example, in the IPCC synthesis from 2023 where the necessity of circular material flow is addressed. (IPPC, 2023)

The economic tradition is built on the extracting of resource that can be refined to something for humans useful until it eventually is used and then considered a waste. This is illustrated in Figure 1 and so is the circular flow as an illustration of circular economy showing the loop of material or products circling back to the system after use.

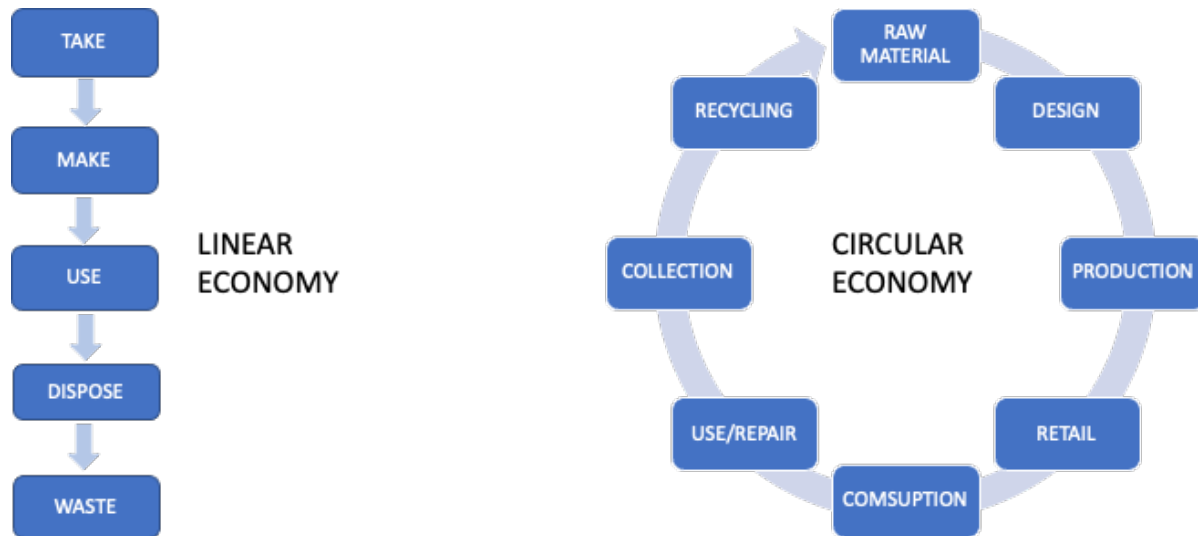


FIGURE 1. LINEAR ECONOMY AND CIRCULAR ECONOMY

Circular economy can exist is the current economic system with market factors and financial growth, but with the difference of breaking the correlation between virgin material extraction and economic growth. Even so, the economics of business are highly relevant from a sustainability perspective, without profit there is no incentives for business and to achieve sustainable development, economic factors are one of the cornerstones in the triple bottom line (Birkel and Müller, 2021). Even if there is no scientific standardized definition of the CE, and still, it is a contested concept. There are quite many, at least 114 definitions as concluded by (Kirchherr, Reike and Hekkert, 2017). Secondly how the practices and the application of the concept are discussions in numerous publications (Ghisellini, Cialani and Ulgiati, 2016; Kalmykova, Sadagopan and Rosado, 2018; Korhonen et al., 2018; Korhonen, Honkasalo and Seppälä, 2018; Harris, Martin and Diener, 2021).

This study will use Ellen Macarthur Foundation circular economy principles.

Eliminate waste and pollution

Circulate products and materials (at their highest value)

Regenerate nature

(Ellen MacArthur Foundation, 2018)

Further, Ellen MacArthur describes CE as a system solution framework to tackle challenges such as those listed in the planetary boundaries (Steffen *et al.*, 2015).

From a contemporary aspect as a reporting organization in a member of the European Union, you are legally affected by the circular economy also well, as the implementation of the EU taxonomy, aims to meet the EU's climate and energy target for 2030. The taxonomy is a classification system for economy activates concerning clear environmental objectives that aim to regulate and assess the environmental performance of economic activities. EU Taxonomy also refers to Circular Economy as a tool for economics and industrial ecology as an identification of sustainable business in value chains (Brändström and Eriksson, 2022; Hedlund et al., 2020;). The taxonomy framework consists of six environmental objectives where the fourth objective is "Transition to a circular economy" This means that you as a cooperation should substantially contribute to the six environmental objectives and at the same time do no harm to the other objectives. This shall be reported according to EU reporting standard for sustainability Cooperate Sustainability Reporting Directive (CSRD). This makes this study relevant from a contemporary aspect (EU Commission, 2020).

1.3.1 The R-10 Framework and the Value Hill

The correlation between the level of circularity and environmental impact is modeled and defined as the circular strategies of the R10 framework. An adaptation of the R10 framework is shown in Figure 2 and will in this study be applied as the definition of material flow scenarios and circular business models (Potting et al., 2017).

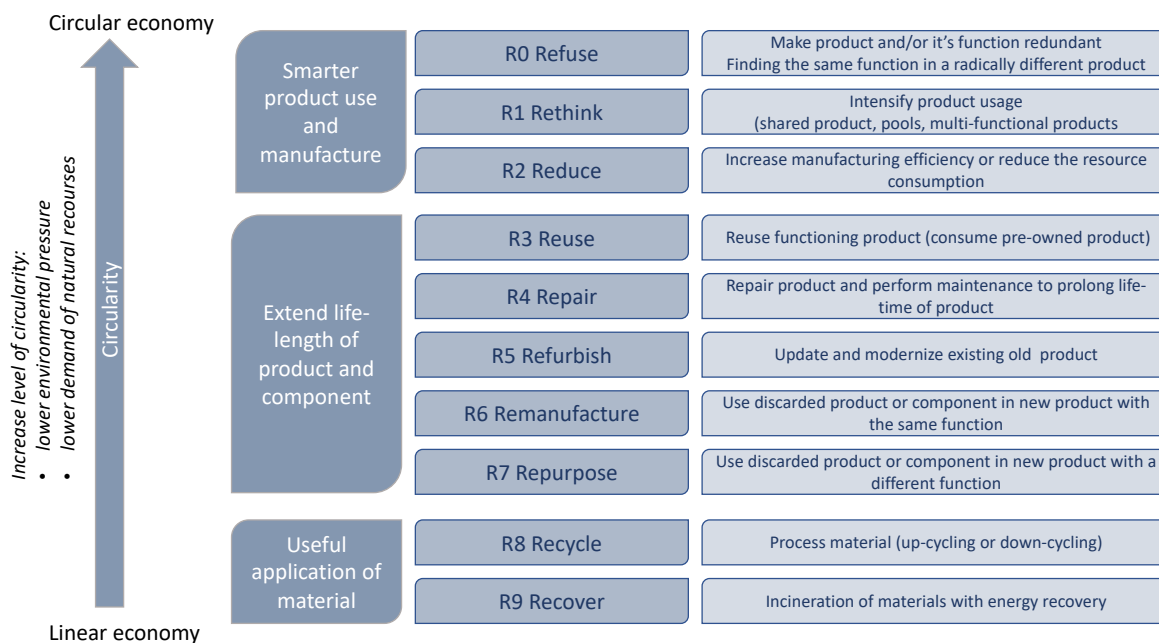


FIGURE 2. THE R10-FRAMEWORK ADAPTED FROM (Potting et al., 2017) HIGHER LEVEL OF CIRCULARITY IS ENABLING HIGHER POSITION ON THE STRATEGIC CIRCULARITY SCALE OF THE R10 FRAMEWORK LADDER.

Figure 3 shows how this value relates to a product's life cycle. Before the use phase the value is added and after use the value drops. In the slope towards *after use*, the value-retaining activities are illustrated and can occur in many phases of the product or material life cycle (Achterberg, Hinfelaar and Bocken, 2016).

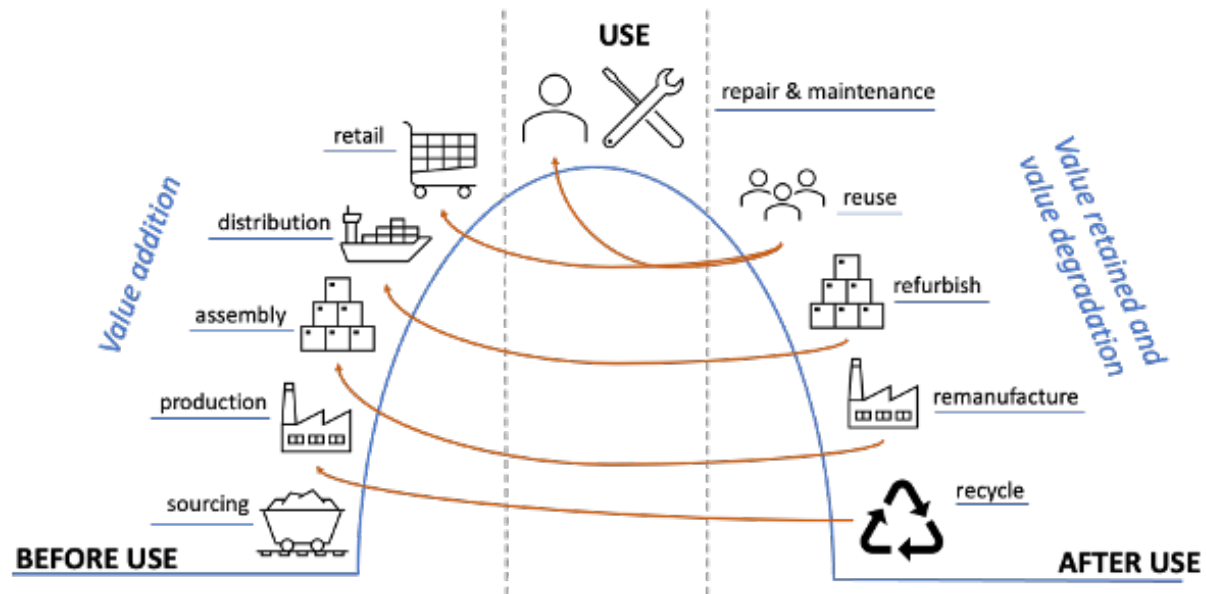


FIGURE 3. (ADAPTATION FROM ACHTERBERG, HINFELAAR AND BOCKEN, 2016) Further down the after-use phase the lower the value. Recycling is often what comes to mind for the public and is a significant part of the circular economy. However, it comes with a low circular value and recovery that in Sweden incineration is even lower as a circular mean. Once incinerated the value contains mainly only heat and then the value is irreversibly consumed. Closing the material and product loops, and not mixing the technical and the biological loops prevent the loss of valuable material models (Bocken *et al.*, 2016; Ellen MacArthur Foundation, 2019).

1.3.2 Circular business model (CBM)

To investigate business strategy on micro-level Circular business model (CBM) can be used as a model to capture business value and as a start the circular economy implementation (Aarikka-Stenroos *et al.*, 2022; Han). Business model approaches can vary by the company set up, cooperate culture, and also depended on the location, if the company operates locally and/or regionally and/or globally (Stahel, 2019). Business model strategies and to define the circular character of a product life cycle or business model. As an adaptation to the circumstances and to learn about circular economy CBM can be used for new customer offers and trimming processes for environmentally sustainable growth (Bocken *et al.*, 2016; Han *et al.*, 2022).

1.3.3 Circular economy assessment

Further, the search for a circular assessment method and circular matrix resulted in several suggested pathways and calculations for assessing the level of circularity. (Boyer et al., 2021; Brändström and Eriksson, 2022). The complex systematic nature challenges the measuring of the circular economy. However, by an established method such as MFA; LCA Circularity indicators, Eco-design tools, and business model analysis the circular strategy can be assessed. By using these methods, businesses and policymakers can identify areas for improvement and track progress toward a more sustainable and circular economy (Böckin *et al.*, 2022).

1.4 Material Flow Analysis

Material flow analysis (MFA) is a method that quantifies the materials flow through a system, including the extraction, processing, use, and disposal of materials. MFA can be used to understand product and material flows that enter and leave the system. Also, as an analysis within the system to identify the main sources of waste and inefficiencies in a system to develop circular economy strategies (Hedlund et al., 2020).

For environmental impact assessment in general and for this study in particular the MFA is relevant a starting point for the assessment according to sustainability parameters. MFA can be used to modify a production processes, design phase, distribution options, material compositions, business model etc. Then adding circular principles MFA can assess different circular strategies. As a method of combining MFA and circular strategies to assess circular economy can be applied within specific sectors, corporations, and regions (Gao *et al.*, 2020; Rahman and Kim, 2020; Hunfeld *et al.*, 2023).

2 Method

The method used in this study was exploratory and quantitative, as the data used was fictive and used for testing modelling as for a verification purpose. A system theory approach was used when applying the method of Material Flow Analysis (MFA) on the circular strategies in R10-framework defining the strategies as scenarios of material flows. The circular strategies from R10-framework used as circular material flows (circular strategies) in this study is R8 *Recycle* and R3 *Reuse* which together with and compared to the baseline set as the *Linear* material flow will be on will be analyzed and discussed. For the study and calculations different example cases representing different products, product set and circular business models are used.

First the MFA was used to conceptualize the Linear flow and the circular strategies of the R10-framework in general. The study was then narrowed to the circular strategies of Recycle and Reuse. After modelling the circular strategies, the circular business models of Take-back and PSS was defined and added to the model. With the MFA model set up the data calculation phase could be performed done using the functional units of GWP (Kg CO2 equivalences per year) and profitability (SEK/year). The data used were fictive example cases, Case 1, and Case 2, used for testing the dimensions of single product as circular strategy and product set as circular business model. Further the result is analyzed in the Result Analysis section 3.3, presented as a suggested circular business model assessment where the two functional units of GWP and profitability are combined in a diagram.

2.1 Conceptualization of MFA by circular strategies

The three circular strategies are visualized in this section as material flow scenarios. The result of the conceptual modeling is according to the definition of the circular flows and can be applied to the material(s), product(s), and monetary flows etc.

2.1.1 Linear flow (baseline) (MF_{lin})

The linear flow is considered the baseline for the study. The baseline is the reference value that is the constant that the calculations will be compared as a delta (Δ) value. Figure 4 show the conceptualized flow of the Linear baseline consisting of the raw material phase, production phase, use phase and waste management phase.

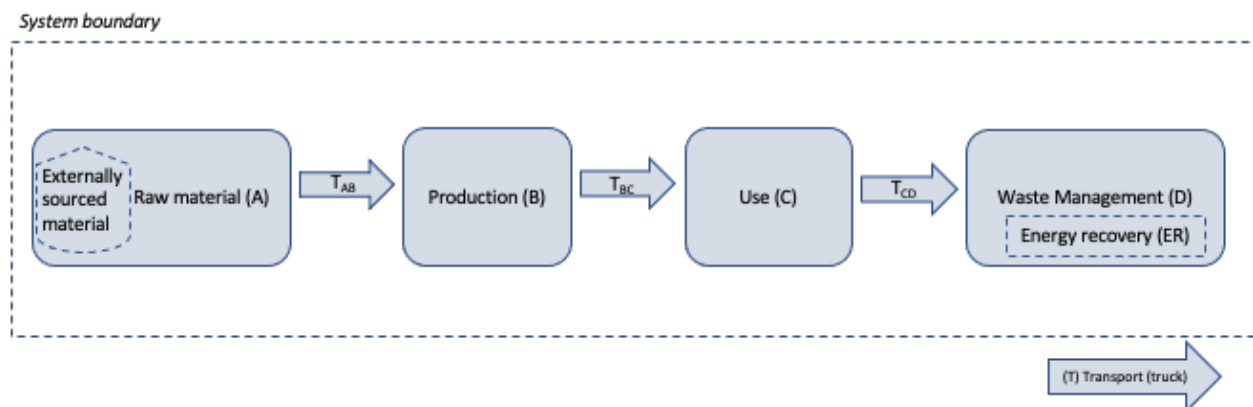


FIGURE 4. LINEAR MATERIAL FLOW (BASELINE) THE AS IS SCENARIO

2.1.2 Recycle flow (MF_{rec})

The recycle flow is a flow where the linear flow is developed to include the materials (the products) are looping back to the production facility after use and entering the production line as raw material. The recycle flow is illustrated in figure 5.

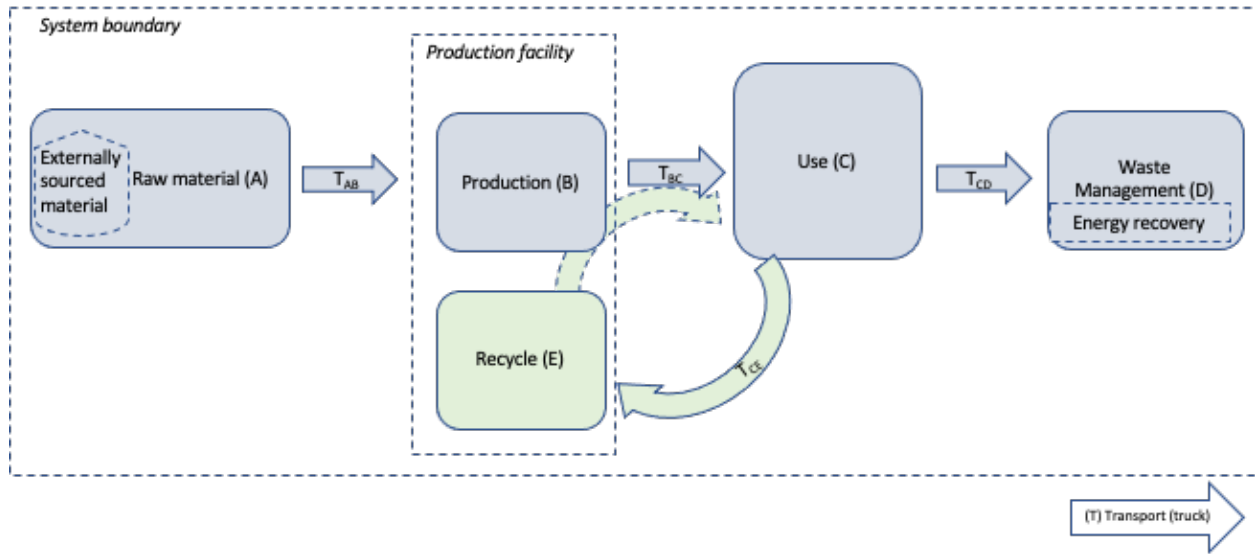


FIGURE 5. RECYCLE MATERIAL FLOW

2.1.3 Reuse flow (MF_{reu})

The reuse flow is illustrated in figure 6 and show products looping back for a second and/or third use period. Recycle is represent in this flow as well as a fraction of the raw material entering the production line as in the recycle flow in figure 5.

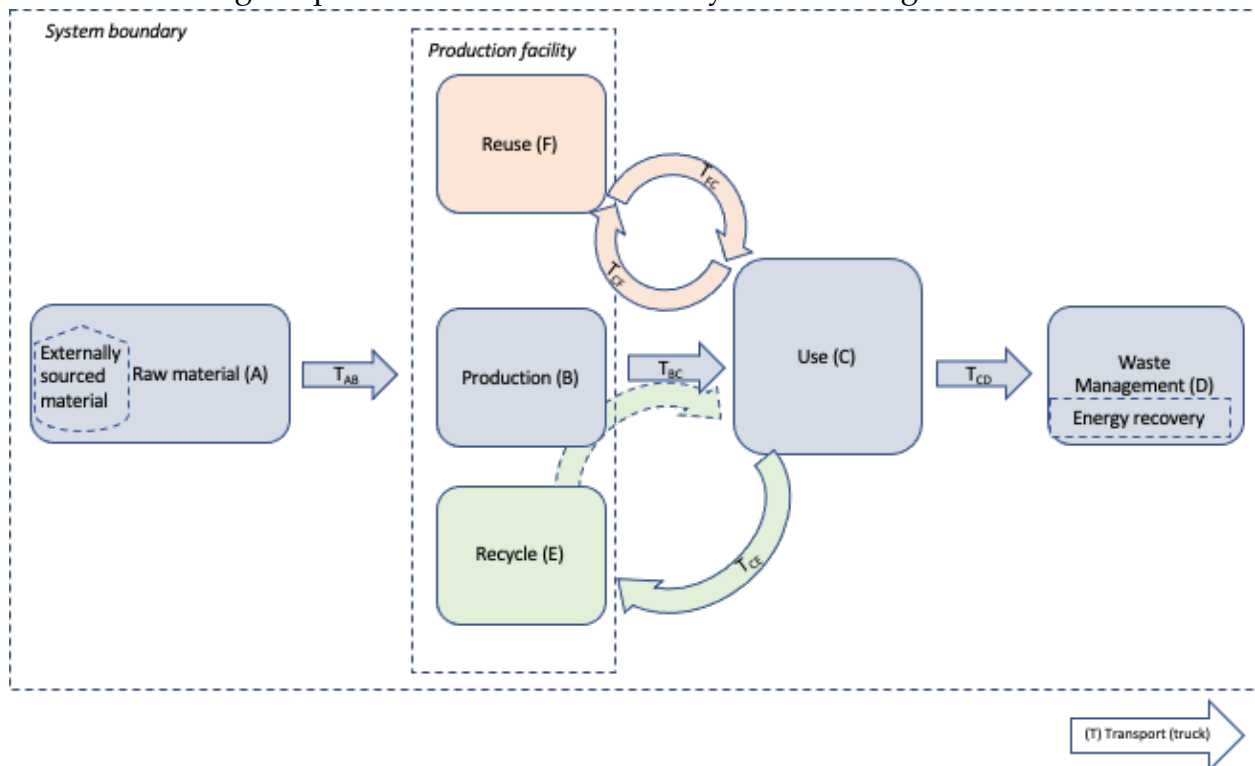


FIGURE 6. REUSE MATERIAL FLOW, WITH A TAKE-BACK AND PSS BUSINESS MODEL

2.2 Modeling and calculations

The model of MFA in combination of the R10 circularity strategies framework is in this section represented by Table 2 and Table 3. This is the general model including all circular strategies from R10, see figure 2.

As displayed in table 2 the material flow combined with the circular strategies enabling analysis of the parameter climate impact. The functional unit is climate impact/year (kg CO₂ eqv./year). The different MFA phases listed are summarized to a climate impact (GWP) per product or product set. By using the baseline calculation of a Δ (kg CO₂ eqv.) and % Δ is possible.

Table 1

Material flow scenario per product or product set as environmental impact assessment.

Circular strategy (CS)	Climate impact (kg CO ₂ eqv.)/use (3 yrs)	Climate impact (kg CO ₂ eqv.)/year	Δ % (kg CO ₂ eqv.) diff. Base line	Climate impact per product/material flow phase												
				Raw material	Transport	Production	Transport	Use	Transport	Waste management	Transport	Recycle	Transport	Reuse	Transport For the case specific MFA phase
Baseline (linear)																
Refuse																
Rethink																
Reduce																
Reuse																
Repair																
Refurbish																
Remanufacture																
Repurpose																
Recycle																
Recover																

Table 3 show the material flow in combination with the circular strategies enabling analysis of the parameter profitability defined as the functional unit is Profitability/year (SEK/year). The model includes the variables; cost, sales price, gross profit, and gross margin as basis for the Δ % gross margin. The cost per material flow phase is summarized and giving a sales price the gross margin and gross margin Δ can be calculated.

$$\begin{aligned}
 \text{Gross profit} &= \text{Sales price} - \text{Cost} \\
 \text{Gross margin\%} &= \text{Gross profit} / \text{Revenue} \\
 \Delta\% \text{ Gross margin} &= \\
 &(\text{Gross margin CS} - \text{Gross margin Baseline}) / \text{Gross margin Baseline}
 \end{aligned}$$

Table 2

Material flow scenario per product and product set used for profitability assessment.

						Profit per product/material flow phase												
Circular strategy (CS)	Cost (SEK)	Sales Price (SEK)	Gross Profit (SEK)	Gross Margin (%)	Δ % gross margin	Raw material	Transport	Production	Transport	Use	Transport	Waste management	Transport	Recycle	Transport	Reuse	Transport For the case specific MFA phase
Baseline (linear)																		
Refuse																		
Rethink																		
Reduce																		
Reuse																		
Repair																		
Refurbish																		
Remanufacture																		
Repurpose																		
Recycle																		
Recover																		

2.3 Circular strategies and business models

The circular business model is represented as material flow scenarios based on the circular strategies. In this study these are *Linear flow*, *Recycle flow*, and *Reuse flow* for a product and a product set, i.e. all the products in circulation at a given time.

- Baseline: a linear process of producing and selling product(s)
- Recycle: collect old products to use as raw material into the production line
- Reuse: collect old product for a new use period

The scope of these limited circular represents the climate impact and profitability models in table 4 and 5.

Table 3

Baseline, Reuse and Recycle applied for the MFA phases for climate impact.

				Climate impact per product/material flow phase											
Circular material flow scenario:	Climate impact kg CO ₂ eqv.	Climate impact kg CO ₂ eqv./use years	Δ % (kg CO ₂ eqv.) <i>diff. Base line</i>	Raw material (A)	Transport (T _{AB})	Production (B)	Transport (T _{BC})	Use (C)	Transport (T _{CD})	Waste management (D)	Transport (T _{CE})	Recycle (E)	Transport (T _{CF})	Reuse (F)	Transport (T _{FC})
Baseline (linear)															
Reuse															
Recycle															

Table 4

Baseline, Reuse and Recycle applied for the MFA phases for profitability.

						Profit per product/material flow phase											
Circular material flow scenario	Cost (SEK)	Sell price (SEK)	Gross profit	Gross margin	Δ % gross margin	Raw material (A)	Transport (T _{AB})	Production (B)	Transport (T _{BC})	Use (C)	Transport (T _{CD})	Waste management (D)	Transport (T _{CE})	Recycle (E)	Transport (T _{CF})	Reuse (F)	Transport (T _{FC})
	Baseline (linear)																
	Reuse																
	Recycle																

A refinement of the circular strategy scenario Reuse is used to analyze different circular business model. These are defined as; Take-back (pre-owned selling) and Product Service System (PSS).

- Take-back: a collection of old products already in use by customers, for a circulation back to facility to be cleaned, repaired, sold, and distributed for use again.
- PSS: a rental set up where ownership remains with the producer. Collection of products when the rental period is due, to clean, repair and sell again as a second or third use period for further circulation. (Ritzén and Sandström)

In the calculation, analysis and discussion of the circular business models the dimension of product set is used. Product set is representing the product stock in circulation and in use by customers, it can be 1st, 2nd, or 3rd use loop. In the analysis the circular business models are also compared to the baseline of linear business model (product set).

2.3.1 Limitations

The study is performed using fictive producing companies in Sweden for testing the model. The recycling scenario is limited to the collection of the company's original products, i.e., no externally recycled material or industrial symbiosis are considered. The reuse scenarios apply to the circular business models of take-back products and PSS. Both are limited to collection products originating from the company. The Reuse material flow scenario includes the cleaning, repairing, and/or refurbishing.

2.4 Data

The data used was inspired by discussions with two un-named product companies in Sweden. From the discussions qualified assumptions defined the climate impact and

economic parameters. In Appendix A and Appendix B the data used in detail are listed and the entire calculations are accessible.

2.4.1 Case 1

This example case 1 was constructed as a 6 kg product distributed in low volume but with high gross margin. Figure 7. Illustrated this case with the margin set to 30%. For the upcoming calculations of product sets and number of products in circulations over the use phases (1-3) the number of 100 products were used.

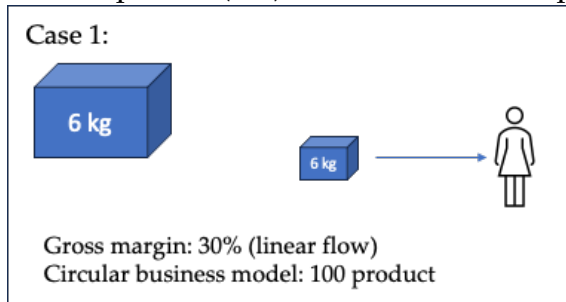


FIGURE 7. CASE 1, 6 KG PRODUCT AND 100 PRODUCT SET

2.4.2 Case 2

This example case 2 was constructed as a 0,02 kg product distributed in high volume but with low gross margin. Figure 8. Illustrated this case with the margin set to 10%. For the upcoming calculations of product sets and number of products in circulations over the use phases (1-3) the number of 30 000 products were used.

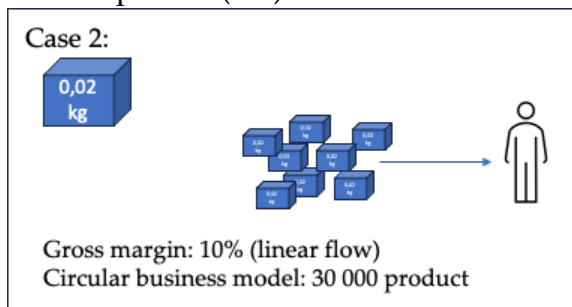


FIGURE 8. CASE 2, 0,02 KG PRODUCT AND 30 000 PRODUCT SET

2.4.3 Common parameters, variables, and assumptions

The analysis is done from a micro-perspective i.e., per product and a meso-perspective of the business model approach with a product set. The use loops used are set to be three years use period, however the result in section 3 is showed as an average per year.

For the model validation generic approximative data is differing dependent on the circular flow are cost, sell price, and recycled material. The defined parameters used and listed in figure 7, figure 8 and in table 5. The quota of recycled material in the differ

loops and circular business models are set according to qualified guessing of reasonable level and listed in table 5. The rows five-seven illustrate the split of the products sets over the use periods.

Commonly used and case specific variables summarized for products, product sets and circular business models

Table 5.

Circular business model, cases and variables.

Circular business models:	Linear		Take-back		PSS	
Case:	1	2	1	2	1	2
Number of products in product set	100	30 000	100	30 000	100	30 000
Quota Recycled raw material 1 st use loop	0%		40%		80%	
Number of products set in 1 st use loop	100%	100%	55	16 500	33,3	10 000
Reusable products 2 nd use loop	0	0	33	9 900	33,3	10 000
Reusable products 3 rd use loop	0	0	12	30 000	33,3	10 000

Further the transportation is set to an average transportation distance. More detailed data used see appendix 1 and 2 and the column, *Assumptions and variable calculations*.

3 Result

The result from the study is structured and visualized in diagrams according to the cases (Case 1 and Case 2) and structured accordingly:

- Climate impact per product (circular strategy)
- Climate impact per product set (circular business model)
- Profitability per product (circular strategy)
- Profitability per product set (circular business model)

A summary of the parameters used is listed in table 5.

Table 6

Parameter summary.

Circular strategies:	Recycle	Reuse
Circular Business models:	Take-back	PSS
Functional units:	GWP (Kg CO2 equivalences per year)	Profitability (SEK/year)
Dimensions	Product	Product sets
Data test example Cases:	Case 1	Case 2

For the diagrams corresponding data calculations see appendix A table A1-A4 and appendix B table B1-B4.

3.1 Case 1

Case 1 consists of a low volume product with a high gross margin, see section 2.4.1 and figure 7 for more details.

3.1.1 Climate impact per product

The climate impact per product and year declared per circular strategy are shown in figure 9. The reuse flow 1st and isolated as a reuse loop gives an impact of 3,67 kg CO₂ eqv./year. The second and third loop consider the first baseline use period as well, which give higher values than the isolated loop. The Baseline has 14,67, Recycle 10,93 and Reuse 6,11 kg CO₂ eqv./year (average after 3 use loops). The longer the product is in use the lower the impact. Calculating all the three phases and split as an average climate impact per year give the last delta value *Reuse 3rd loop*.

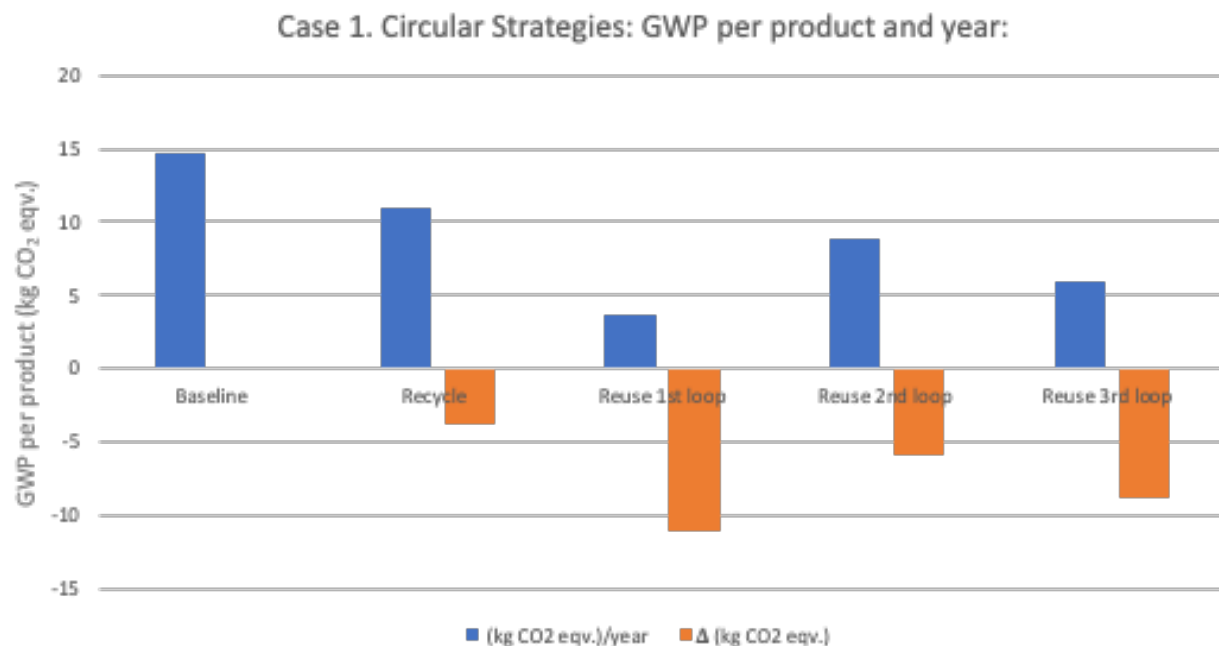


FIGURE 9. CLIMATE IMPACT PER PRODUCT AND USE. SHOWING THE RESULT OF THE CIRCULAR STRATEGIES RECYCLE AND REUSE INCL. USE LOOPS

3.1.2 Climate impact per business model

The result of climate impact per business model is divided in two diagrams, one per business model (Take-back and PSS). For calculations see appendix A table A2.

For the Take-back business model, the level of recycled material is assumed to be bigger than the baseline, which gives a lower climate impact initially. Figure 10 show the environmental impact for Take-back of 100 products in circulation and the split assumed to be dropping per use phase according to (1st 55, 2nd 33 and 3rd %).



FIGURE 10. TAKE-BACK: GWP PER PRODUCT SET (100 PRODUCTS) WITH THE SPLIT (1ST 55, 2ND 33 AND 3RD 12).

For the reuse business model PSS 100% of the products circulate back in this scenario. With a split of one third in each use loop giving a lower climate impact for each use year. In table 10 the GWP for the Take-back business model is visualized.

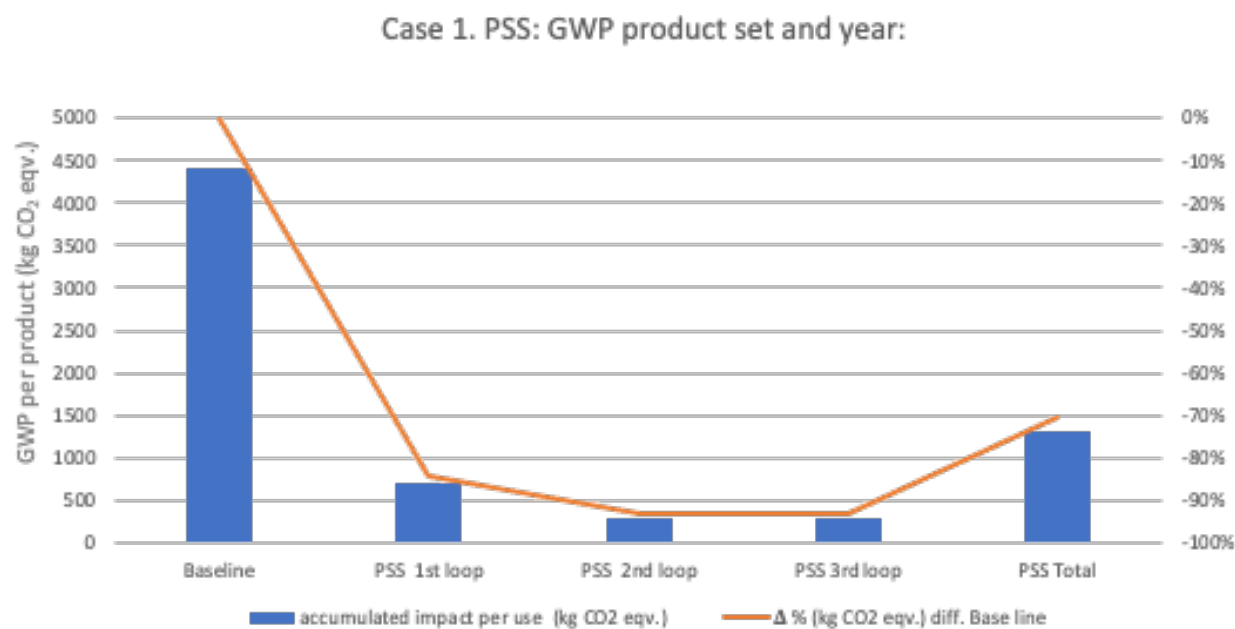


FIGURE 11. PSS: GWP PER PRODUCT SET (100 PRODUCTS) WITH THE SPLIT (1ST 33,3, 2ND 33,3 AND 3RD 33,3).

3.1.3 Profitability per product

The profitability assessment used the parameters cost, sell price, gross profit, and gross profit margin. Gross margin for baseline is 30%. Figure 12 show the product perspective over the circular strategies.

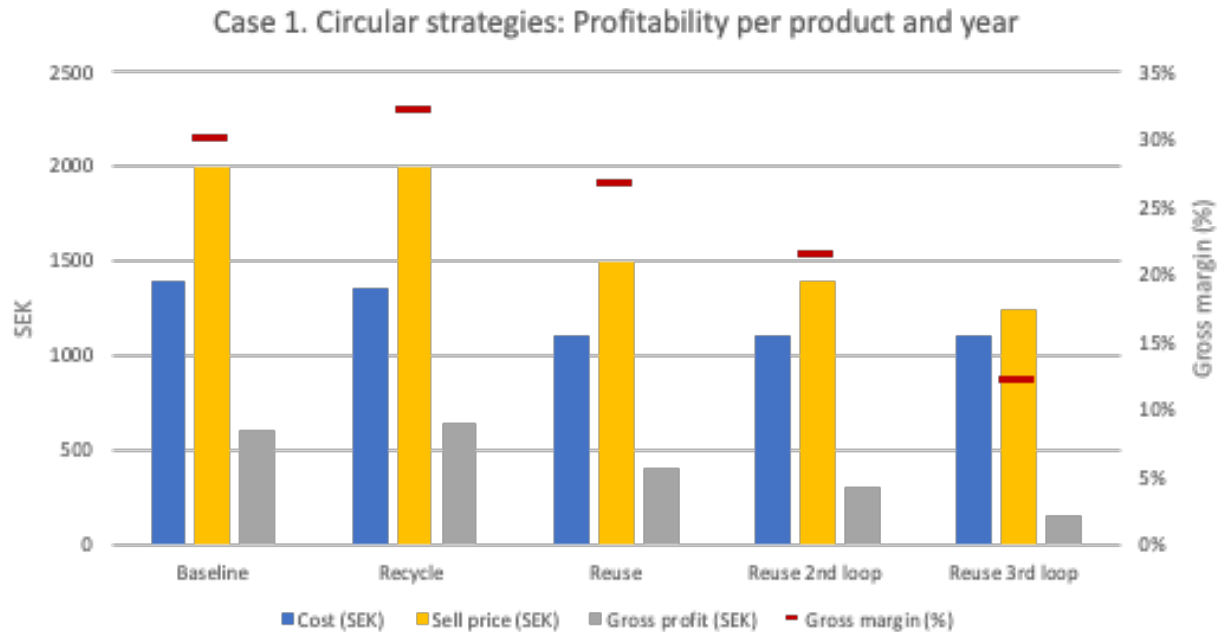


FIGURE 12. PROFITABILITY PER PRODUCT AND PER USE YEAR ASSESSED BY THE PARAMETERS COST, SELL PRICE, GROSS PROFIT AND GROSS PROFIT MARGIN. THE DIAGRAM SHOW THE RESULT PER CIRCULAR STRATEGIES RECYCLE AND REUSE (INCL. THE USE LOOPS)

The result show that the recycle gives higher profitability, affected by the lower resource cost with maintained sell price. In the isolated loop of reuse scenario, the profitability remains at a similar level even with a lower sell price for take-back products. However, the profit drops with each additional usage period that the product goes through, due to transportation costs per usage loop stands for a bigger part.

3.1.4 Profitability per business model

The assessment of the circular business model Take-back of the product set of 100 product in circulation is show in figure 13. The profitability of the Take-back are not reaching the baseline level. The total Take-back profitability is not reaching the baseline level in gross margin ($\Delta=-9\%$) nor gross profit.

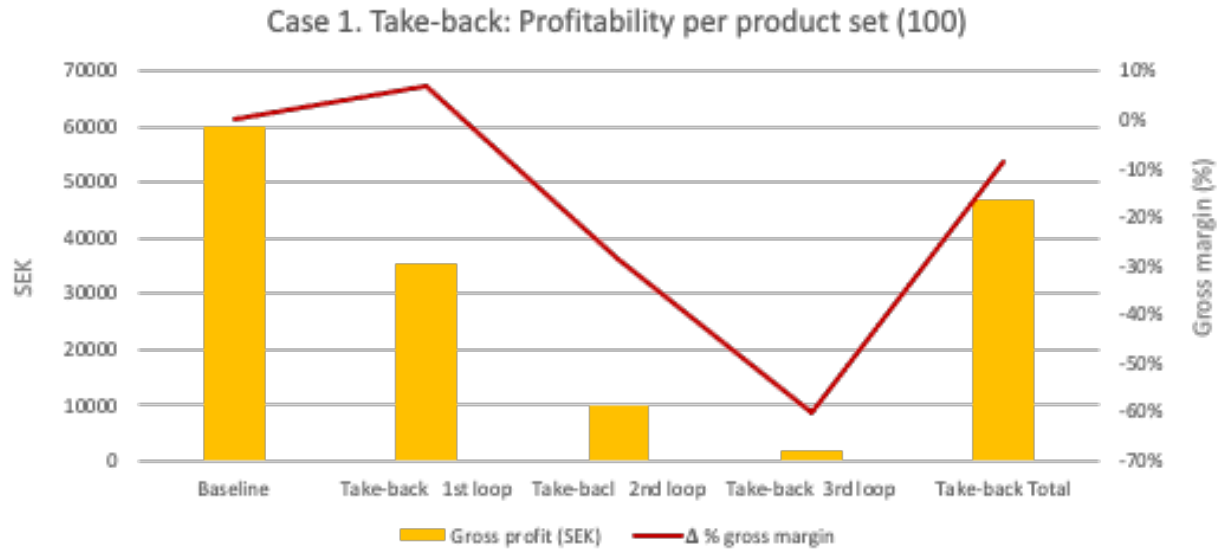


FIGURE 13. ASSESSMENT OF PROFITABILITY TAKE-BACK PER USE YEAR, USING THE PARAMETERS GROSS PROFIT AND $\Delta\%$ GROSS MARGIN. THE PROFITABILITY PER USE LOOP ACCORDING TO THE SPLIT (1ST 55, 2ND 33 AND 3RD 12).

Profitability assessment for PSS is represented by figure 14. The total PSS profitability is not reaching the baseline level in gross margin ($\Delta=-6\%$) nor gross profit.

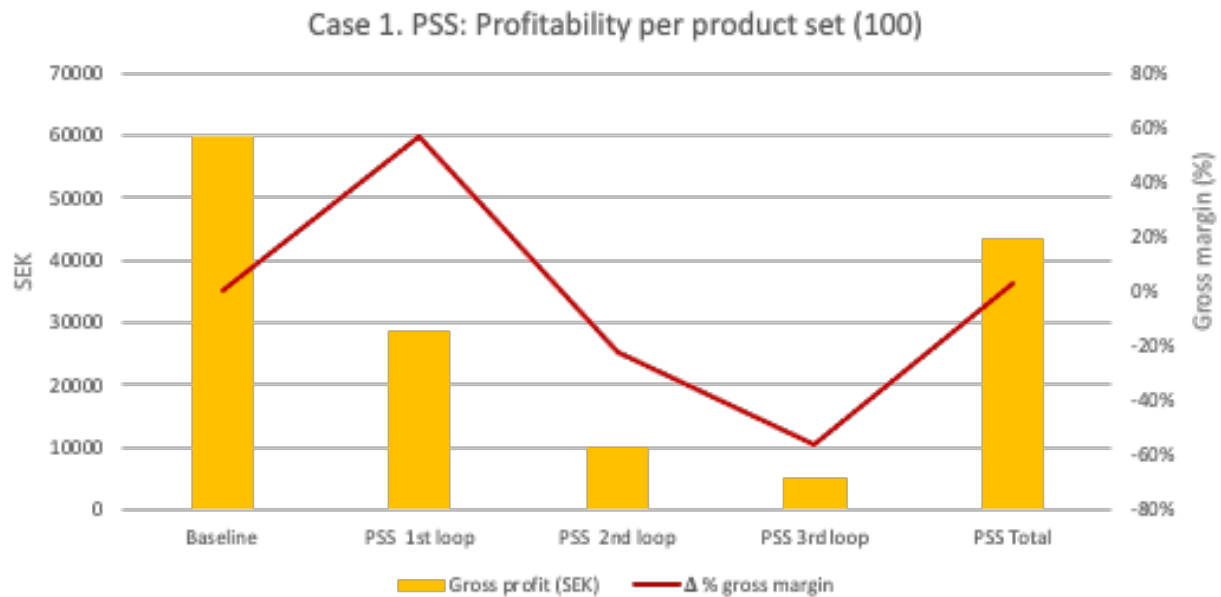


FIGURE 14. ASSESSMENT OF PROFITABILITY PSS PER USE YEAR, USING THE PARAMETERS GROSS PROFIT AND $\Delta\%$ GROSS MARGIN. THE PROFITABILITY PER USE LOOP ACCORDING TO THE SPLIT (1ST 33,3 2ND 33,3 AND 3RD 33,3).

3.2 Case 2

Case 2 consist of a 30 000 product with a 10% (linear flow), see figure 8 for more details.

3.2.1 Climate impact per product

The reuse flow isolated as a 1st reuse loop gives an GWP of 0,01 kg CO₂ eqv./year. The second and third loop consider the first baseline use period as well, which give higher values than the isolated loop. The Baseline has 0,39, Recycle 0,37, and Reuse total 0,13 kg CO₂ eqv/year (average after 3 use loops). The longer the product is in use the lower the impact. Calculating all the three phases and split as an average climate impact per year give the last delta value *Reuse 3rd loop*.

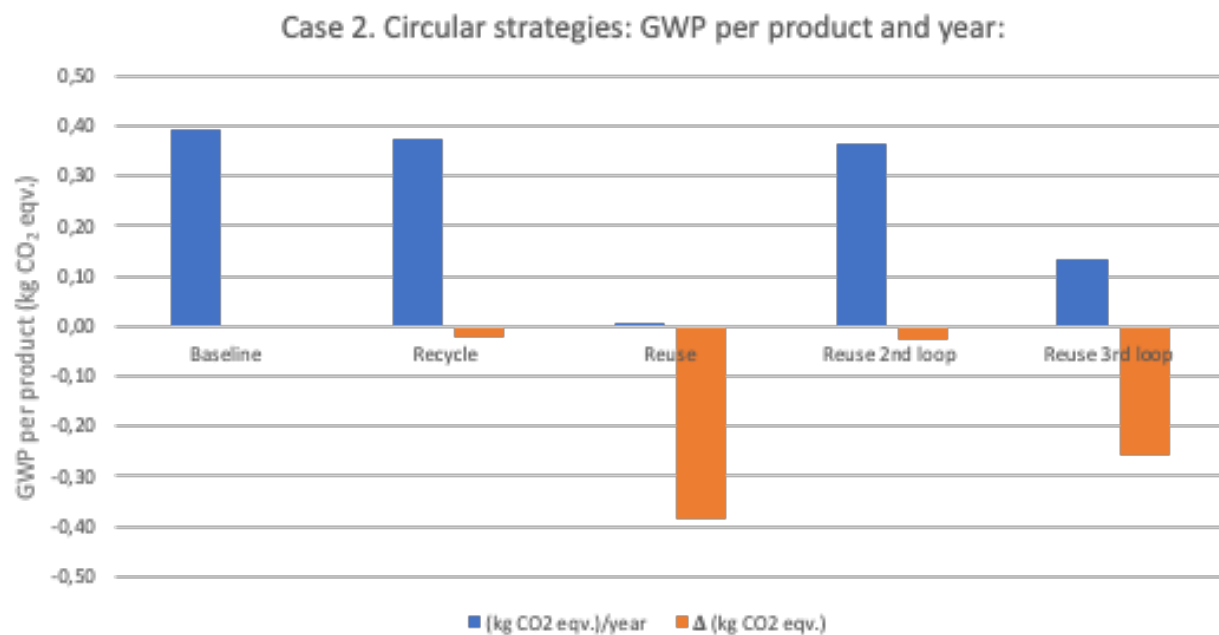


FIGURE 15. CLIMATE IMPACT PER PRODUCT AND USE. SHOWING THE RESULT OF THE CIRCULAR STRATEGIES RECYCLE AND REUSE INCL. USE LOOPS

3.2.2 Climate impact per business model

Figure 16 show the GWP per Take-back business model of 30000 products in circulation. The split of the products in 2nd and 3rd loops differ due to the assumed possibility to re-collect products in the take-back business model.

The split of the 30000 products over the use loops is (1st 55%, 2nd 33% and 3rd 12%). The actual reuse appears in the 2nd and 3rd loops since the 1st loop is almost equal to baseline with the difference of the level of recycled material is assumed to be bigger than the baseline, which gives a lower climate impact initially.



FIGURE 16. TAKE-BACK: GWP PER PRODUCT SET (30 000 PRODUCTS) WITH THE SPLIT (1ST 16 500, 2ND 9 900 AND 3RD 3 600).

For PSS business model, the assumption of 100% of the products are circulate back give the result shown I figure 17. The 100% products returning the amount of virgin raw materials that are replaced by recycled material is higher.

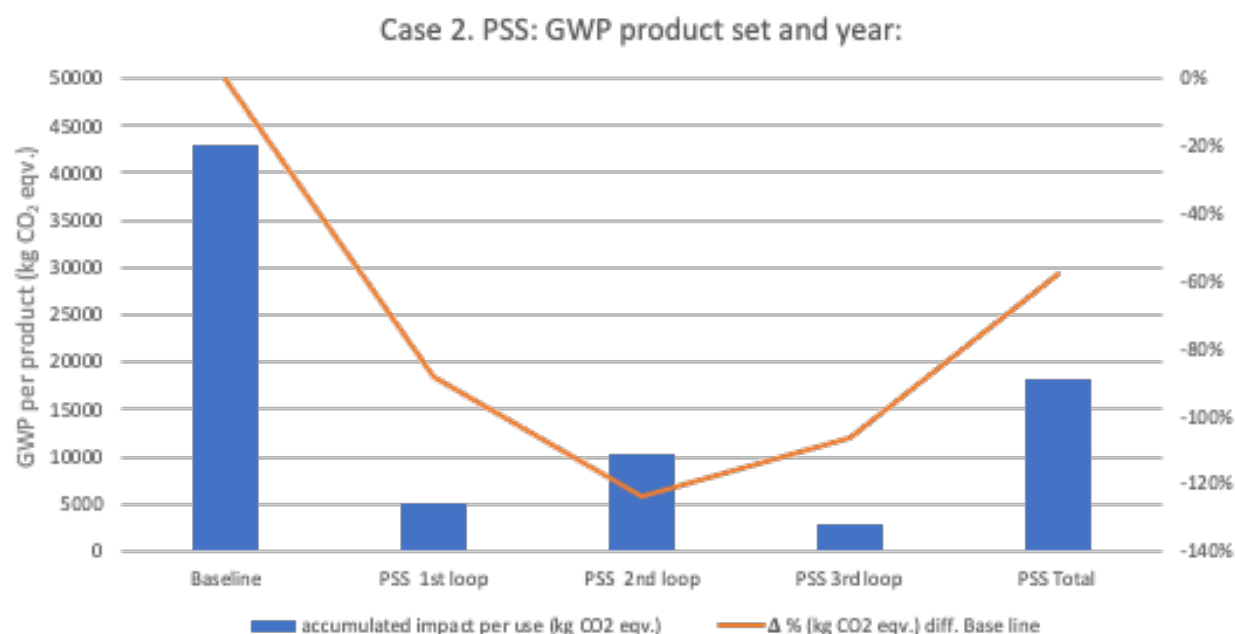


FIGURE 17. PSS: GWP PER PRODUCT SET (30 000 PRODUCTS) WITH THE SPLIT (1ST 10 000, 2ND 10 000 AND 3RD 10 000).

3.2.3 Profitability per product

Profitability assessment of Case 2 single product is shown in figure 18. The linear baseline gross margin is set to 10%, for recycle it is 27% and after 3rd loop Reuse the gross margin is 53%. The increase in gross profit follow the same tendency.

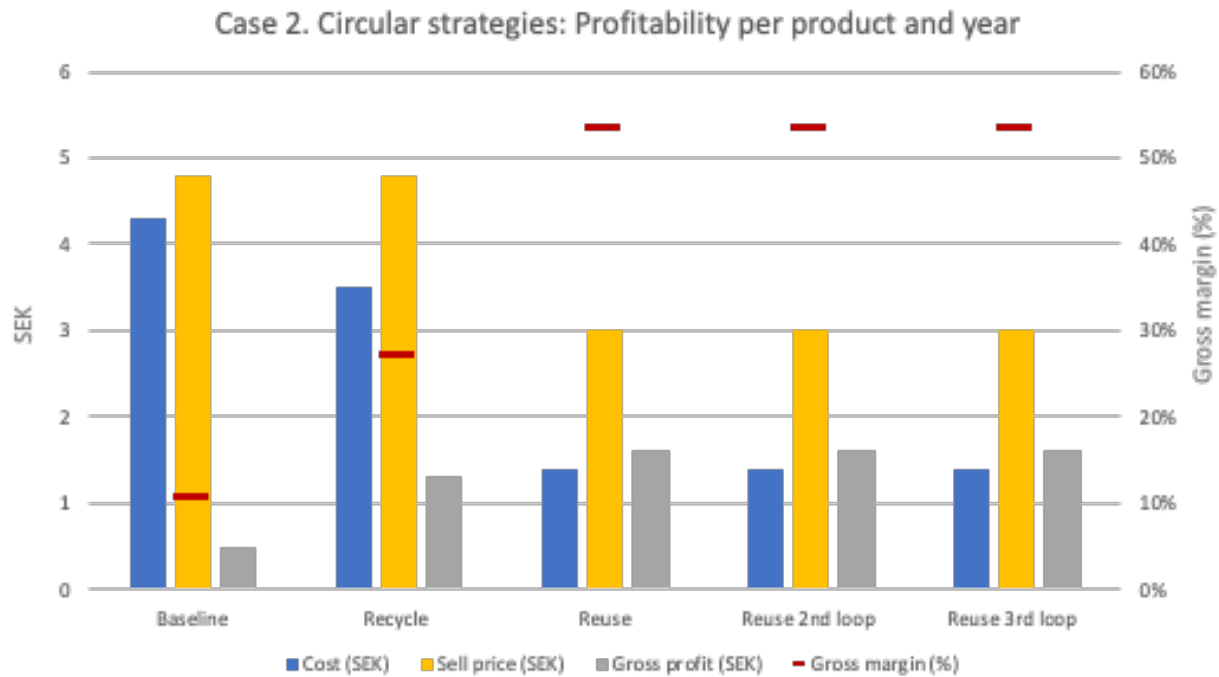


FIGURE 18. PROFITABILITY PER PRODUCT AND PER USE YEAR

3.2.4 Profitability per business model

In Figure 19 the gross margin shows the potential profitability of a Take-back business model. The potential profit expressed in $\Delta\%$ gross margin show a significant increase, 240% for all use loops (*Take-back Total*), of business model Take-back in relation to Baseline.



FIGURE 19. TAKE-BACK: PROFITABILITY PER USE YEAR 30 000 PRODUCTS IN TOTAL (1ST LOOP 16 500, 2ND LOOP 9 900 AND 3RD LOOP 3 600).

In Figure 20 the gross margin shows the potential profitability of a PSS business model. The potential profit expressed in Δ % gross margin show a significant increase, 435% for all use loops (*PSS Total*), of business model PSS in relation to Baseline.

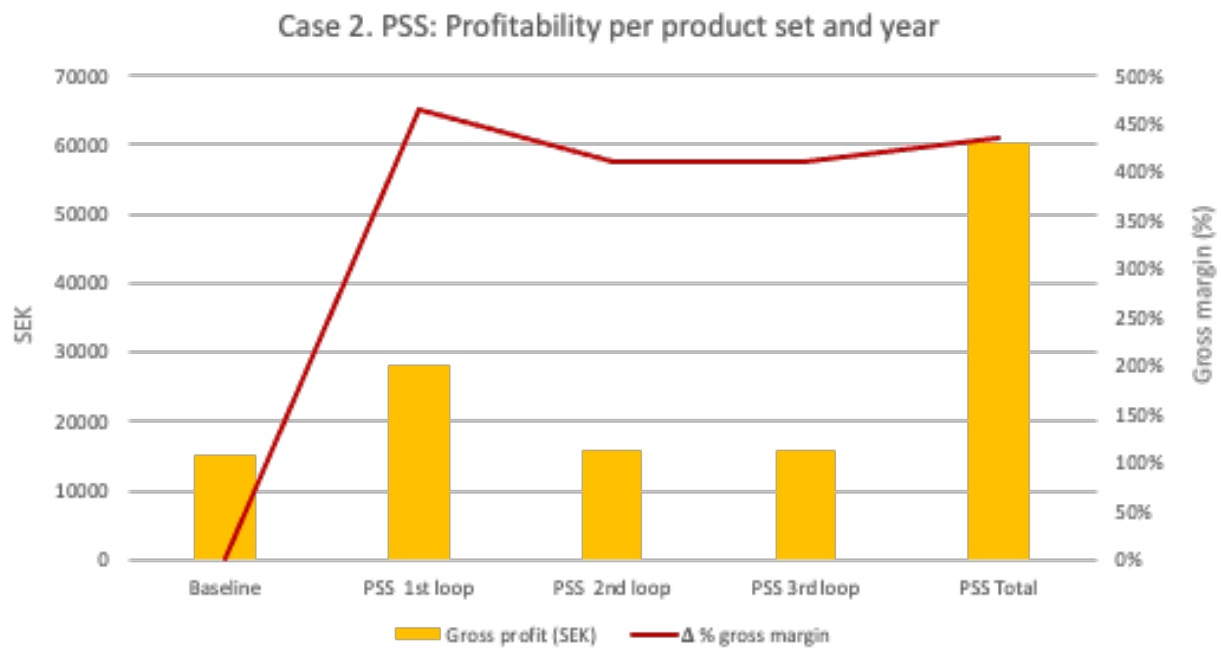


FIGURE 20. PSS: PROFITABILITY PER USE YEAR 30 000 PRODUCTS IN TOTAL (1ST LOOP 10 000, 2ND LOOP 10 000 AND 3RD LOOP 10 000).

3.3 Result Analysis

To analyzing the result in section 3.1 and 3.2 an assessment framework for circular business models has been developed. The framework is based on a coordinate system with origin representing baseline in the center. The orange and blue dots representing the differences as climate impact $\Delta\%$ and gross margin $\Delta\%$

3.3.1 Assessment of circular business models

Figure 21 show the suggested assessment model as a two-dimensional for circular business models. The model can be used for comparing different circular business models, with different material flows.

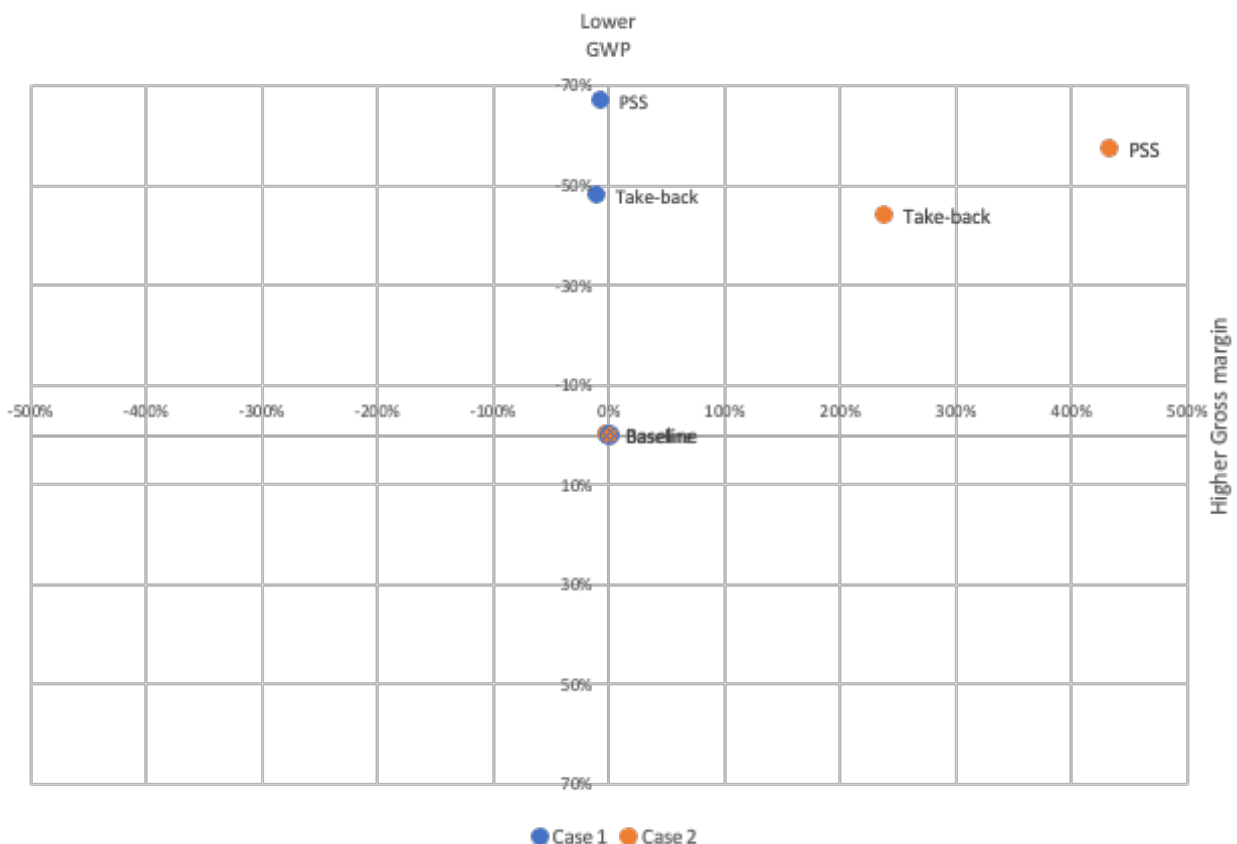


FIGURE 21. ASSESSMENT MODEL OF CIRCULAR BUSINESS MODELS

The result presented in the *Assessment of circular business models* is aligned with the R10-framework concluding that higher on circularity level the lower the environmental impact. The two cases follow the same pattern, however for the profitability there is a difference. Dependent on the business model this affect the outcome as well as how much of the impact is origin from transportation per unit. The transport in case 1 stands for a significant part of the cost with the heavier products with a low volume. The transport does not have the same impact on the profitability for the high-volume light

weight products. Quite the opposite where more products circle back give a higher the gross margin.

As a further development of the indicator the model could be represented as in Figure 15. This shows an even more scaled and general model showing how different circular pathways an organization can embark on. This can be used as a visual input for strategic business decisions all depended on the objective of the organization. In regards of sustainability for example. Adding a field of sustainability to the four squares can indicate where to aim with a product, circular business model or other relevant change activity.

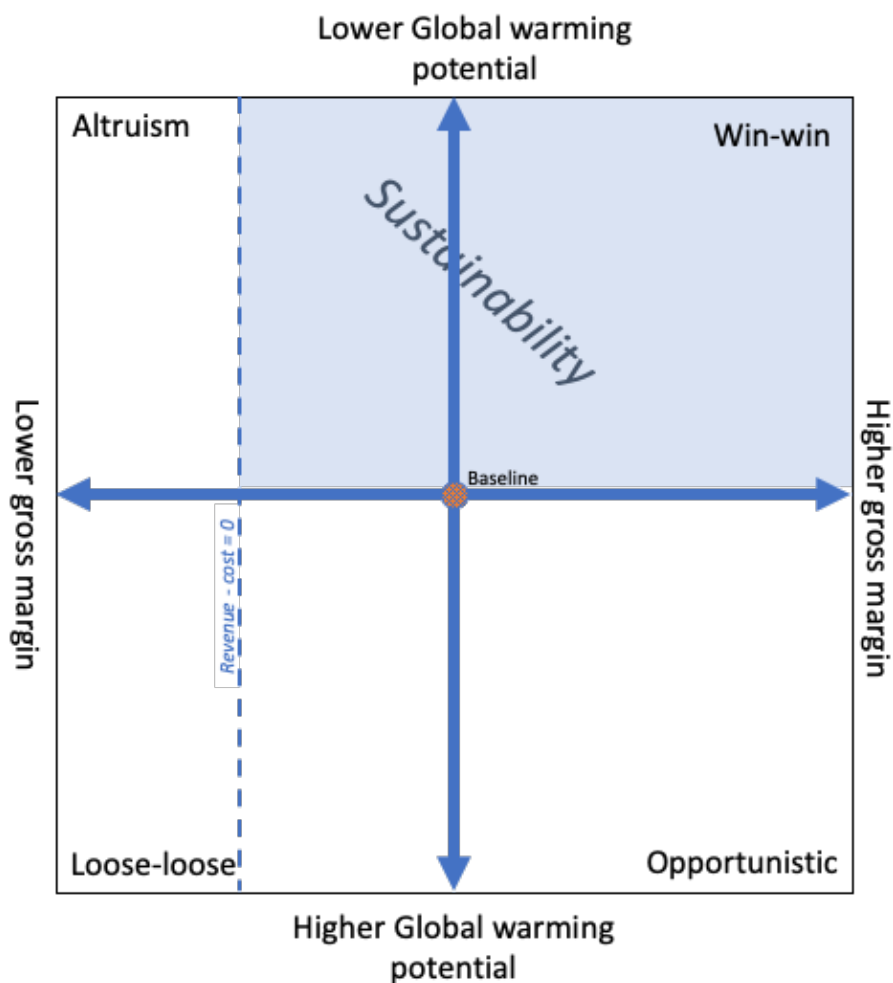


FIGURE 22. GENERIC ASSESSMENT OF CIRCULAR BUSINESS MODELS

4 Discussion

In general, regarding the overall concepts of circular economy, the fields would benefit from a standardized definition. A standard would bring some clarity and make the theory of circular economy usable with less scientific hesitation which would be useful for research and in practice.

4.1 Method discussion

The study was exploratory as the method were conceptualized modeling for testing the objective of MFA as a circularity assessment. The validation section was consisted of quantitative and fictive data. As the data used was inspired by real cases the data can I overall be considered imaginary. This can be seen as a weakness of the study, however following the procedure of the conceptualization the used data is losing importance for these specific cases. For further research a case study would be beneficial for the development and validity of the MFA as assessment model for circular economy activities and the assessment model of circular business models (Figure 21 and 22)

4.1.1 Data Collection

The data used is inspired by discussions with un-named organizations and from which qualified assumptions of climate impact and financial parameters were defined.

The purpose of this study was to develop a model to investigate the differences in climate impact and profitability when using different circular strategies (level of circularity) how does this effect the outcome). So, the relevance was to investigate two different levels of circularity ((R# of the R10 framework) and to differentiate the business set ups (the Case 1 and Case 2). With this what kind of product is not mentioned in the study and is in this research considered irrelevant as the circular strategies is the subject of investigation using climate impact and profitability as parameters.

4.1.2 Method improvements

The method can be developed further with more aspects and parameters for an even more fine-grained result, and accuracy. An extended MFA or LCA could be done but not within the frame of this study. For more accurate figures as an assessment of a real case scenario.

The allocation issue of use to the first use loop affected the result. Give for example a very low climate impact for the first reuse loop that only consisted of transportation,

clean and repair posts. This allocation method could be developed to be more even split of the climate impact over the product lifetime all use phases.

In these calculations the MFA flows are assumed to be the same. This would for a case study be different between different products. Two products have seldom the exact same flow even if the material composition is identical, parameters such as location, distribution, energy consumption, raw material cost etc.

4.1.3 Scope

The definition of the functional unit and the allocation of the impact per product and use phase affect the result. The use loop could have been defined as longer or shorter. The financial parameter of $\Delta\%$ gross margin gave one this, however the increased margin does not necessary relate linear to a increased revenue.

The approach to compare the output with the origin baseline also effect the result especially considering sustainability. Economic sustainability is that only increased profitability or a plus result in the financial data? With setting the baseline, this study assumed that higher gross margin was the aim.

Limitations such as the design phase was not included. The model can however be used to assess different design options for a product, where the two parameters are set to different material compositions or manufacturing processes for two different product design pathways.

As the study is performed for producing companies in Sweden the loops are kept as close as possible to the simplification of the products and materials circling back after use. If the location would have been global the transportation costs and impact would probably have had an even higher impact on the result. No industrial symbiosis is considered in this research. This could be further developed as a more complex material flow and assessed.

4.2 Result discussion

The phase of a product produced in the first place has the biggest impact independent of the product. Go back to the R10 framework the Refuse option is still the best environmentally considered. This is however not an option from a commercial aspect as a business.

The climate impact calculations confirm the theory of the Value Hill and R-10 framework, showing that keeping material and product looping at a high level of

usefulness lower the impact on the environment. This is also aligned with the principles of circular economy by Ellen MacArthur (What is a circular economy? | Ellen MacArthur Foundation, 2018). This refers to the usage period for a certain customer as well as the product's entire lifetime. If the product stays at the same customer of the entire lifetime there is a gain in climate impact compared to circulating back to facility and to other customers.

4.2.1 Recycling (product)

Recycling can be a way to secure the recycled material flow back and into the production line. The environmental benefit is as the circular strategies significant. To not extract new virgin material is a gain.

4.2.2 Recycling (Business model)

Dependent on the difference between the raw material cost and the recycled material the circular strategy of looping back products and materials can be profitable. The PPS business model such as a leasing agreement gives the company control of the material flow and can that way secure the recycled material sourcing back to the production line.

4.2.2 Reuse (product)

In the reuse scenarios, the first use is the same as the linear flow, the second round has a much lower impact looking at the usage and transport only. However, looking at the second usage the impact is still much lower than the linear scenario, calculated over the entire lifetime and divided by the number of years as the functional unit describes. For the third usage period, the climate impact is reduced even more with the increased number of usage years. Aligned with this, how long the use period is set to affect the results in this study. Short use periods but long lifetime result in transport and maintenance becoming a greater part of the impact. Calculating the same life span, where one product is used over nine years by a single owner the transportation, repair, and refurbish can be ignored.

4.2.3 Reuse (Business model)

Reuse has the most potential to reduce the climate impact but could have a big effect on the business to adjust to a new business model with a new pricing model and logistic challenges to take back and potentially store returned goods. A challenge here is also to adapt to an uneven flow of returning products and planning difficulty. For the business model, the take-back scenario variables are affecting the impact. For example, case 1 with a high margin but with low volume the transportation cost is already in the first reuse cycle adding up to a significant impact on the financial result.

The business model and the profitability are affected by the number of products in circulation in usage periods two and three. In the rental business model, all products are assumed to be coming back to the facilities. Meanwhile, in the take-back business model, more products are assumed to be in the first usage period and fewer in the third. The first use period for Case 1 products is the most profitable which effect the result and the climate impact increase as well as the costs with the amount of transportation.

The business model applied for Case 2 has not had the same impact per product as the examples in the study. There is potential for the PSS business model shows that profitability increases due to increased margin. This is enabled by the low transportation and maintenance cost per product in circulation.

If the purpose is investigating the actual gross profit the actual monetary number is to be used. This study is however aiming to validate the indication of a business model and no specific figure. So even though the Take-back business model has a lower profit the gross margin (35%) is higher than the baseline (10%).

4.3 Analysis discussion

The *assessment model of the business models* is developed as a tool to analyze the result of the two functional units in one view as the concepts of climate impact and economic factor both must be considered in a business situation. Do the two parameters show a positive direction, one of them or none. As a new a suggested model this is a useful visualization tool of the parameters

4.3.1 Climate impact business model(s)

All activities that reduce the climate impact could be considered a development of the toward a more sustainable business. However, reality tend to be more complex. For example, one product could be much more profitable with a new composition with higher climate impact. But the profit from that product could enable investment for a greener technology in other parts of the organization. So as always, a holistic approach is necessary.

4.3.2 Profitability of business model(s)

There must be incitements for the company as well as the customer for the business model to be successful. For the company, a contribution to the profitability is required and for the customer, there are other factors. For example, a customer offer is fully developed. The company would implement an incitement for the existing customer to:

- return their already purchased products, such as for a payment or discount.
- rental with a fee, instead of an investment, with an appropriate pricing model.

Companies could be driven by other incitements than profit, such as altruism, but this can often not be the only purpose. If the goal is to reduce the climate impact, strategic sustainability goals, find new business opportunities, secure material for the production line, legal requirements, and goodwill.

The study has shown that a single product and a product volume give different results with different boundaries. Isolated loops of reuse are not realistic but can of course be taken out of context and used for a green-washed message. This indicates that to holistic assess the circular strategy the view of the material flow of the business model should be analyzed. Dependent on the purpose of the assessment the impact per product could be useful, for example as a selling argument and commercial communication.

Recycling is considered in the reuse scenarios. Besides that, this study assessed isolated business models, with no greater mix of the three. In a reality this could be a mix of business models that are trimmed and possibly adaptative according to circumstances and for maximized profitability. This requires strategic and logistics management. PSS can be a complement to an existing linear business model, where the company can serve and provide the market with more products with the same production capacity.

PSS and rental business model mean that the producing organization keep the ownership of the product which result in strategic incitements to work with the quality of the product to be long-lived and last over multiple uses. This too enhance the sustainability.

4.3.3 Assessment model of circular business models

The suggested assessment model of the circular business model the combines the ecologic and economic aspects can be applied as a sustainability indicator for the parameter GWP and profitability. Adding a social factor, the model could be three dimensional.

In figure 21 the set up seen as a change from baseline(origin). Lower gross profit is not desired for societies, organizations nor individuals. Our external exponential growth paradigm doesn't access lower growth. Even if you after applying this model end up with a result such as for case 1, it is most likely bad (economic). Even though there are still a gross margin and a profit. As from a climate sustainability perspective all above the x-axis should be considered sustainable.

Figure 22 is a further conceptualized and development to show the growth obsession of our time, where only increased profit is considered successful, all other cases is a failure. Even though all right to the dotted line is a profitable scenario. Dependent on the business set up and owner structure etc. this will most likely influence the way the figure is interpreted.

For some companies, this transformation could require a radically new business model. On the other hand, a system changes towards a circular business model from a fraction of the production, allowing some initial cost, can be a way to test new more sustainable processes.

5 Conclusion

This study has contributed to the developing concepts of circular economy by assessing circular business models and to test different approaches for circularity in a measurable and practical way. By showing that MFA in combination with principles for circular economy can be used as a method to evaluate effect of circular strategies as circular business models. The evaluation of circular strategies effects on financial aspect and climate impact by applying MFA, work as an assessment method for circular business models. This is visualized in the *Assessment model for circular business models* where analysis of climate impact (GWP) and financial (gross margin) aspects are visualized all in accordance with the objective of this study.

The climate impact per product gives a fraction of the climate impact of the business. The result can be used as communication but must be considered an isolated scenario and risk to be miss-guiding and perhaps even used for green-washing if not considered properly.

As to climate impact per business model give a more holistic approach where the result from the MFA is show for all products. The result section shows the same pattern for both the products but on different scale. This indicates that if the conditions result in the same conclusion that process, and distribution have a similar effect on the climate impact. The result show that circular strategies with higher level of circularity also result in lower the climate impact. Circulation time is also a factor to consider, where longer lifetime means lower annual climate impact.

The MFA of profitability for single product is showing differences between the cases. Analyzing one product risk to not give a realistic view, if not the allocation of impact and cost is done thoroughly.

The profitability of a circular business model depends on the volume, the transportation distance, transportation cost. The low volume products also had high costs for transportation, effecting the profit negatively. There is dependence to the share of material cycled back to replace virgin raw material, especially for the high-volume company effecting the profit positively. This can be done control of the material flow, as in the PSS business model where business opportunities, savings with replacement of raw virgin material and of rental of already produced and use product is given another use loop.

The Assessment model of circular business models is a useful tool for decision making in organization when both the parameters of climate impact and profitability need to be considered in parallel. The two-dimension align with two of the pillars of sustainability, ecologic and economic therefore sustainability assessment an also be relevant for the method and the Generic Assessment of circular business models (figure 22). As the result confirmed the value hill showing that slowing down products and material processes with reduced garbage as an outcome which resulting in a regenerative approach where new value is created. This is a householding of resources to keep them useful to humans, and a mean to reduce the dependence on extracted resources. That way a recourse scarcity could be avoided, and perhaps prove Malthus wrong once more, that we are in fact able to feed and provide for the entire population. As for a sustainable method circular economy and control of the material flow can provide a sustainable future for the system of planet Earth.

6 Further research

Further development of the two-dimensional assessment model for circular business models with more functional units are needed. More economic factors can be added to the assessment to divers the analysis. The next step would be to test the study and concept of this study in case studies of corporate business models, products, and processes.

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APPENDIX A - Data Calculations Global warming potential

The tables (A1-A4) below summarize all MFA phases GWP to a total. The result were then compare to baseline (the linear flow) expressed as delta (Δ) in CO2 equivalences for potential climate impact reduction.

The columns *Assumptions and variables for calculations* are parameters used in the different circular strategies and circular business models.

Table A1. Case 1: GWP per product

Low volume high margin		Functional unit		Material flow phase											Assumptions and variables for calculations				
Circular material flow scenario (per product):	Climate impact (kg CO2 eqv.)/use (3 yrs)	Climate impact (kg CO2 eqv.)/year	Δ (kg CO ₂ eqv.)	Raw material (A)	Transport (T _{AB})	Production (B)	Transport (T _{BC})	Use (C)	Transport (T _{CD})	Waste management (D)	Transport (T _{CE})	Recycle (E)	Transport (T _{CF})	Reuse (F)	Transport (T _{FC})	usage years:	3		
MF _{lin} (Baseline)	44	14,67	0,00	30	1	5	4	2	1	1					energy recovery:	-2	Distribution/ collection (facility-customer)	4	
MF _{rec} (Recycle)	32,8	10,93	-3,73	18	0,6	5	4	2	0,6	0,6	1,6	0,4			recycling quota	40%	Recycle (E)	1	
MF _{reu} (Reuse)	11	3,67	-11,00					2					4	1	4	a reused product in a 2 nd loop		Reuse (incl. Repair/refirbish) (F)	1
MF _{reu} (Reuse) 2 nd loop (incl. 1 st loop = Baseline)	9	8,83	-5,83					0					4	1	4	reusable products for a 2 nd loop	100%		
MF _{reu} (Reuse) 3 rd loop (incl. 1st loop = Baseline, and 2nd loop)	9	5,89	-8,78					0					4	1	4	reusable products for a 3 rd loop	100%		

Table A2. Case 1: GWP per Business model (product set)

Low volume high margin		Functional			Material flow phase										Assumptions and variables for calculations					
Circular Material flows (per business model)		Accumulated Climate Impact per use (kg CO2 eqv.)	Product Split, (total products in rotation)	Δ % (kg CO ₂ eqv.) diff. Base line	Raw material (A)	Transport (T _{AB})	Production (B)	Transport (T _{BC})	Use (C)	Transport (T _{CD})	Waste management (D)	Transport (T _{CE})	Recycle (E)	Transport (T _{CF})	Reuse (F)	Transport (T _{FC})	usage years:	3	number of products in circulation	100
MF _{lin} (Baseline)		4400	100	0%	30	1	5	4	2	1	1					energy recovery:	-2	Distribution/ collection (facility-customer)	4	
Take-back	MF _{rec} (Recycle) 1 st loop	1804	55	-59%	18	0,6	5	4	2	0,6	0,6	1,6	0,4				recycling quota	40%	recycling, rental quota	80%
	MF _{reu} (Reuse) 2 nd loop	297	33	-93%					0					4	1	4	reusable products for a 2 nd loop	50%	Reuse (incl. Repair/refurbish) (F)	1
	MF _{reu} (Reuse) 3 rd loop	108	12	-98%					0					4	1	4	reusable products for a 3 rd loop	25%		78%
	Total	2209	100	-50%																
PSS	MF _{rec} (Recycle) 1 st loop	700	33	-84%	6	0,2	5	4	2	0,2	0,2	3,2	0,2							
	MF _{reu} (Reuse) 2 nd loop	300	33	-93%					0					4	1	4	reusable products for a 2 nd loop	100%		
	MF _{reu} (Reuse) 3 rd loop	300	33	-93%					0					4	1	4	reusable products for a 3 rd loop	100%		
	Total	1300	100	-70%																

Table A3. Case 2: GWP per product

High volume low margin		Functional unit		Material flow phase												Assumptions and variables for calculations			
Circular material flow scenario (per product):	Climate impact (kg CO ₂ eqv.)/use (3 yrs)	Climate impact (kg CO ₂ eqv.)/year	Δ (kg CO ₂ eqv.)	Raw material (A)	Transport (T _{AB})	Production (B)	Transport (T _{BC})	Use (C)	Transport (T _{CD})	Waste management (D)	Transport (T _{CE})	Recycle (E)	Transport (T _{CF})	Reuse (F)	Transport (T _{FC})	usage years:	3		
MF _{lin} (Baseline)	1,177	0,39	0,00	0,150	0,007	0,008	0,007	0,003	1,000	0,002						energy recovery:	-0,003	Distribution/ collection (facility-customer)	0,01
MF _{rec} (Recycle)	1,12	0,37	-0,02	0,090	0,004	0,008	0,007	0,003	0,600	0,001	0,003	0,400				recycling quota	40%	Recycle (E)	1
MF _{reu} (Reuse)	0,02	0,01	-0,39					0,003					0,007	0,002	0,007	a reused product in a 2 nd loop		Reuse (incl. Repair/refurbish) (F)	0,002
MF _{reu} (Reuse) 2 nd loop (incl. 1 st loop = Baseline)	1,01	0,37	-0,03					0,000					0,007	1,00	0,007	reusable products for a 2 nd loop	100%		
MF _{reu} (Reuse) 3 rd loop (incl. 1st loop = Baseline, and 2nd loop)	0,02	0,13	-0,26					0,000					0,007	0,002	0,007	reusable products for a 3 rd loop	100%		

Table A4. Case 2: Climate impact per Business model (product set)

High volume low margin		Functional unit			Material flow phase											Assumptions and variables for calculations					
Circular Material flows (per business model)		Accumulated Climate Impact per use (kg CO2 eqv.)	Product Split, (total products in rotation)	Δ % (kg CO2 eqv.) diff. Base line	Raw material (A)	Transport (T _{AB})	Production (B)	Transport (T _{BC})	Use (C)	Transport (T _{CD})	Waste management (D)	Transport (T _{CE})	Recycle (E)	Transport (T _{CF})	Reuse (F)	Transport (T _{FC})	usage years:	3	number of products in circulation	30000	
MF _{lin} (Baseline)		42930,0	30000	0%	0,150	0,013	0,250	0,013	0,007	1,000	-0,002					energy recovery:	-0,003	Distribution/ collection (facility-customer)	0,013		
Take-back	MF _{rec} (Recycle) 1 st loop	20161,9	16500	-147%	0,090	0,008	0,250	0,013	0,007	0,600	-0,001	0,005	0,250					recycling quota	40%	recycling, rental quota	80%
	MF _{reu} (Reuse) 2 nd loop	2739,0	9900	-106%					0,000					0,013	0,250	0,013	reusable products for a 2 nd loop	50%	Reuse (incl. Repair/refirbish) (F)	0,25	
	MF _{reu} (Reuse) 3 nd loop	996,0	3600	-102%					0,000					0,013	0,250	0,013	reusable products for a 3 rd loop	25%		78%	
	Total	23896,9	30000	-44%																	
PSS	MF _{rec} (Recycle) 1 st loop	5128,7	10000	-88%	0,030	0,003	0,250	0,013	0,007	0,200	0,000	0,011	0,000								
	MF _{reu} (Reuse) 2 nd loop	10266,7	10000	-124%					0,000					0,013	1,000	0,013	reusable products for a 2 nd loop	100%			
	MF _{reu} (Reuse) 3 rd loop	2766,7	10000	-106%					0,000					0,013	0,250	0,013	reusable products for a 3 rd loop	100%			
	Total	18162,0	30000	-58%																	

APPENDIX B - Data Calculations profitability potential

The tables below (Table B1-B4) summarize all MFA phases costs to a total. Parameters used are Cost (SEK), Sales price (SEK), Gross profit (Sales price-Cost), Gross Margin (%) The result was then compared to baseline (the linear flow) expressed as delta (Δ) in gross margin delta (%).

The columns *Assumptions and variables for calculations* are parameters used in the different circular strategies and circular business models.

Table B1.Case 1. Profitability per product

Low volume high margin			Functional unit		Material flow phase												Assumptions and variables for calculations			
Circular material flow scenario (per product):	Cost (SEK)	Sales Price (SEK)	Gross Profit (SEK)	Gross Margin (%)	Raw material (A)	Transport (T _{AB})	Production (B)	Transport (T _{BC})	Use (C)	Transport (T _{CD})	Waste management (D)	Transport (T _{DE})	Recycle (E)	Transport (T _{EF})	Reuse (F)	Transport (T _{FC})	usage years:	3		
MF _{lin} (Baseline)	1400	2000	600	30%	600	200	200	400	0	0	0				energy recovery:	-2	Distribution/collection	400		
MF _{rec} (Recycle)	1360	2000	640	32%	360	120	200	400	0	0	0	160	120				recycling quota	40%	Recycle (E)	300
MF _{reu} (Reuse)	1100	1500	400	27%					0					400	300	400	a reused product in a 2 nd loop		Reuse (incl. Repair/refirbish) (F)	300
MF _{reu} (Reuse) 2 nd loop (incl. 1 st loop = Baseline)	1100	1400	300	21%					0					400	300	400	reuseable products for a 2 nd loop	100%		
MF _{reu} (Reuse) 3 rd loop (incl. 1st loop = Baseline, and 2nd loop)	1100	1250	150	12%					0					400	300	400	reuseable products for a 3 rd loop	100%		

Table B2. Case 1. Profitability per Business model (product set)

Low volume high margin						Functional unit			Material flow phase												Assumptions and variables for calculations			
Circular Material flows (per business model)	Product Split, (total products in rotation)	Unit Cost (SEK)	Accumulated Cost (SEK)	Sales Price (SEK)	Revenue (SEK)	Gross Profit (SEK)	Gross Margin (%)	Δ % gross margin	Raw material (A)	Transport (T _{AB})	Production (B)	Transport (T _{BC})	Use (C)	Transport (T _{CD})	Waste management (D)	Transport (T _{CE})	Recycle (E)	Transport (T _{CF})	Reuse (F)	Transport (T _{FC})	usage years:	3	number of products in circulation	100
MF _{lin} (Baseline)	100	1400	140000	2000	200000	60000	30%	0%	600	200	200	400	0	0	0						energy recovery:	-2	Distribution/collection (facility-customer). (GWP)	400
Take-back	MF _{rec} (Recycle) 1 st loop	55	1360	74800,0	2000	110000,0	35200,0	32%	7%	360	120	200	400	0	0	0	160	120			recycling quota	40%	recycling, rental quota	80%
	MF _{reu} (Reuse) 2 nd loop	33	1100	36300,0	1400	46200,0	9900,0	21%	-29%					0				400	300	400	reuseable products for a 2 nd loop	50%	Reuse (incl. Repair/refirbish) (F)	300
	MF _{reu} (Reuse) 3 rd loop	12	1100	13249,5	1250	15056,3	1806,8	12%	-60%					0				400	300	400	reuseable products for a 3 rd loop	25%		78%
	Total	100		124349,5		171256,3	46906,8	27%	-9%															
PSS	MF _{rec} (Recycle) 1 st loop	33	1140	37996,2	2000	66660,0	28663,8	43%	43%	120	40	200	400	0	0	0	320	60						
	MF _{reu} (Reuse) 2 nd loop	33	1100	36663,0	1400	46662,0	9999,0	21%	-29%					0				400	300	400	reuseable products for a 2 nd loop	100%		
	MF _{reu} (Reuse) 3 rd loop	33	1100	36663,0	1250	41662,5	4999,5	12%	-60%					0				400	300	400	reuseable products for a 3 rd loop	100%		
	Total	100		111322,2		154984,5	43662,3	28%	-6%															

Table B3. Case 2. Profitability per product

High volume low margin			Functional unit		Material flow phase												Assumptions and variables for calculations			
Circular material flow scenario (per prodcut):	Cost (SEK)	Sales Price (SEK)	Gross Profit (SEK)	Gross Margin (%)	Raw material (A)	Transport (T _{AB})	Production (B)	Transport (T _{BC})	Use (C)	Transport (T _{CD})	Waste management (D)	Transport (T _{CE})	Recycle (E)	Transport (T _{CF})	Reuse (F)	Transport (T _{FC})	usage years:	3		
MF _{lin} (Baseline)	4,3	4,8	0,5	10%	600	200	200	400	0	100	0					energy recovery:	-2	Distribution/collection (facility-	400	
MF _{rec} (Recycle)	3,5	4,8	1,3	27%	360	120	200	400	0	60	0	160	120			recycling qouta	40%	Recycle (E)	300	
MF _{reu} (Reuse)	1,4	3,0	1,6	53%					0					400	300	400	a reused product in a 2 nd loop		Reuse (incl. Repair/refirbish) (F)	300
MF _{reu} (Reuse) 2 nd loop (incl. 1 st loop = Basline)	1,4	3,0	1,6	53%					0					400	300	400	reuseable products for a 2 nd loop	100%		
MF _{reu} (Reuse) 3 rd loop (incl. 1st loop = Basline, and 2nd loop)	1,4	3,0	1,6	53%					0					400	300	400	reuseable products for a 3 rd loop	100%		

Table B4. Case 2. Profitability per Business model (product set)

High volume low margin						Functional unit			Material flow phase											Assumptions and variables for calculations							
Circular Material flows (per business model)		Product Split, (total products in rotation)	Unit Cost (SEK)	Accumulated Cost (SEK)	Sales Price (SEK)	Revenue (SEK)	Gross Profit (SEK)	Gross Margin (%)	Δ % gross margin	Raw material (A)	Transport (T _{AB})	Production (B)	Transport (T _{BC})	Use (C)	Transport (T _{CD})	Waste management (D)	Transport (T _{CE})	Recycle (E)	Transport (T _{CF})	Reuse (F)	Transport (T _{FC})	usage years:	3	number of products in circulation	30000		
MF _{lin} (Baseline)		30000	4,3	129000	4,8	144000	15000	10%	0%	3	0,1	1	0,2	0	0,2	0								energy recovery:	-2	Distribution/collection (facility-customer). (GWP)	0,2
Take-back	MF _{rec} (Recycle) 1 st loop	16500	3,5	58410	4,8	79200	20790	26%	152%	1,8	0,06	1	0,2	0	0,12	0	0,08	0,4				recycling quota	40%	recycling, rental quota	80%		
	MF _{reu} (Reuse) 2 nd loop	10000	1,4	14000	3,0	30000	16000	53%	412%					0					0,2	1	0,2	reusable products for a 2 nd loop	50%	Reuse (incl. Repair/refirbish) (F)	1		
	MF _{reu} (Reuse) 3 rd loop	3500	1,4	4900	3,0	10500	5600	53%	412%					0					0,2	1	0,2	reusable products for a 3 rd loop	25%		78%		
	Total	30000		77310		119700	42390	35%	240%																		
PSS	MF _{rec} (Recycle) 1 st loop	10000	2,0	19800	4,8	48000	28200	59%	464%	0,6	0,02	1	0,2	0	0,04	0	0,16	0									
	MF _{reu} (Reuse) 2 nd loop	10000	1,4	14000	3,0	30000	16000	53%	412%					0					0,2	1	0,2	reusable products for a 2 nd loop	100%				
	MF _{reu} (Reuse) 3 rd loop	10000	1,4	14000	3,0	30000	16000	53%	412%					0					0,2	1	0,2	reusable products for a 3 rd loop	100%				
	Total	30000		47800		108000	60200	56%	435%																		