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# Evaluating business model environmental performance with BM-LCA

A comparative case study in an automotive company

Master's thesis in industrial ecology

Jens Sandqvist  
Hannes Westberg

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS  
DIVISION OF ENVIRONMENTAL SYSTEMS ANALYSIS

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Report no. E2022:112  
Department of Technology Management and Economics  
Chalmers University of Technology  
SE-412 96 Göteborg  
Sweden  
Telephone + 46 (0)31-772 1000

# Evaluating business model environmental performance with BM-LCA

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Jens Sandqvist  
Hannes Westberg

Department of Technology Management and Economics  
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### Abstract

Business models are identified as the “engines” of the economy, and economic growth is identified as a driver for increased environmental impacts. It is therefore not surprising that sustainable business model innovation, not at least circular business models, has gained increased interest to achieve sustainability and impact decoupling (Bocken et al., 2019).

A review of sustainable business models by Nosratabadi et al., (2019) makes it clear that there is a research gap when it comes to the assessment of environmental performance of business models. If the environmental performance of business models is not assessed, there is a risk of assuming, without knowing, that certain types of business models are more sustainable than others with a risk of greenwashing. This is a pressing issue since it often is uncertain if sustainability-labeled business models deliver on the promise of being sustainable (Baumann et al., 2022).

A new LCA methodology for the assessment of environmental performance of business models called Business Model Life Cycle Assessment (BM-LCA) has been introduced and successfully applied on the first case in the garment sector comparing a sale and a rental model for jackets (Goffetti et al., 2022). BM-LCA switches the focus from impacts related to product function to impacts related to business value. The functional unit can e.g., be “1M€ in profit per quarter”.

The aims of this study is to conduct a BM-LCA on a different type of case and assess the relevance of the tool for business model assessment and sustainable business model innovation. A case study performing a carbon footprint BM-LCA on Partner sales, Direct sales, and three types of subscription-based business models, in an automotive company, was performed to achieve these aims. The automotive case significantly differs from the previous BM-LCA case by more complex product and economic structures, larger company, and emissions during the use phase. Another difference compared to the previous BM-LCA case is that an existing product LCA will be used and complemented with business model data to reduce the work needed to perform the BM-LCA. Findings are explored with regards to the feasibility to perform a BM-LCA, the usefulness of BM-LCA as a tool for environmental assessment of business models as well as sustainable business model innovation.

The BM-LCA revealed a significant difference in CO<sub>2</sub>eq of up to 40% between the business model's environmental performance per contribution margin in favor of the subscription-based business models. However, the results were sensitive to factors such as the influence of external subsidies for low-emission vehicles and market prices of used cars.

This study showed that it is possible to assess both current business models and future scenarios. Thus, BM-LCA fills a knowledge gap when it comes to quantitative assessments of business models. The study followed the methodology of BM-LCA described in (Baumann et al., 2022b; Böckin et al., 2022a, 2022b; Goffetti et al., 2022), although it was not achievable to replicate it step by step, and therefore there are some deviations in the study. When it comes to the usefulness of the result, further research is needed to better understand how to interpret and use the produced results from a company perspective.

Keywords: BM-LCA, environmental assessment of business models, environmental performance of business models



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# 1 Introduction

If human and nature are to live in harmony, decoupling economic growth from environmental impacts are necessary. This is not that easy to achieve within some industries. Decoupling is a term most used in macro-context, nevertheless, it needs to be applied to real cases. Sustainable business models are one way for companies to improve their environmental performance. The transport and automotive sector are intense contributors to environmental impacts and different business models are tested within the industry. These business models' environmental performance can however be difficult and problematic to assess (Harris, Martin, et al., 2021).

Business model innovations are becoming more and more important to stay competitive and are becoming a "key source of competitive advantage" (Santa-Maria et al., 2021). Reasons for the increased focus on business model innovations are the need to differentiate in an increasingly competitive world, the view of business models as drivers for the circular economy (N. Bocken et al., 2019), and information technology as an enabler for new business models (Planing, 2018). Business models are further identified as the engine of the economy (Baumann et al., 2022a) and economic growth is identified as a driver for increased environmental impacts (Fischer-Kowalski et al., 2011). It is therefore not surprising that sustainable business models, not at least circular business models, have gained increased interest as a way to achieve sustainability (N. Bocken et al., 2019) while at the same time maintaining or increasing competitiveness on a global market. Differentiating a company's offer by decreasing environmental impacts has in recent years also become a competitive advantage in itself (França et al., 2021).

The combination of the need for decoupling, business models as economic drivers, sustainable business models with unclear environmental performance, and product and function focus in conventional LCAs indicates the need for the novel approach of business model life cycle assessment (BM-LCA) with a focus on the environmental performance of the actual business model. This modified LCA methodology links business and environmental parameters and focuses on the environmental performance of the business model itself. The novelty of the method means however that it is not clear if it is meaningfully applicable and feasible for the complex product and business systems in the automotive industry.

## 1.1 Background

Over the past century, human welfare and economic growth have been strongly linked to natural resource use, not at least to fossil fuel use which grew by a factor of twelve over the past century, resulting in climate change. The economic growth has not been equitably distributed, while the environmental impacts are a global issue (Fischer-Kowalski et al., 2011).

Climate action is targeted as one out of seventeen sustainable development goals (SDGs) by the United Nations. At the same time, several SDGs are either directly or indirectly connected to economic growth e.g., decent work, economic growth, and no poverty (*THE 17 GOALS / Sustainable Development*, n.d.). Population growth and increasing wealth are estimated to lead to a tripling in resource use in 2050 compared to today's level (Planing, 2018). There is therefore an urgent need for economic growth and environmental impact reduction at the same time.

### 1.1.1 Decoupling

Decoupling is the term for reducing environmental impacts per unit of economic output (Fischer-Kowalski et al., 2011). Decoupling can be defined as either relative when the economic growth is relatively higher than the increase in environmental impacts, or as absolute when the economic growth is no longer at all linked to environmental impacts. There is evidence of relative decoupling during the last three decades from various nations and regions, however, it can be said that relative decoupling will not be enough to stay within the planetary boundaries when it comes to for example climate change (Ward et al., 2016). The United Nations Intergovernmental Panel on Climate Change estimates a remaining carbon budget of 400 GtCO<sub>2</sub> to stay below a 1.5°C increase for a likelihood of 67% (Masson-Delmotte et al., 2021).

Although there is no clear evidence of absolute decoupling so far, some pollutants have in the past been decoupled from economic growth. Removal of tetraethyl lead from automotive fuel and CFCs from refrigerants and propellants are two examples, and it can be envisioned that GDP growth can be decoupled from the use of fossil fuels and their related CO<sub>2</sub> emissions by switching to 100% renewable energy (Ward et al., 2016). To stay within the climate change planetary boundary and reduce GHG-emissions on a global scale, there is a need for micro-scale decoupling at society and company levels. Tools for assessing this micro-scale environmental performance, for example on the company or business model level, are needed to ensure their contribution towards a large-scale decoupling.

### 1.1.2 Business model and their sustainable adaptation

The concept of a business model originates from the idea to communicate complex business ideas effectively by describing a company's value proposition and how value is created, delivered, and captured. A sustainable business model is a business model that delivers value and performs activities in a sustainable manner (Nosratabadi et al., 2019). Sustainable business models are used to simultaneously meet a company's ambitions in the areas of economic, environmental, and social performance, which is also referred to as the triple bottom line (Khan et al., 2021). Other common components of the definition of sustainable business models include comprehensive stakeholder consideration by including the society and environment as stakeholders as well as switching from short-term to long-term perspectives (Comin et al., 2020).

The environmental part of corporate sustainability has so far mostly focused on products, activities, and organizational practices to reduce environmental impacts. To take the next steps in improving environmental performance it is necessary to also include business model innovation. Academic interest in the research field of sustainable business models is increasing, but information about sustainable business models is still rather fragmented and difficult to grasp.

Table 1 presents the number of search results for listed search phrases in the Scopus database. Since no comprehensive information on different types of sustainable business models was found the focus has been on circular business models and product service systems (PSS) since they frequently appear in the literature etc. The well-cited article by Bocken et al. (2014) describes different archetypes of sustainable business models which include circular economy

and PSS as examples. Articles about *sustainable business models* have increased by 65% between 2018 and 2021. It can also be seen that the number of articles on the topics *circular business model* and *circular economy* has increased more than for *product service system business model* and *product service system* while the two last terms started at a higher number of search results.

Table 1 - Search results

Search phrase	Year published			
	2021	2020	2019	2018
sustainable business model	1 944	1 686	1 406	1 176
circular business model	472	322	282	169
circular economy	4 940	3 178	2 152	1 391
product service system business model	336	357	346	336
product service system	3 365	3 690	3 766	3 344

### 1.1.3 Circular economy

The circular economy has gained a lot of attention and excitement from businesses, policymakers as well as academia as a potential driver for sustainable development. A circular economy aims to shift the current linear or semi-circular economic system of the “take-make-dispose” resource model to circular flows (Fernandes et al., 2020). A common description of how this is done is by slowing, closing, and narrowing resource flows (Fernandes et al., 2020) which can be achieved by e.g., extended product life, re-manufacturing, and recycling (Planing, 2018). Circular business models are described by Bocken et al. (2018) as “the rationale of how an organization creates, delivers and captures value to close and slow material loops” and business model innovation is according to Fernandes et al. (2020) seen as “vehicles for innovation towards a circular economy”.

Products and services are the main types of business model orientations, and it becomes increasingly common to offer a combination of these two business model orientations due to the difficulty for companies to compete with product differentiation only. The shift towards service-based business models can act as an enabling factor for the circular economy. To succeed with the transformation to circular business models it is important to consider stakeholder motivational factors including non-rational customer motives (Planing, 2018). Table 2, from (Planing, 2018), presents common business model classification and motivation from manufacturers and service providers.

Table 2 - Hypothesis matrix: manufacturer/service provider motivation for circular economy business models (Planning, 2018)

Business model	Ownership-based business models	Access- or usage-based business models	Performance-based business models	Result-based business models
Example	<i>Purchasing a washing machine</i>	<i>Leasing a washing machine for 12 months</i>	<i>Leasing a washing machine for 1,000 washing cycles</i>	<i>Providing a pick-up and delivery washing service</i>
I Longer-usage period	Low motivation to design products for longer-usage period, since this would deteriorate sales	Low motivation to design products for longer-usage period, since consumers pay for a defined usage time (100% depreciation calculated into the business model) and expect new models	High motivation to design products for longer-usage period, since this translates in higher revenues	High motivation to design products for longer-usage period, since this translates in higher revenues
II Extend product-life	Low motivation to design products for easy repair or refurbish since new product sales is financially more attractive than repairs	Medium motivation to design products for easy repair or refurbish since it is often more economical to replace broken products rather than repairing them	Medium motivation to design products for easy repair or refurbish since it is often more economical to replace broken products rather than repairing them	High motivation to design products for easy repair or refurbish since products are operated by the service provider and are generally built for maximum performance (yet high investment)
III Re-manufacturing	Low motivation to design products for remanufacturing since new product sales is financially more attractive	Medium motivation to design products for remanufacturing since consumers pay for a defined usage time (100% depreciation calculated into the business model) and expect new models	High motivation to design products for remanufacturing since consumers pay for a defined performance (rather than a specific model type)	High motivation to design products for remanufacturing since this will reduce machinery cost for the service provider
IV Recycling	Motivation to design products for recycling can be considered as medium, since it is mainly driven by legislation rather than interest in material reuse	High motivation to design products for recycling since products will be returned after usage time	High motivation to design products for recycling since products will be returned after usage time	High motivation to design products for recycling since products are wholly owned by service provider

As can be seen in Table 2, ownership-based business models have low to medium stakeholder motivation for circular strategies such as longer-usage periods, extended product-life, remanufacturing, and recycling while result-based models have high stakeholder motivation for all these strategies (Planing, 2018). Correspondingly the level of circularity of business models is commonly seen as the lowest for traditional ownership-based business models with increasing levels of circularity for access-based, performance-based, and result-based business models.

Both products, activities, and business models are seen as essential to slow, close, and narrow resource loops. The field of circular business model innovation is growing but few adapted tools are used in practice. This is true for sustainable business model tools in general. There are, however, general business model innovation tools that are popular in practical use. This is not bad from a sustainable perspective, but there is a risk of dilution of sustainability focus (N. Bocken et al., 2019).

#### 1.1.4 Product service system

Product service systems are an offer that combines products and services in a joint bundle to deliver and capture more value than if either the product or the service was offered alone. There is a palette of PSS definitions in the literature and a large share of the definitions includes sustainability. It is however argued that sustainability might be an outcome of a PSS business model but is not central to the PSS concept in the same way as the concepts of product, service, system, and function fulfillment are (Mahut et al., 2017). It is therefore unclear if PSS business models should be seen as sustainable business models. It can also be noted that there is an overlap between circular economy and circular business models that often involves a business model shift from product to service.

#### 1.1.5 Assessing the environmental performance of sustainable business models

There is, according to Nosratabadi et al. (2019), a research gap when it comes to the evaluation of sustainable business models. This gap includes the assessment of environmental performance of business models. At the same time, an increasing number of tools for sustainable business model design are emerging. Bocken et al (2019) argues that many of the

business model tools that focus on sustainable business model innovation is lacking qualities to fit company needs or are for other reasons not widely used in practice. There are popular and widely used business model innovation tools that do not come with an environmental focus, such as the lean startup approach and the business model canvas. The use of these tools presents a risk of dilution of the sustainability focus even when used for example for circular business model innovation. One reason for the popularity of these generic tools is that they appear simple to use and are adaptable (N. Bocken et al., 2019). It is therefore of great importance to develop business model innovation tools that safeguard the environmental performance of business models and to get these tools in use in practice (Lüdeke-Freund et al., 2018).

Bocken et al. (2016) propose a streamlined assessment tool for the early stages of circular business model innovation. The method intends to be useful in the early stages of business model innovation when there are multiple immature models to choose between and the design parameters are still flexible. The method focuses on qualitative expectations based on four key aspects of circular business models: slowing effects, closing effects, life cycle effects, and systems effects. Its usefulness for quantitatively and accurately assessing sustainable business models is therefore limited.

From the review of sustainable business models by Nosratabadi et al., (2019), it becomes clear that there is a research gap when it comes to the assessment of sustainability parameters for sustainable business models. If the business model's sustainability performance is not assessed there is a risk of assuming, without knowing, that certain types of business models are more sustainable than others with a risk of greenwashing. This is a pressing issue since it often is uncertain if sustainability-labeled business models deliver on the promise of being sustainable (Baumann et al., 2022a).

Das et al. (2022) article focus on how companies forecast environmental impacts when implementing circular business models. The findings reveal that most of the companies included in the study measure the environmental impact of existing circular business models while only 4% of the interviewed companies forecast environmental impacts before the implementation of new circular business models. This results in a risk of lock-ins in circular business models with poor environmental performance since companies often are reluctant to withdraw successfully employed business models. The need for assessment tools measuring environmental impacts during experimentation phases is therefore identified as important (Das et al., 2022). The most common method to measure the environmental performance of current circular business models is rule of thumb and LCA/LCA-based methods. It is however unclear if the methods are mainly product-oriented or include the impacts from business-specific activities. A conclusion from the Das et al. (2022) article is that few studies examine the use of forecasting environmental performance in companies.

#### 1.1.6 The use of LCA to evaluate the environmental performance of business models

The use of LCA for environmental assessments is increasing in industry, research, and policymaking (Gradin & Björklund, 2021). LCA is, in the ISO 14040 standard from 1997, defined as "... a technique for assessing the environmental aspects and potential impacts associated with a product ..." (Baumann & Tillman, 2004). The focus in traditional LCA is on environmental

impacts related to the use of the product and targets products and process improvements and is not an assessment of the business model's environmental performance.

The use of LCA in decision-making has, according to Calado et al. (2019), not been as wide as expected. One attempt to increase the usefulness of life cycle approaches in decision-making is to assess environmental and economic performance simultaneously by performing an integrated LCA and Life Cycle Costing (LCC) (Calado et al., 2019; Luthin et al., 2021). Combining LCA and LCC is, at least in literature, a rather popular way to add economics to a regular LCA but the aim is normally to identify environmental-economic trade-offs with a focus on products and activities rather than the business models (Calado et al., 2019; Luthin et al., 2021). There is a range of different types of LCC, the main types being conventional/economic LCC, environmental LCC, and societal LCC. The costs can therefore be either from a company perspective or the environmental costs caused to the society, called externalities.

Common for all LCC types is that they aim at including costs from all parts of the product's life cycle and that they are especially useful when choosing the most cost-effective product/solution among alternatives (Calado et al., 2019). It is however worth noting that there are no general standards for LCC (França et al., 2021). The main aim of combining LCA and LCC methodologies is, according to literature, to address both environmental and economic aspects and provide decision support for environmental-economic trade-offs (Calado et al., 2019; França et al., 2021; Luthin et al., 2021). Costs are included in the LCC, while revenues normally are excluded. This makes the integrated LCA/LCC approach useful for assessing product and process alternatives. It is, however, not a useful tool for the environmental assessment of business models from a business value perspective.

The combined LCA/LCC assessment is just one flavor of the many types of LCA that emerged to complement the conventional LCA. Social LCA focuses on the social dimension of sustainability while life cycle sustainability assessment was developed to take environmental, social, and economic sustainability into account by combining LCA, LCC, and Social LCA. Another type of LCA is the life cycle energy and sustainability assessment which is used in the construction sector (Luthin et al., 2021). Life cycle thinking is, as the name suggests, a more qualitative way of thinking where cradle-to-grave implications are considered but without going into the quantitative details of an LCA (Baumann & Tillman, 2004).

#### 1.1.7 Business model LCA

Business model LCA (BM-LCA) is a novel tool so far tested on one case assessing the environmental performance of two different business models offering the same product, a shell jacket. By using a functional unit that focuses on business value, the method aims at assessing the environmental performance of the business models rather than product function. Creating business value can be seen as the core function of a business model. Business value can be for example profit or contribution margin. It is therefore relevant to assess business models from this perspective as a complement to conventional LCA's focusing on the function of the product. BM-LCA can fill a knowledge gap when assessing existing business models but also as a tool in the business model innovation process adding a quantitative environmental perspective to the more qualitative business model innovation tools such as the business model canvas. By assessing the environmental performance of business models, companies can contribute to decoupling by business model choices as well

as avoiding greenwashing by excessive claims connected to the environmental performance of business models (Böckin et al., 2022b; Goffetti et al., 2022).

The description of the BM-LCA methodology below is based on the only earlier performed BM-LCA described in (Baumann et al., 2022b; Böckin et al., 2022a, 2022b; Goffetti et al., 2022). These steps are followed to a large extent in this study and are therefore an important background.

Since the aim of the BM-LCA is to assess the business model, which is based on both products, services, and activities, the goal and scope must be extended from purely a product focus to a business focus. To do this, the traditional product-oriented physical functional unit is replaced with an economic functional unit that can capture the aim of business models, which is to generate business value, for example, profit. Also, the functional unit needs to represent that profitability is measured over certain time periods for example months, quarters, or years. The functional unit in BM-LCA is thus expressed as “a chosen profit level over a given time period” (Böckin et al., 2022b). Profit level can be exchanged for other relevant terms that are used to measure business value.

To assess the business model, a descriptive and coupling phase is included in the goal and scope methodology traditionally found in LCAs. The description phase intends to specify all activities and key features for each business model, where the physical flows and who has the ownership of the products in different life-cycle stages are established via an actor-analysis. A flowchart in a conventional LCA does not take into account which actors that are accountable for the different activities, it is actor neutral. An actor analysis is added in a BM-LCA to understand the actor perspective and which monetary transactions are of interest.

Relevant for the description phase is to describe the number of produced products that are required to fulfill one customer transaction. For traditional sales, every transaction requires one produced product whereas, for rental, every produced product can satisfy multiple customer transactions (Goffetti et al., 2022). Like traditional LCAs, system boundaries and impact categories are determined based on the aim and case.

In the coupling phase, the functional unit is determined based on a profit level suitable for the case company and business model. The profit level can be based on historical data to do the assessment more comparable to a current business model or based on a desired profit level that is more suitable for business model innovation. The second step is to establish the monetary transactions associated with the case company and the involved actors such as suppliers, partners, and customers. These monetary transactions are then coupled to the physical flow through coupling equations. With these coupling equations, the number of transactions necessary to reach the profit level can be solved by breaking out the number of transactions from revenues and costs. The number of produced products can be derived from the number of needed transactions and the number of transactions per product from the description phase. With the same profit level, the number of required products for each business model is calculated. Creating coupling equations is key in this phase and necessary to connect monetary and physical flows.

The next phase of the BM-LCA is to construct a Life Cycle Inventory of the relevant in and output flows of the technical system, preferably, case-specific data on the resource use and pollutant emissions. When there is no specific data to collect, generic data or best estimations are used. Documentation of the collected data is required to ensure transparency. The last step of the LCI is to calculate the environmental loads according to the established numbers of products produced for each business model (Baumann & Tillman, 2004).

Thereafter, a quantitative assessment of the impacts generated from the collected data inventory is performed in the next phase called Life Cycle Impact Assessment. The resources and emissions from the inventory are classified into their respective defined impact category for example CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O all affect global warming and are thus classified together. The emissions are then aggregated according to their impact potential, called characterization factor, for example 1kg of methane affects global warming equivalent to 25kg of carbon dioxide using GWP100. Depending on the goal and scope, normalizing the results to a reference value, and aggregating the different impact categories to a weighted one-dimensional index are optional measures to further analyze the results.

The final phase of BM-LCA is to interpret and present the results. This is the stage in which the findings of either LCI, LCIA, or both are presented in line with the goal and scope to reach conclusions and recommendations (Baumann & Tillman, 2004). The results are also tested regarding their soundness and validity, by iteratively analyzing and investigating the collected data (Böckin et al., 2022b). This is done by a sensitivity analysis where parameters are changed to understand how this will affect the results. A sensitivity analysis in a BM-LCA can also be of interest to guide decisions toward more sustainable business models. The actor analysis within the BM-LCA can be used for guiding the interpretation of what impacts and measures are within or outside the control or influence of the company. A summary of the methodology is depicted in Figure 1.

Figure 1- Methodology of BM-LCA (Böckin et al., 2022b)

<b>Business Model LCA</b>	
Phase	Description of each step
Goal and Scope: Descriptive phase	Give general description of the setup of each business model to be compared and of the related product(s) and state the relevant time period.
	Define system boundaries and environmental impact categories of the assessment. Map actors in the product chain.
	Find the connection of how the amount of production, $q$ , depends on the number of transactions, $t$ , for each business model.
Goal and Scope: Coupling phase	Step 1: Define the functional unit as the profit, $\pi$ , that each business model must achieve.
	Step 2: Identify all of the business' costs and revenues associated with running one of the business models for the stated period. Find conversion factors, $f$ , to couple costs and revenues to customer transactions, $t$ . Set up an equation for the profit as revenues minus costs:  $\pi = f_{revenue} * t - f_{direct} * t - f_{indirect} * t - f_{contingent} * t$
	Step 3: Solve the equation to find the transactions, $t$ , required to reach the profit. Derive the required amount of production, $q$ .
	Step 4: Repeat steps 2 and 3 for every business model to be compared.
Life Cycle Inventory	Construct a system model and quantify all environmentally relevant flows, scaled according to the functional unit.
Life Cycle Impact Assessment	Aggregate all flows from LCI and quantify their effects on the chosen environmental impact categories.
Interpretation	Analyse the results and scrutinise their robustness to identify pros and cons of compared business models.

### 1.1.8 Automotive Business models

In the past, private ownership and traditional sales models have been prevailing in the business-to-consumer automotive market. However, in recent years, there has due to, for example, climate awareness and changing customer needs and preferences, been a shift towards business models with increased customer flexibility and reduced environmental impact (Brandtner & Freudenthaler-Mayrhofer, 2020). Wells (2013) states that a new paradigm in this sector is emerging, that could be dominated by product system services, diversified business models, the lowest lifetime cost for consumers, and the lowest burden to society and the environment.

Recent and up and coming business models within the car mobility sector include different types of car sharing, subscription-based sales, leasing, multi-modal mobility-as-a-service concepts, ride-along and multi-sided consumer-to-consumer platforms (Brandtner & Freudenthaler-Mayrhofer, 2020; Grieger & Ludwig, 2019). The automotive business models are diversifying from solely business-to-consumer to also including consumer-to-consumer.

Large-scale car-sharing systems are a type of business model where a company, for example the OEMs, own the entire car fleet and have them placed either on specific sites or as free-floating. Free-floating car sharing is a model without any fixed parking. The cars can be picked up and parked within a permitted geographical area, which facilitates one-way travel. Subscription-based sale is a mix of renting and leasing, which offers consumers a month-to-month payment where maintenance, service, and insurance are included. Short notice period and the possibility to change vehicles are common features of the subscription model which targets customers with a demand for flexibility. Other common sales arguments favoring

subscription-based models are the all-inclusive no surprise deal as well as no need for a down payment.

#### 1.1.9 Assessing automotive business models

The literature on environmental assessments of automotive business models is lagging behind the assessment of the products, where several automotive manufacturers have performed LCA on their products. Even though car sharing has emerged as a potential solution to increased sustainability within the automotive industry, there is a paucity of academic literature on its implication (Harris, Mata, et al., 2021). There are even fewer assessments on other types of automotive business models. Most studies assessing the environmental implications of car sharing conduct an LCA with a cradle-to-grave perspective, based on person-kilometer traveled as a functional unit. The main contribution to lower environmental impacts from car-sharing is stemming from fewer vehicles fulfilling the total customer needs and consumer behavioral changes. Additionally, some studies account for rebound effects and modal change which gives a more holistic picture of environmental impacts on a societal level (Amatuni et al., 2020; Ding et al., 2019). However, as the emphasis in these studies is on the environmental impacts from a functional and societal perspective, the methods exclude the company-level business value implications caused by these new types of business models.

#### 1.1.10 Conclusion of background

The review has made it clear that the assessment of the environmental performance of business models is an underdeveloped area compared to the environmental assessment of products and/or functions. The tools used for business model assessment are at present most often of qualitative nature and tools aiming at sustainable business model innovation are rarely used in practice. Additionally, environmental assessments of business models are currently observed from a functional or societal perspective, ignoring the implications caused to the companies. As the automotive industry stands for a high share of environmental impacts, automotive companies are experimenting with several business models, and there are several existing product LCAs, which might make a BM-LCA more feasible, it is appropriate to conduct a study in this field.

BM-LCA is a tool developed for assessments of business models' environmental performance which makes it promising from a company perspective. As the BM-LCA method so far has only been tested on one case, it is considered a natural next step to test the BM-LCA on another type of case and also to understand the usability and feasibility of the method.

## 1.2 Aim

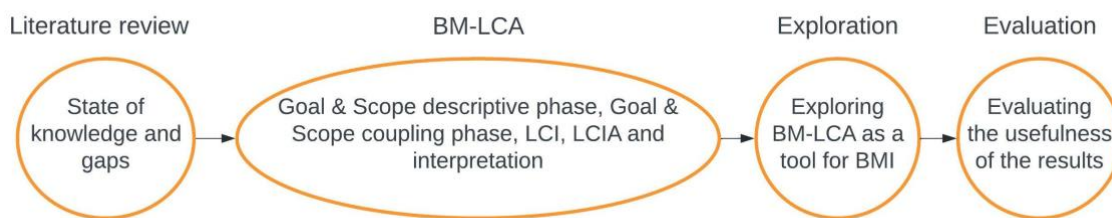
This report has two aims. The first aim is to apply BM-LCA to evaluate the environmental performance of automotive business models with an existing product LCA. The second aim is to explore and evaluate the method as a tool for business model environmental assessment and innovation for business practice.

## 2 Method

An overview of the methodological procedure is presented in Figure 2. The methods of the different steps are further described in the following sections.

The application and evaluation of BM-LCA are conducted through a comparative case study of five different business models identified and derived from Volvo Car Corporation (VCC). Although one of the business models is not operated, it is subject to application and evaluation. The case study is used to assess the environmental performance of the business models and to assess the usability of the BM-LCA for the case company. Specifically, to fulfill the first aim a BM-LCA is conducted. To fulfill the second aim, an evaluation of the usefulness of the results and method is performed.

Figure 2 - Description of methods



### 2.1 Literature review

To get an overview of the current state of knowledge about assessing the environmental performance of business models, a literature review is conducted. The literature review included several search phrases for each of the categories in the list below.

- Sustainable business models
- Product service system business models
- Circular business models
- Business models in the automotive industry
- Environmental performance of business models
- Environmental assessment of business models
- Life cycle costing in combination with life cycle assessment
- Decoupling

The literature review is limited to primary sources published in peer-reviewed journals. Searches were performed in the Scopus, Web of Science, and Business Source Ultimate databases as well as in Google Scholar. The search phrases under each subject, presented in the list above, were developed during the literature review. An initial search on the subject led to information that helped in creating more specific search phrases.

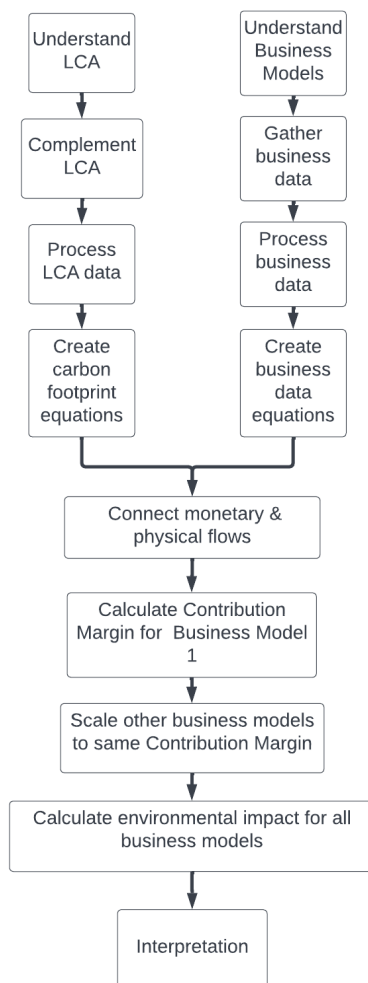
The outcome of the literature review is a contextual description of the environmental assessment of business models and sustainable business model innovation. This literature review resulted in a background against which the findings from this study were compared and discussed.

## 2.2 BM-LCA of five business models

Five business models were identified and derived for the application of BM-LCA. The procedure follows the steps in the so far only previous conducted BM-LCA and the corresponding article focused on the BM-LCA method (Böckin et al., 2022a, 2022b; Goffetti et al., 2022) to as large extent as possible. A chosen methodological alteration is the use of an existing product LCA on the C40 battery-electric vehicle (*Carbon Footprint Report C40 Recharge*, n.d.). The existing product LCA is used to take advantage of existing knowledge and avoid extra work and test the feasibility of using an existing product LCA when conducting a BM-LCA. Business model-specific data is added and the existing LCA is complemented with spare part data.

The chapter describing the actual conduction of the BM-LCA, see chapter 3 below, includes methodological descriptions of for example the calculation steps. The description of the BM-LCA methodology in this chapter aims at creating an overview rather than an in-depth methodological understanding. Figure 3 below shows the workflow and activities performed in this BM-LCA study.

Figure 3 - BM-LCA case method



Starting from the top in Figure 3, the understanding, gathering of data, and creation of flowcharts and transaction equations are done in parallel for both environmental and business data. The environmental and business data is then coupled by connecting monetary and physical flows. The next step is to calculate the contribution margin for the Partner sales business model which is the reference business model in this study. The other business models are then scaled to the same contribution margin as for Partner sales. Environmental impacts connected to the functional unit are then calculated using transaction and coupling equations.

Due to sensitive business data, the economic and specific business model values are not displayed in the report. The coupling equations and parameters are however shown. The results are presented as normalized values, which reflect the correlation between the models.

A model is built in excel, with the possibility to modify all input parameters, to be able to use the model for sensitivity analysis, but also as a simulation tool for changes in the business models and to be able to innovate sustainable business models.

### 2.3 Exploration – BM-LCA as a tool for sustainable business model innovation

As a part of fulfilling the second aim, an exploration of the possibilities to use BM-LCA as a tool for sustainable business model innovation is performed. The starting point in this exploration is the five business models assessed. As the creation of the model for the assessment was done with business model innovation in mind, it includes an ability to change environmental as well as monetary parameters. The sustainable business model innovation is done by changing individual parameters as well as combinations of parameters to see the effect on the environmental performance of the business model.

### 2.4 Evaluation

The second method to fulfill the second aim is to evaluate the usefulness of the results intended for VCC to assess the environmental performance of business models and as a tool for sustainable business model innovation. This is performed by a workshop. The workshop is conducted together with relevant people within environmental and financial departments to generate holistic perspectives. A short presentation of the BM-LCA method and results is followed by an interactive session where the participants had the opportunity to alter interesting parameters. Lastly, discussion and feedback are given on the results.

The work process was also documented during the entire project, including spent time on different activities, to evaluate the feasibility of performing a BM-LCA.

### 3 BM-LCA - Environmental Assessment of five Business Models

This chapter reports the application of BM-LCA to five business models, two sales business models, and three subscription business models. It can be seen as an individual report within the bigger report. The structure follows the main structure proposed by Böckin et al. (2022b) in the following chapters.

- Goal and Scope: Descriptive phase
- Goal and Scope: Coupling phase
- Life Cycle Inventory
- Life Cycle Impact Assessment
- Interpretation
- Conclusions

#### 3.1 Goal & scope: Descriptive phase

This part of the BM-LCA focuses on a description of the five business models as well as a description of system boundaries and choices of impact categories.

##### 3.1.1 Descriptions of the business models

Five business models have been assessed: Partner sales, Direct sales, Flex, Fix, and Multicycle. These are described with key features, flowcharts, and tables in the sections below.

###### 3.1.1.1 Partner sales

Partner sales are considered the reference model in this study. VCC produces cars that are sold to a dealer. The dealer sells the car to the end-user. The sale of the car is the main transaction but there are also other types of transactions during the car's lifetime. Spare parts are sold during the whole lifetime of the car, there is however a diminishing number of loyal customers as the car gets older since customers move over to other spare part dealers. This phenomenon is called the retention curve. The Partner sales business model and its physical, as well as monetary flows, are shown in

Figure 5 below with an explanation of the flowchart elements in Figure 4. Flows that cross the boundary between VCC and other actors are of interest regarding monetary flows while environmental impacts are considered independent of the actor. The monetary transactions for the Partner sales model are presented in Table 3. The revenues and costs in Table 3 correspond to the cost and revenue numbers in the flowchart. Material recycling is outside the system boundaries due to the use of the cut-off method.

Figure 4 - Flowchart explanations



Figure 5 - Flowchart Partner sales

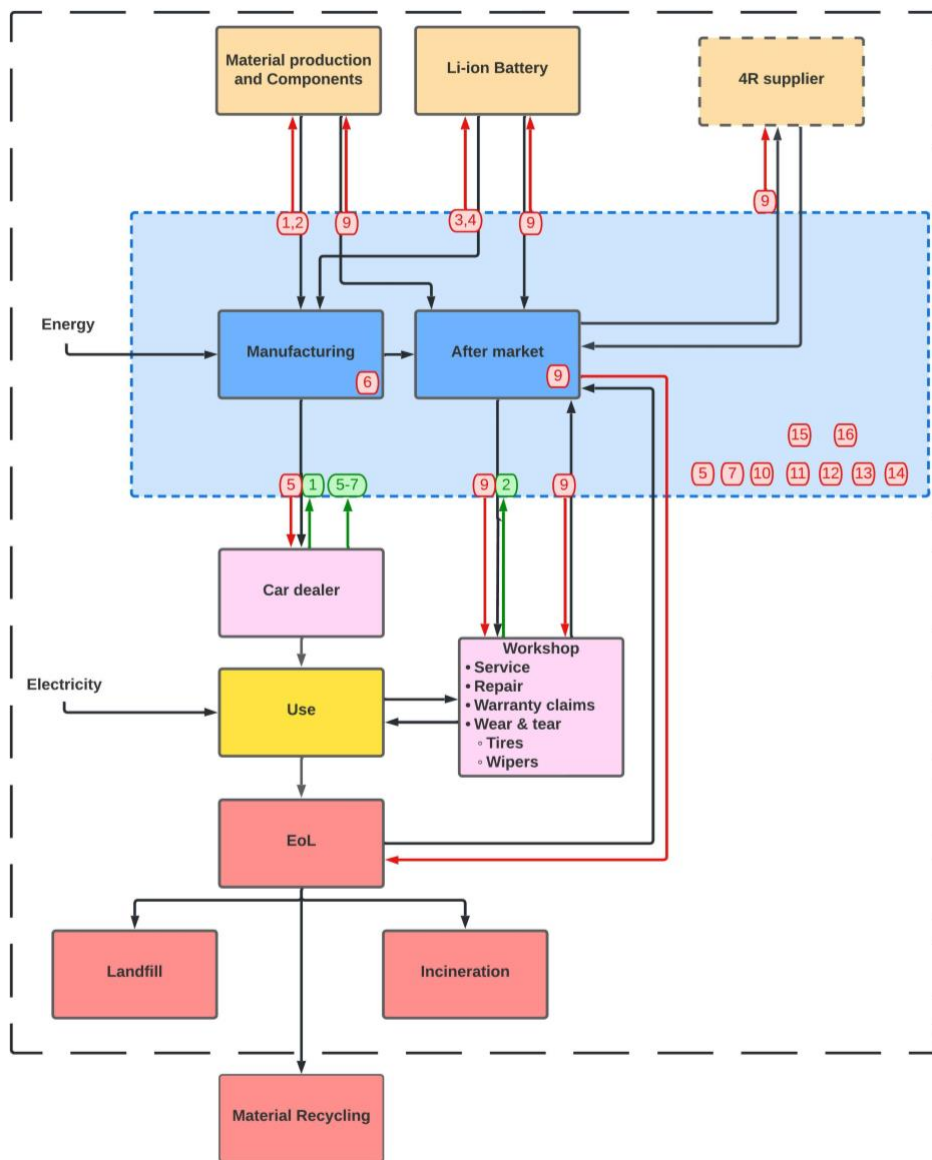


Table 3 - Transactions Partner sales

Transaction	Description
Rev 1	Car sale
Rev 2	Revenue spare parts - "Frisk försäljning"
Rev 5	Extended warranty
Rev 6	Original service
Rev 7	Insurance

Transaction	Description
Cost 1	Materials and components
Cost 2	Inbound logistics for material and components
Cost 3	Li-ion battery
Cost 4	Inbound logistics for Li-ion battery
Cost 5	Duty
Cost 6	Variable manufacturing cost
Cost 7	Outbound logistics
Cost 9	Cost of sale spare parts
Cost 10	Warranty
Cost 11	Battery warranty
Cost 12	Road assistance
Cost 13	Unspecified service
Cost 14	Extended warranty
Cost 15	Original service
Cost 16	Insurance



Table 4 - Transactions Direct sales

Transaction	Description
Rev 1	Car sale
Rev 2	Revenue spare parts - "Frisk försäljning"
Rev 3	Subsidy
Rev 5	Extended warranty
Rev 6	Original service
Rev 7	Insurance

Transaction	Description
Cost 1	Materials and components
Cost 2	Inbound logistics material and components
Cost 3	Li-ion battery
Cost 4	Inbound logistics Li-ion battery
Cost 5	Duty
Cost 6	Variable manufacturing cost
Cost 7	Outbound logistics
Cost 8	Pre-delivery inspection
Cost 19	Dealer compensation
Cost 9	Cost of sale spare parts
Cost 10	Warranty
Cost 11	Battery warranty
Cost 12	Road assistance
Cost 13	Unspecified service
Cost 14	Extended warranty
Cost 15	Original service
Cost 16	Insurance
Cost 17	Service - Subscription

### 3.1.1.3 Flex

The Flex business model is subscription-based and focuses on flexibility and all-inclusive hassle-free access to a car. The customer pays a monthly fee that includes most car-related costs except electricity for driving. An important revenue from this business model is the sale of the used car when the subscription is canceled. The car is then sold to a dealer that sells the car to an end customer. The business model Flex can be terminated with a three-month notice period by the user. To simplify the modeling, an assumed average user period of 18 months was chosen based on historical data and VCC experts. See Figure 7 for the flowchart and Table 5 for transaction descriptions.

Figure 7 - Flowchart Flex

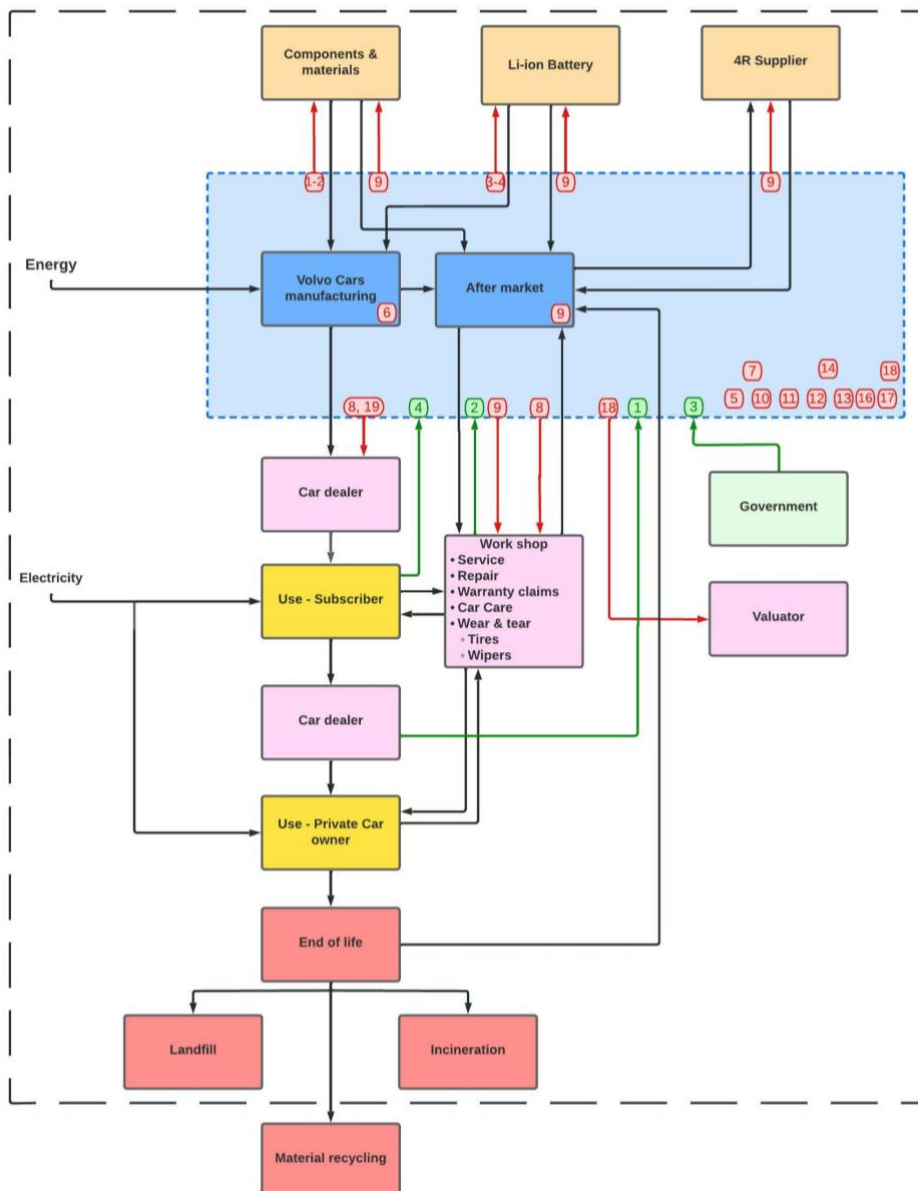


Table 5 - Transactions Flex

Transaction	Description
Rev 1	Car sale
Rev 2	Revenue spare parts - "Frisk försäljning"
Rev 3	Subsidy
Rev 4	Subscription fee / month

Transaction	Description
Cost 1	Materials and components
Cost 2	Inbound logistics material and components
Cost 3	Li-ion battery
Cost 4	Inbound logistics Li-ion battery
Cost 5	Duty
Cost 6	Variable manufacturing cost
Cost 7	Outbound logistics
Cost 8	Pre-delivery inspection
Cost 19	Dealer compensation
Cost 9	Cost of sale spare parts
Cost 10	Warranty
Cost 11	Battery warranty
Cost 12	Road assistance
Cost 13	Unspecified service
Cost 14	Extended warranty
Cost 15	Original service
Cost 16	Insurance
Cost 17	Service - Subscription
Cost 18	Valuator cost

### 3.1.1.4 Fix

Fix is a subscription-based business model that is similar to the Flex business model. The biggest difference is that the subscriber commits to a period of 36 months while getting a lower monthly price compared to the more flexible Flex business model. The used car is sold to a dealer after the 36 months subscription period. See the flowchart in Figure 8 and transaction descriptions in Table 6.

Figure 8 - Flowchart Fix

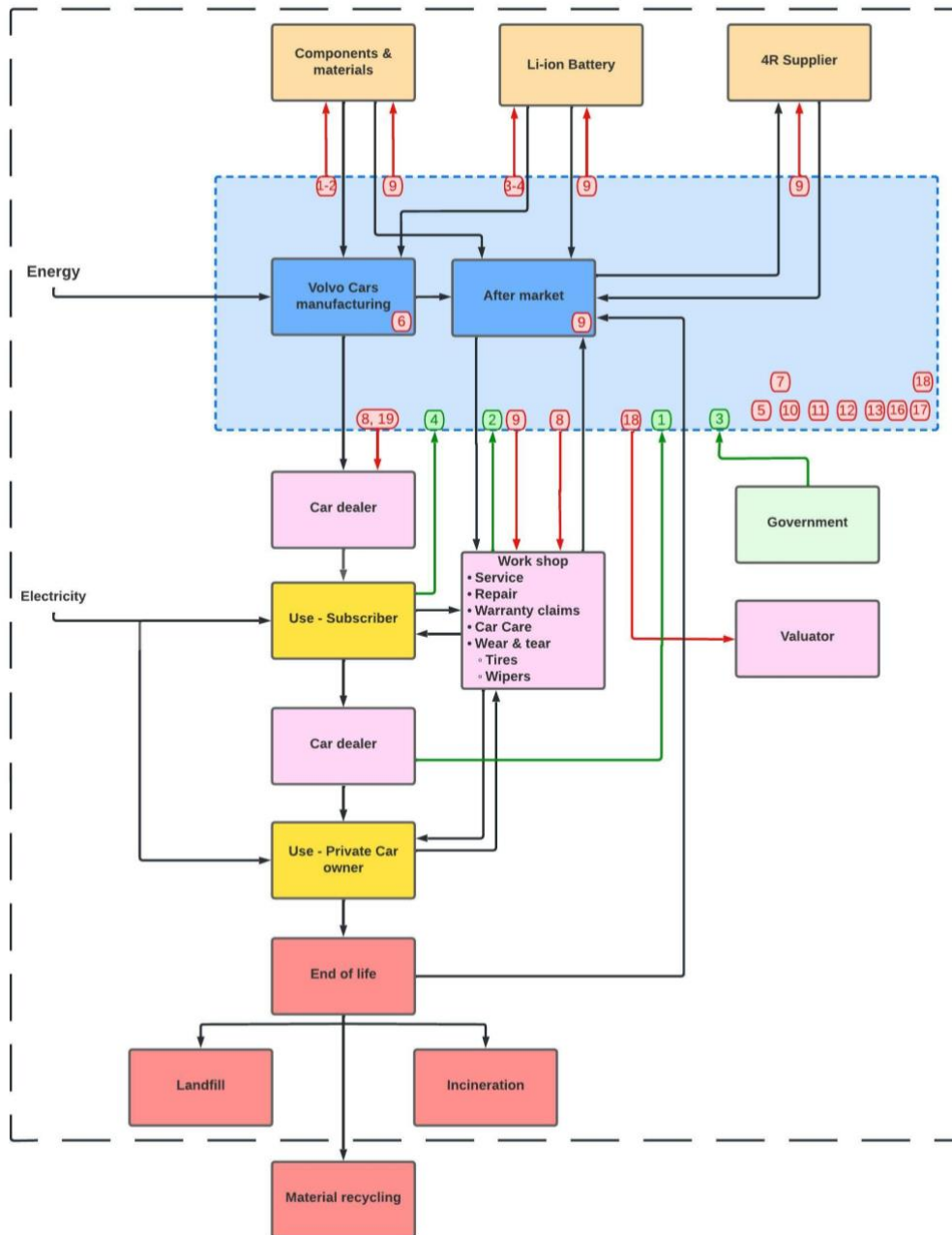


Table 6 - Transactions Fix

Transaction	Description
Rev 1	Car sale
Rev 2	Revenue spare parts - "Frisk försäljning"
Rev 3	Subsidy
Rev 4	Subscription fee / month

Transaction	Description
Cost 1	Materials and components
Cost 2	Inbound logistics material and components
Cost 3	Li-ion battery
Cost 4	Inbound logistics Li-ion battery
Cost 5	Duty
Cost 6	Variable manufacturing cost
Cost 7	Outbound logistics
Cost 8	Pre-delivery inspection
Cost 19	Dealer compensation
Cost 9	Cost of sale spare parts
Cost 10	Warranty
Cost 11	Battery warranty
Cost 12	Road assistance
Cost 13	Unspecified service
Cost 14	Extended warranty
Cost 15	Original service
Cost 16	Insurance
Cost 17	Service - Subscription
Cost 18	Valuator cost

### 3.1.1.5 Multicycle

The Multicycle business model is at present not an existing business model but could be a potential next step for the subscription-based business models. The difference compared to the Flex model is that the car that is returned from the first subscriber is remarketed and used by another subscriber. The assessment of this potential business model builds on assumptions regarding the number of remarketing occasions, car lifetime in the subscription model before it is sold and a decreased monthly subscription fee, and increased service and maintenance cost as the car gets older. See the flowchart in Figure 9 and transaction descriptions in Table 7.

Figure 9 - Flowchart Multicycle

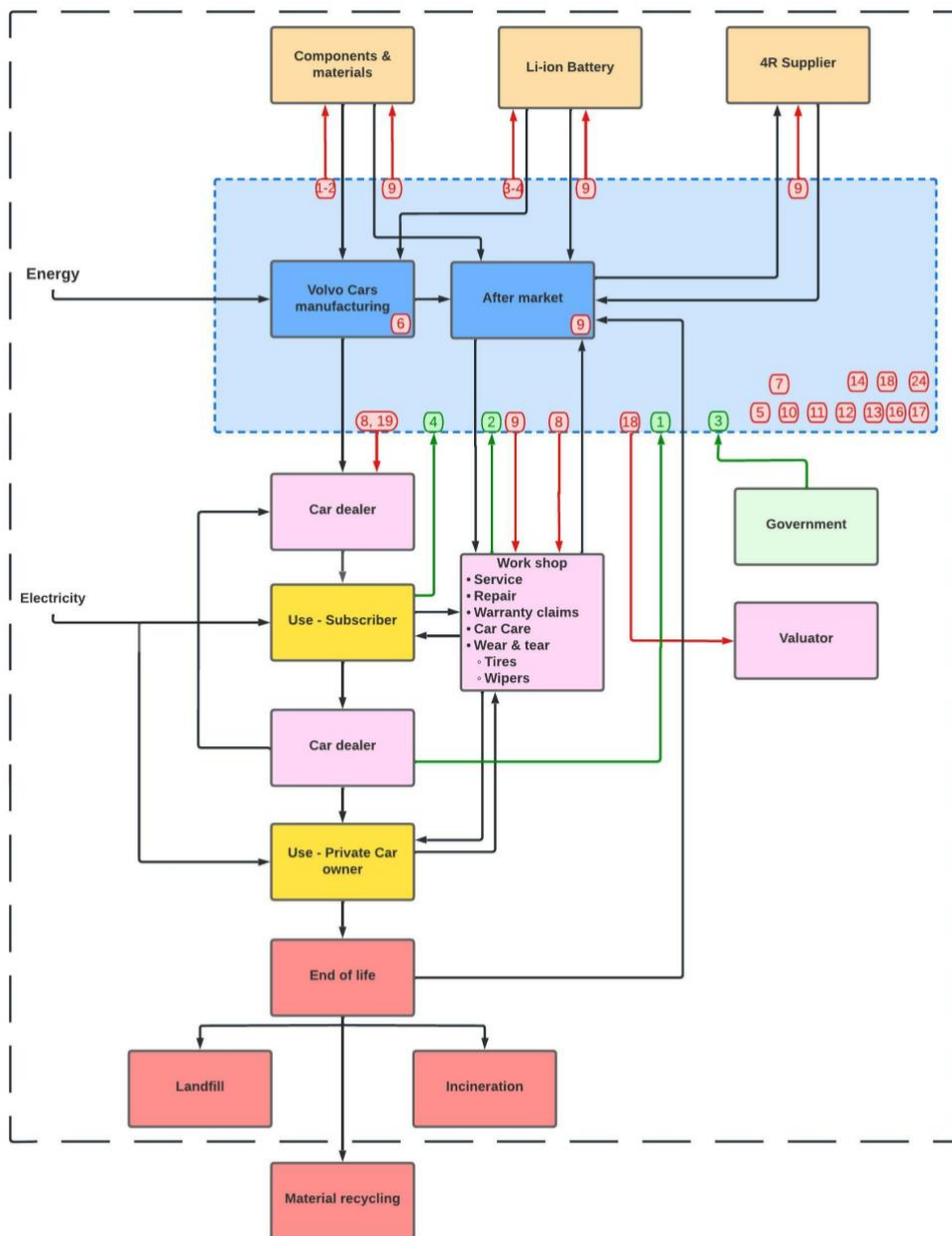


Table 7 - Transactions Multicycle

Transaction	Description
Rev 1	Car sale
Rev 2	Revenue spare parts - "Frisk försäljning"
Rev 3	Subsidy
Rev 4	Subscription fee / month
Rev 5	Extended warranty
Rev 6	Original service
Rev 7	Insurance

Transaction	Description
Cost 1	Materials and components
Cost 2	Inbound logistics material and components
Cost 3	Li-ion battery
Cost 4	Inbound logistics Li-ion battery
Cost 5	Duty
Cost 6	Variable manufacturing cost
Cost 7	Outbound logistics
Cost 8	Pre-delivery inspection
Cost 19	Dealer compensation
Cost 9	Cost of sale spare parts
Cost 10	Warranty
Cost 11	Battery warranty
Cost 12	Road assistance
Cost 13	Unspecified service
Cost 14	Extended warranty
Cost 15	Original service
Cost 16	Insurance
Cost 17	Service - Subscription
Cost 18	Valuator cost
Cost 24	Re-marketing

### 3.1.2 Functional unit

The functional unit in this study is the contribution margin of the Partner sales business model for a business period of 25 years from the start of production. The Partner sales business model is used as the reference model as it is the dominating and traditional business model for VCC.

The 25-year business period consists of six years of car production, followed by the car lifetime of the last produced car, which is assumed to be 20 years. During the car's lifetime, spare parts are replaced and emissions are ongoing since the cars require energy during their use phase.

The business period of 25 years is long, to say the least. It could be argued that a shorter business period is more relevant but there are also arguments for choosing a long period. Consequences of the result due to a shorter business period are elaborated upon in the sensitivity analysis. The reasoning behind the chosen business period is to model a realistic scenario for the C40 battery-electric vehicle. The 25 years is derived from a combination of the long lifetime of the products, assumed production over six years, emissions as well as monetary transactions during the whole lifetime of the product, and differences in when revenues and costs occur in the different business models. By choosing 25 years business period, the time from the start of production to the end-of-life of the last car in the fleet for the assessed car model is included, resulting in several cars with different car ages for each business year as can be seen in Table 8. The computational excel model is built in a way so that results for shorter periods, for example, one specific business year, can be presented as well.

*Table 8 - Which activities occur during the different phases of the entire business period*

<b>Business year within the business period</b>	<b>Car production</b>	<b>Active emission</b>	<b>Spare part production</b>	<b>End-of-life management</b>
1-6	x	x	x	
7-19		x	x	
20-25		x	x	x

It is important to consider the time value of money as the business period is long and the timing of monetary flows differs between the business models. The equations behind the modeling are therefore prepared to include discounted revenues, costs, and contribution margins. However, the discount rate is set to 0% in this assessment but changed to 2,5%, 5%, and 10% in the interpretation section.

The previously done BM-LCA by Böckin et al. (2022a) is based on a certain level of profit while this study is based on contribution margin. The reason for this is mainly the economic structure at VCC and the fact that it is not possible to assign all costs to a certain product due to the complexity of a car manufacturer's R&D, production, etc. where different product models share costs for technology resources as well as human resources and investments. The drawback with using contribution margin is mainly if the different business models have different levels of costs to cover before reaching the profit level. This could lead to a misleading assessment in a BM-LCA.

### 3.1.3 Environmental system boundaries

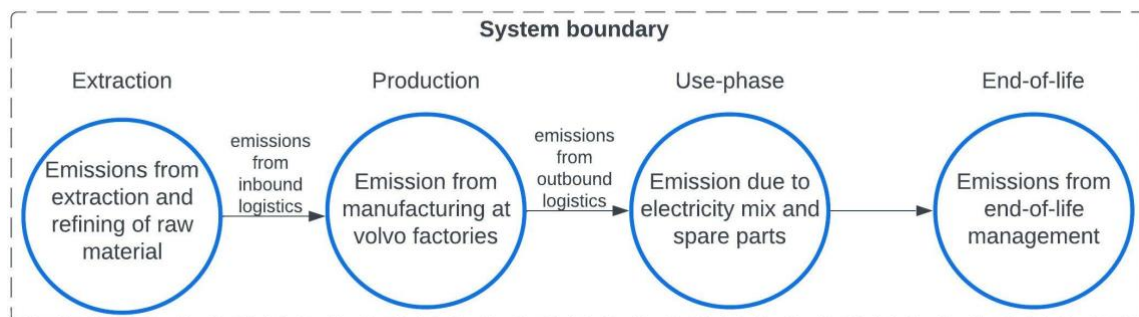
The study is a cradle-to-grave, including activities over the entire life cycle for the product system within the business model, depicted in Figure 10, starting with extracting and refining raw material and ending with end-of-life management. Environmental data comes from the C40 LCA report performed by VCC (*Carbon Footprint Report C40 Recharge*, n.d.), with additional modeling of spare part data, see Table 9.

Table 9 - Data sources

Process	Data source
Materials production and refining	C40 LCA
Li-ion battery modules	C40 LCA
Volvo Cars manufacturing	C40 LCA
Use phase emissions	C40 LCA
Spare parts	Based on information provided by VCC
End-of-life	C40 LCA

Emissions from extraction and refining of material, production, and end-of-life management are global averages. Use phase emissions from the carbon intensity of electricity mixes are considered to be European averages. The reason behind this is the grid interconnection between Sweden and the rest of Europe. Every new introduced car within Swedish territory results in less low-carbon intensive electricity exported and thus an equivalent usage of the marginal electricity instead, which is the European average.

Figure 10 - Environmental system boundary



### 3.1.4 Environmental limitations

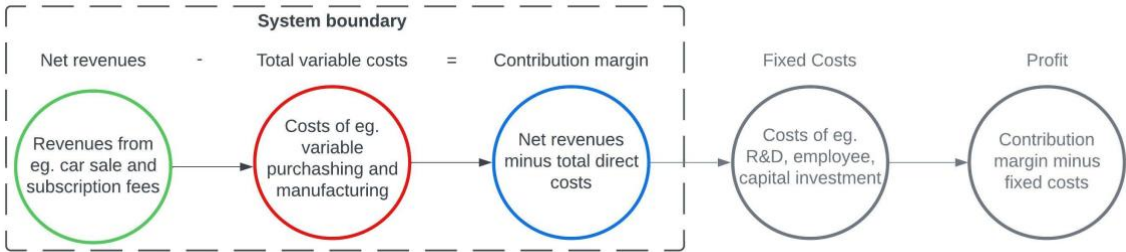
A cut-off approach has been used, meaning that 100% of the emissions from scrap generated in the production is allocated to the vehicle, even though, the scrap can sometimes be used as input material for other product systems.

Emissions from the production of spare parts are included, which is an additional activity taken into consideration compared to the LCA that this study is based on. Maintenance emissions other than spare parts, e.g. energy requirements for workshop tools, are excluded.

3.1.5 Economic system boundaries

Data considering the economic parameters and the corresponding values are specific to the company and the operations of the business models in the Swedish market. Due to the economic structures at VCC, collecting eg. R&D-, capital investment, and personnel-related over head-costs for a specific business model and the associated product was not feasible. Thus, the functional unit is limited to contribution margin and deviates from the suggested profit-based functional unit (Böckin et al., 2022b), see Figure 11. EU Carbon permits nor an internal carbon price are taken into consideration in this study

Figure 11 - Economic system boundary



3.1.6 Impact categories

The BM-LCA study is limited to greenhouse gas emissions, a so-called carbon footprint report. Our choice of impact categories follows those of the existing VCC product LCA report.

3.2 Goal and scope: Coupling

This chapter aims at describing the coupling phase and equations needed to get to the results. Each business year consists of several cars with different car ages. The age of the car is connected to both monetary transactions and CO<sub>2</sub>eq emissions. The technical lifetime of the cars is assumed to be 200 000 km based on assumptions made in the VCC C40 LCA. The driving distance per year is set to 10 000 kilometers based on discussions with VCC. This results in a car lifetime of 20 years which together with a chosen business period of 25 years results in a lot of calculations of e.g. costs, revenues, and emissions needed. These calculations were performed in Microsoft Excel using values/equations related to car age in Table 11-14 as input in equations 1 to 19 below.

The transactions resulting in a contribution margin are in the center of the coupling equations and a BM-LCA computational excel model was built where input parameters for monetary transactions result in different production quantities, different CO<sub>2</sub>eq emissions, etc. As can be seen in Table 3-7 there are several different transactions within each business model, e.g. the sale of a new or used car, subscription fees, sale of spare parts, and warranty costs.

To compare the different business models, a set level of economic performance is used as the basis for the comparison. The contribution margin for business model 1, in this case, the

Partner sales business model, is set to be the reference level to which the other business models also should achieve. Business model 1 in this BM-LCA is the Partner sales business model. The contribution margin of this business model is calculated by using sales figures per business year within the chosen business period. The same distribution of new cars per business year as for business model 1 is used for the other business models for either sale of new cars or new cars introduced to a subscription scheme.

The long business period chosen in this BM-LCA is motivated by the long lifetime of the car, the time difference of monetary flows between the business models, and the fact that it was of interest to model a realistic scenario for the C40 BEV and therefore look at the whole period when the car model is produced and in use. The BM-LCA model created allows for shorter business periods as well. It is important to at least look at a long enough period to include the revenues from the subscription-based business models, both monthly revenues and sales of used cars, to get a fair comparison.

By calculating contribution margin, revenues, costs, and emissions per business year, it is possible to look at monetary results and environmental impacts for shorter periods for example business periods 1-3, while at the same time keeping the longer business period as a reference period.

The Partner sales and Direct sales business model is up-front revenue heavy while the revenues come later in the Flex, Fix, and Multicycle business models. The possibility to use discounting of monetary flows is applied in the sensitivity analysis. This is to take the time value of money into account as the business period is long and the monetary flows differ per business year between the business models even if the discounted contribution margin for the whole period is set to be the same.

The equations below use general parameters such as  $BM_x$  where  $x$  denotes the business model. The reasoning behind this is to keep the equations as general as possible. It should however be made clear that parameters and equations are a result of business model logic and methodological choices and are therefore not general in the sense that they are applicable for all other cases.

The input to the coupling equations 1-19 is revenues, costs, and emissions per car age found in Table 11-14 together with the number of cars of a certain car age that is present during a specific business year. At which car age the transactions and emissions occur is depicted in the equations, e.g. for transactions or emissions during car age 0-1 that is denoted by  $CA_j = CA_1$ . The parameter description in Table 10 below describes the general parameters used in Table 11-14 and equations 1-19.

Table 10 - Parameter description

Parameter description	Parameter
Business Model x	$BM_x$
Business Year i	$BY_i$
Car age j	$CA_j$
Nr of cars with car age $CA_j$ for business model $BM_x$ and business year $BY_i$	$q_{BM_x, BY_i, CA_j}$
Contribution margin per car age	cm
Contribution margin per business year or business period	CM
Revenue per car age	rev
Revenue per business year or business period	REV
Cost per car age	cost
Cost per business year or business period	COST
CO <sub>2</sub> eq emission per business year or business period	EMISSION
Emission per emission source, business model, and car age	$em_{c, BM_x, CA_j}$
Revenue per emission source, business model, and car age	$rev_{a, BM_x, CA_j}$
Cost per emission source, business model, and car age	$cost_{b, BM_x, CA_j}$

### 3.2.1 Monetary transactions per car age

Five revenue streams were identified for the Partner sales model and four for the subscription models. Sixteen and eighteen costs were identified for the respective business models. These transactions have been expressed as per car age to enable coupling equations (eq.1-eq.19) at a later stage. The values and at what car age they occur are presented in Table 11-14. The values and when they occur differ between the business models due to the business model logic and follows the structure presented above. When the different revenues and costs that occur for one car in relation to its age are presented in Table 15 and Table 16.

Table 11 - Revenues – Partner sales - Per car age

Transaction parameter	Description of transaction	Transactions per car age
$rev_{1,BM_x,CA_j}$	Sale of new car to dealer	$rev_{1,BM_x,CA_j} = price\_car\_Partner\ sales$ $j = 1$
$rev_{2,BM_x,CA_j}$	Revenue spare parts - "Frisk försäljning"	Car age ( $CA_j$ ): $j = 1$ to $j = car\_lifetime$  $rev_{2,BM_x,CA_j} = price\_spare_{CA_j}$
$rev_{3,BM_x,CA_j}$	Subsidy from the government if buying an electric car	N/A
$rev_{4,BM_x,CA_j}$	Subscription fee / month	N/A
$rev_{5,BM_x,CA_j}$	Extended warranty year 3	$rev_{5,BM_x,CA_j}$ $= price\_extended\_warranty$ $j = 1$
$rev_{6,BM_x,CA_j}$	Original service 3 years	$rev_{6,BM_x,CA_j}$ $= price\_extended\_warranty$ $j = 1$
$rev_{7,BM_x,CA_j}$	Insurance	$rev_{7,BM_x,CA_j}$ $= price\_extended\_warranty$ $j = 1$

Table 12 - Revenues – Flex - Per car

Transaction parameter	Description of transaction	Transactions per car age
$rev_{1,BM_x,CA_j}$	Sale of a used car to dealer	$rev_{1,BM_x,CA_2}$ $= price\_used\_car\_subscription$
$rev_{2,BM_x,CA_j}$	Revenue spare parts - "Frisk försäljning"	Car age ( $CA_j$ ): $j = 1$ to $j = car\_lifetime$  $rev_{2,BM_x,CA_j} = price\_spare_{CA_j}$
$rev_{3,BM_x,CA_j}$	Subsidy from the government when buying an electric car	$rev_{3,BM_x,CA_j} = rev\_subsidy$ $j = 1$
$rev_{4,BM_x,CA_j}$	Revenue from monthly subscription price per year	Car age ( $CA_j$ ): $j = 1$ to $j = 2$

		$rev_{4,BM_x,CA_j} = price\_subscription_{CA_j}$
$rev_{5,BM_x,CA_j}$	Extended warranty year 3	N/A
$rev_{6,BM_x,CA_j}$	Original service 3 years	N/A
$rev_{7,BM_x,CA_j}$	Insurance	N/A

Table 13 - Costs – Partner sales - Per car age

Transaction parameter	Description of transaction	Transactions per car age
$cost_{1,BM_xCA_j}$	Cost of purchasing materials and components	$cost_{1,BM_xCA_j} = cost\_material\_components$ $j = 1$
$cost_{2,BM_xCA_j}$	Inbound logistics cost of material and components	$cost_{2,BM_xCA_j} = cost\_inbound\_logistics1$ $j = 1$
$cost_{3,BM_xCA_j}$	Cost of purchasing a Li-ion battery	$cost_{3,BM_xCA_j} = cost\_battery$ $j = 1$
$cost_{4,BM_xCA_j}$	Inbound logistics cost of Li-ion battery	$cost_{4,BM_xCA_j} = cost\_inbound\_logistics2$ $j = 1$
$cost_{5,BM_xCA_j}$	Cost of duty related to logistics	$cost_{5,BM_xCA_j} = cost\_duty$ $j = 1$
$cost_{6,BM_xCA_j}$	Variable manufacturing cost	$cost_{6,BM_xCA_j} = cost\_manufacturing$ $j = 1$
$cost_{7,BM_xCA_j}$	Outbound logistics cost of car	$cost_{7,BM_xCA_j} = cost\_outbound\_logistics$ $j = 1$
$cost_{8,BM_xCA_j}$	Cost of pre-delivery inspection performed by dealers	N/A
$cost_{19,BM_xCA_j}$	Dealer compensation cost of handing out car	N/A
$cost_{9,BM_xCA_j}$	Cost of sale spare parts - Purchase material & components - Other direct costs such as logistics - 4R specific costs	Car age (CA <sub>j</sub> ): $j = 1$ to $j = car\_lifetime$  $cost_{9,BM_xCA_j} = cost\_spare_{CA_j}$
$cost_{10,BM_xCA_j}$	Cost of warranty for years 1-2	Car age (CA <sub>j</sub> ): $j = 1$ to $j = 2$  $cost_{10,BM_xCA_j} = cost\_warranty_{CA_j}$
$cost_{11,BM_xCA_j}$	Cost of battery warranty for years 1-8	Car age (CA <sub>j</sub> ): $j = 1$ to $j = 8$  $cost_{11,BM_xCA_j} = cost\_battery\_warranty_{CA_j}$
$cost_{12,BM_xCA_j}$	Cost of road assistance for years 1-3	Car age (CA <sub>j</sub> ): $j = 1$ to

		$j = 3$ $cost_{12, BM_x, CA_j} = cost\_assistance_{CA_j}$
$cost_{13, BM_x, CA_j}$	Cost of unspecified service for years 1-3	Car age ( $CA_j$ ): $j = 1$ to $j = 3$  $cost_{13, BM_x, CA_j} = cost\_on\_call_{CA_j}$
$cost_{14, BM_x, CA_j}$	Cost of extended warranty for year 3	$cost_{14, BM_x, CA_3} = cost\_extended$
$cost_{15, BM_x, CA_j}$	Cost of original service for years 1-3	Car age ( $CA_j$ ): $j = 1$ to $j = 3$  $cost_{15, BM_x, CA_j} = cost\_original\_service_{CA_j}$
$cost_{16, BM_x, CA_j}$	Cost of insurance for years 1-3	Car age ( $CA_j$ ): $j = 1$ to $j = 3$  $cost_{16, BM_x, CA_j} = cost\_insurance_{CA_j}$
$cost_{17, BM_x, CA_j}$	Cost of subscription-specific service & warranty	N/A
$cost_{18, BM_x, CA_j}$	Cost of evaluating a used car	N/A

Table 14 - Costs – Flex - Per car age

Transaction parameter	Description of transaction	Transactions per car age
$cost_{1, BM_x, CA_j}$	Cost of purchasing materials and components	$cost_{1, BM_x, CA_j} = cost\_material\_components$ $j = 1$
$cost_{2, BM_x, CA_j}$	Inbound logistics cost of material and components	$cost_{2, BM_x, CA_j} = cost\_inbound\_logistics1$ $j = 1$
$cost_{3, BM_x, CA_j}$	Cost of purchasing a Li-ion battery	$cost_{3, BM_x, CA_j} = cost\_battery$ $j = 1$
$cost_{4, BM_x, CA_j}$	Inbound logistics cost of Li-ion battery	$cost_{4, BM_x, CA_j} = cost\_inbound\_logistics2$ $j = 1$
$cost_{5, BM_x, CA_j}$	Cost of duty related to logistics	$cost_{5, BM_x, CA_j} = cost\_duty$ $j = 1$
$cost_{6, BM_x, CA_j}$	Variable manufacturing cost	$cost_{6, BM_x, CA_j} = cost\_manufacturing$ $j = 1$

$cost_{7,BM_xCA_j}$	Outbound logistics cost of car	$cost_{7,BM_xCA_j} = cost\_outbound\_logistics$ $j = 1$
$cost_{8,BM_xCA_j}$	Cost of pre-delivery inspection performed by dealers	$cost_{8,BM_xCA_j} = cost\_PDI$ $j = 1$
$cost_{19,BM_xCA_j}$	Dealer compensation cost of handing out car	$cost_{19,BM_xCA_j} = cost\_dealer\_compensation$ $j = 1$
$cost_{9,BM_xCA_j}$	Cost of sale "frisk försäljning" - Purchase material & components - Other direct costs such as logistics - 4R specific costs	Car age (CA <sub>j</sub> ): $j = 1$ to $j = car\_lifetime$  $cost_{9,BM_xCA_j} = cost\_spare_{CA_j}$
$cost_{10,BM_xCA_j}$	Cost of warranty for years 1-2	Car age (CA <sub>j</sub> ): $j = 1$ to $j = 2$  $cost_{10,BM_xCA_j} = cost\_warranty_{CA_j}$
$cost_{11,BM_xCA_j}$	Cost of battery warranty for years 1-8	Car age (CA <sub>j</sub> ): $j = 1$ to $j = 8$  $cost_{11,BM_xCA_j} = cost\_battery\_warranty_{CA_j}$
$cost_{12,BM_xCA_j}$	Cost of road assistance for years 1-3	Car age (CA <sub>j</sub> ): $j = 1$ to $j = 3$  $cost_{12,BM_xCA_j} = cost\_assistance_{CA_j}$
$cost_{13,BM_xCA_j}$	Cost of unspecified service for years 1-3	Car age (CA <sub>j</sub> ): $j = 1$ to $j = 3$  $cost_{13,BM_xCA_j} = cost\_on\_call_{CA_j}$
$cost_{14,BM_xCA_j}$	Cost of extended warranty for year 3	$cost_{14,BM_xCA_3} = cost\_extended$
$cost_{15,BM_xCA_j}$	Cost of original service for years 1-3	N/A
$cost_{16,BM_xCA_j}$	Cost of insurance for the subscription period	Car age (CA <sub>j</sub> ): $j = 1$ to $j = 2$

		$cost_{16,BM_x,CA_j} = cost\_insurance_{CA_j}$
$cost_{17,BM_x,CA_j}$	Cost of subscription-specific service	Car age (CA <sub>j</sub> ): $j = 1$ to $j = 2$  $cost_{17,BM_x,CA_j} = cost\_subscription\_service_{CA_j}$
$cost_{18,BM_x,CA_j}$	Cost of evaluating a used car	$cost_{18,BM_x,CA_2} = cost\_valuator$

Table 15 - Partner sales, a summary of revenues and costs in relation to car age

Car age	Car sale	Included services	Warranty	Spare parts
1	x	x	x	x
2		x	x	x
3		x	x	x
4-9			x	x
10-20				x

Table 16 - Flex, a summary of revenues and costs in relation to car age

Car age	Car sale	Subscription	Included services	Warranty	Spare parts
1		x	x	x	x
2		x	x	x	x
3	x		x	x	x
4-8				x	x
9-20					x

The parameters for revenues and costs in Table 10-13 are per business model and car age for the Partner sales and Flex business models. Similar tables and calculations have been made for the other business models but excluded for the sake of simplifying the report. The values of these parameters are then used as input in the couplings equations described below and step-by-step in Table 17. The step-by-step summary in Table 17 below includes CO<sub>2</sub>eq calculations that are based on emission values per source and car age found in Table 18.

Table 17 - Description of calculation steps

Step	Description
1-3	Calculate rev, cost & cm per car ages for one car for all business models
4-5	Calculate contribution margin per business model, business year, and the whole business period. This will result in different contribution margins for the different business models.
6-7	Finding the scale factor by using the contribution margin from business model 1 as the reference value. The scale factor is used to find quantities of produced cars per business year for the different business models needed to reach the set contribution margin.
8	Calculate contribution margin, revenue, and cost per business model and business year.
9-10	Calculate contribution margin, revenue, and cost per business model and business period. The contribution margin per business period should be the same for all business models so this step can be seen as a verification.
11	Calculate the emission per emission source and business year by using the emissions per car age and quantity per car age and business year.
12-13	Calculate emissions per emission source and business model as well as emissions from all emission sources per business model.
14	Calculate the main measurement of this BM-LCA – CO <sub>2</sub> eq per SEK contribution margin for each business model as well as CO <sub>2</sub> eq per SEK revenue.

Step 1. Starting with calculating the revenue per car, business model, and car age by Eq. 1 by summing all revenues for a specific car age. This is needed as the monetary transactions are connected to specific ages of the cars.

$$rev_{BM_xCA_j} = \sum_{a=1}^{11} rev_{a,BM_x,CA_j}$$

Eq.1 - Revenue (rev) per car, business model, and car age.

Step 2. The next step is to do the same for cost per car, business model, and car age by Eq. 2.

$$cost_{BM_xCA_j} = \sum_{b=1}^{23} cost_{aCA_j}$$

Eq.2. Cost per car, business model, and car age.

Step 3. Eq. 3 below is a general equation showing the relationship between contribution margin (CM), revenue (Rev), and cost (Cost). This general equation is combined with Eq. 1 and Eq. 2 to get the contribution margin per car, business model, and car age shown in Eq. 4.

$$cm = rev - cost$$

Eq.3 - General equation for contribution margin (CM).

$$cm_{BM_xCA_j} = \sum_{a=1}^{11} rev_{aCA_j} - \sum_{b=1}^{23} cost_{bCA_j}$$

Eq.4. Contribution margin (cm) per car, business model, and car age.

Step 4. The next step is to calculate the contribution margin per business year by using Eq. 5. The quantity of cars for a certain car age is multiplied by the contribution margin for a car for that car age and summed for all car ages. As the business period is long and the distribution of revenues and costs per business year differs between the years it is reasonable to consider the time value to fairly compare the business models. Although it is not included in the impact assessment, the possibility to calculate with discounting is included in Eq. 5 below.

$$CM_{BM_xBY_i\_scale} = \left( \frac{1}{(1+r)^{i-1}} \right) \sum_{j=1}^{20} q_{BM_1BY_iCA_j} * cm_{BM_xCA_j}$$

Eq. 5. Contribution margin (CM) for a chosen business model (x) for a chosen business year (i) with the same production quantity ( $q_{BM_1BY_iCA_j}$ ) as for BM1.

Step 5. The result of Eq. 6. is the discounted contribution margin for a business model for the whole business period. The business period consists, in this case, of several business years.

$$CM_{BM_x\_scale} = \sum_{i=1}^k \sum_{j=1}^{20} q_{BM_1BY_iCA_j} * CM_{BM_xCA_j}$$

Eq. 6. Discounted contribution margin (CM) for a chosen business model (x) over the business period (k) in years with the same production quantity ( $q_{BM_1BY_iCA_j}$ ) as for BM1.

Step 6. The most significant deviation between the previously made BM-LCA and this study is within this step. In this step, the scale factor is found to scale the product system based on the set contribution margin level. The contribution margin is postulated to be the same for all business models for the business period. Scale factors for each business model are calculated by dividing the contribution margin for business model 1 by the contribution margin for each business model according to Eq. 7. The scale factor for business model 1 then becomes 100% which is logical since this is the reference business model. This methodological deviation is possible since all monetary flows are expressed per product. If there would be fixed or semifixed costs as in the previous BM-LCA study, scaling the business models would not be feasible.

$$f_{BM_x} = \frac{CM_{BM_1}}{CM_{BM_x}}$$

Eq. 7. Find scale factor for all business models

Step 7. The scale factors from Eq. 7. are used to scale the production per business year, done in Eq. 8., to reach the same contribution margin over the business period.

$$q_{BM_xBY_iCA_j} = q_{BM_1BY_iCA_j} * f_{BM_x}$$

Eq. 8. Scaled amount ( $q$ ) to reach the same contribution margin as BM1, by multiplying the amount from business model 1 with the scaling factor.

Step 8. Use equations 9, 10, and 11 to calculate contribution margin, revenues, and costs for each business year. This is not a necessary step but as the business period chosen is long, to say the least, it is probably of interest to be able to present cost and revenues as well as contribution margin per business year.

$$CM_{BM_xBY_i} = \left( \frac{1}{(1+r)^{i-1}} \right) \sum_{j=1}^{20} q_{BM_xBY_iCA_j} * cm_{BM_xCA_j}$$

Eq. 9. Contribution margin (CM) for a chosen business model ( $x$ ) for a chosen business year ( $i$ ).

$$REV_{BM_xBY_i} = \left( \frac{1}{(1+r)^{i-1}} \right) \sum_{j=1}^{20} q_{BM_xBY_iCA_j} * rev_{BM_xCA_j}$$

Eq. 10. Revenue (REV) for a chosen business model ( $x$ ) for a chosen business year ( $i$ ).

$$COST_{BM_xBY_i} = \left( \frac{1}{(1+r)^{i-1}} \right) \sum_{j=1}^{20} q_{BM_xBY_iCA_j} * cost_{BM_xCA_j}$$

Eq. 11. Cost (COST) for a chosen business model ( $x$ ) for a chosen business year ( $i$ ).

Step 9. Eq. 12. is used to calculate the contribution margin per business model for the whole business period. This can be seen as a verification or check of the scaling step as the contribution margin is postulated to be the same for all business models.

$$CM_{BM_x} = \sum_{i=1}^k \sum_{j=1}^{20} q_{BM_xBY_iCA_j} * CM_{BM_xCA_j}$$

Eq. 12. Discounted contribution margin (CM) for a chosen business model (x) over the business period (k) in years.

Step. 10. Eq. 13 and 14. result in revenues and costs per business period. This is not a necessary step but the outcome is seen as important considering the long lifetime of the vehicles and the long business period.

$$REV_{BM_x} = \sum_{i=1}^k \sum_{j=1}^{20} q_{BM_x BY_i CA_j} * REV_{BM_x CA_j}$$

Eq. 13. Discounted cost for a chosen business model (x) over the business period (k) in years.

$$COST_{BM_x} = \sum_{i=1}^k \sum_{j=1}^{20} q_{BM_x BY_i CA_j} * COST_{BM_x CA_j}$$

Eq. 14. Discounted revenues for a chosen business model (x) over the business period (k) in years.

### 3.2.2 Emissions per car age

Thirteen sources of emissions have been identified for each business model. Emission 1-10 is related to production and activities before the use-phase and thus assigned to the first age of the car (CA<sub>1</sub>). Emission 12 and 13 occurs during the use phase, between the car age one to twenty, (CA<sub>1</sub>-CA<sub>20</sub>). Emission 11 takes place at the end of the car's lifetime (CA<sub>20</sub>). The full description of when the emissions take place is described in Table 18. When the different emissions that occur for one car in relation to its age are presented in Table 19.

Table 18 - Emissions –all business models - Per car age

Emissions per car age	Source description	Equation
$em_{1-8, BM_x CA_j}$	Emissions related to the production and refining of material & Components	$em_{1-7, BM_x, CA_1} = em\_material\_components$
$em_{1, BM_x CA_j}$	- Aluminum	$em_{1, BM_x, CA_1} = em\_aluminum$
$em_{2, BM_x CA_j}$	- Steel and iron	$em_{2, BM_x, CA_1} = em\_steel\_iron$
$em_{3, BM_x CA_j}$	- Electronics	$em_{3, BM_x, CA_1} = em\_electronics$
$em_{4, BM_x CA_j}$	- Polymers	$em_{4, BM_x, CA_1} = em\_polymers$
$em_{5, BM_x CA_j}$	- Fluids and undefined	$em_{5, BM_x, CA_1} = em\_fluids$
$em_{6, BM_x CA_j}$	- Other metals	$em_{6, BM_x, CA_1} = em\_other\_metals$
$em_{7, BM_x CA_j}$	- Copper	$em_{7, BM_x, CA_1} = em\_copper$
$em_{8, BM_x CA_j}$	- Tires	$em_{8, BM_x, CA_1} = em\_tyres$
$em_{9, BM_x CA_j}$	Production of Li-ion battery modules	$em_{9, BM_x, CA_1} = em\_Battery$
$em_{10, BM_x CA_j}$	Manufacturing, assembling, in-, and out-bound logistics at/to Volvo manufacturing facilities	$em_{10, BM_x, CA_1} = em\_manufacturing = 1\ 400\ kgCO_2 - eq$
$em_{11, BM_x CA_j}$	End-of-life emissions from landfill and incineration	$em_{11, BM_x, CA_{20}} = em\_EoL = 500\ kgCO_2 - eq$
$em_{12, BM_x CA_j}$	Production and transport of spare parts	Car age (CA <sub>j</sub> ): $j = 1$ to $j = car\_lifetime$ $em_{12, BM_x, CA_j} = em\_spare_{CA_j}$
$em_{13, BM_x CA_j}$	Emissions from use phase, due to carbon intensity of electricity mix	Car age (CA <sub>j</sub> ): $j = 1$ to $j = car\_lifetime$ $em_{13, BM_x, CA_j} = driving\_distance_{CA_j} * fuel\_efficiency * electricity\_mix$

Table 19 - All business models, a summary of emission sources in relation to car age

Car age	Materials & components	Li-ion battery	Manufacturing	Spare parts	Use phase/driving	EOL
1	x	x	x	x	x	
2-19				x	x	
20				x	x	x

Step 11. CO<sub>2</sub>eq per emission source and business year is calculated in Eq. 15. Emissions per car age and emission source from Table 18 are used in eq. 15-17 below. These emissions might differ between the business models assessed.

$$EMISSION_{c, BM_x, BY_i} = \sum_{j=1}^{20} q_{BM_x, BY_i, CA_j} * em_{c, BM_x, CA_j}$$

Eq. 15. Emission per business year, business model, and emission source.

Step 12. Eq. 16 takes the leap from business year to the whole business period per emission source.

$$EMISSION_{c, BM_x} = \sum_{i=1}^k \sum_{j=1}^{20} q_{BM_x, BY_i, CA_j} * emission_{c, BM_x, CA_j}$$

Eq. 16. Emission per business period and business model per emission source.

Step 13. To get to the main measurement for the BM-LCA, CO<sub>2</sub>.eq/SEK(CM), all emissions for the whole business period are calculated in eq. 17. -

$$EMISSION_{BM_x} = \sum_{c=1}^{17} \sum_{i=1}^k \sum_{j=1}^{20} q_{BM_x, BY_i, CA_j} * emission_{c, BM_x, CA_j}$$

Eq. 17. Emission per business model for all emission sources.

Step 14. The main measurement of this BM-LCA, CO<sub>2</sub>.eq/SEK(CM), is calculated for all business models in eq. 18 by using the result in eq. 12 and 18. Eq. 17 results in CO<sub>2</sub>eq per SEK revenue for the different business models. This measurement is considered to be of interest together with the CO<sub>2</sub>eq measure based on contribution margin.

$$CO_2.eq/SEK(CM)_{BM_x} = \frac{EMISSION_{BM_x}}{CM_{BM_x}}$$

Eq. 18. CO<sub>2</sub>eq per SEK contribution margin for each business model

$$CO_2.eq/SEK(REV)_{BM_x} = \frac{EMISSION_{BM_x}}{REV_{BM_x}}$$

Eq. 19. CO<sub>2</sub>eq per SEK revenue for each business model

### 3.3 Life cycle inventory

The life cycle inventory originates from the public LCA report made by VCC on the C40 battery-electric vehicle. Thus, the existing report set the base of the system boundary. The values from the report are shown per car in Table 20 with the functional unit of 200 000 km.

Table 20 - XC40 LCA results used in the BM-LCA

Activity	Kg CO <sub>2</sub> eq
Material production and refining	17 000
Li-ion battery modules	7 000
Manufacturing	1 400
Use-phase emissions (EU-28 electricity mix)	16 000
End-of-life	500

To make the values compliant with these BM-LCA equations, they have been expressed as per car age (CA<sub>j</sub>). Emission 1-10, occurs before and during production, thus all the emissions can be allocated to car age 0-1 (CA<sub>1</sub>). Emission 13, use-phase emissions, occur during the entire lifetime of the car and are distributed evenly along the car ages. Based on driving distance data from VCC, a car is estimated to travel 10 000 km per year. Dividing the functional unit of 200 000 km from the LCA report by the driving distance gives a lifetime of 20 years per car. The emissions from use-phase (EU-28 electricity mix) per car age is thus calculated in the following way: CA<sub>j</sub>=16 000 kg CO<sub>2</sub>eq / 20 years = 800 kg CO<sub>2</sub>eq / year. Emission 11, end-of-life emission from incineration and landfill, are allocated to car age 20 (CA<sub>20</sub>). See Table 21 below.

Table 21 - Emission values and equations

Emission values in relation to the coupling equations
$em_{1-8, BM_x, CA_1} = em_{material\_components} = 17\ 000\ kgCO_2eq$
$em_{9, BM_x, CA_1} = em_{Battery} = 7\ 000\ kgCO_2eq$
$em_{10, BM_x, CA_1} = em_{manufacturing} = 1\ 400\ kgCO_2eq$
Car age (CA <sub>j</sub> ): $j = 1$ to $j = car\_lifetime$
$em_{13, BM_x, CA_j} = driving\_distance_{CA_j} * fuel\_efficiency * electricity_{mix}$ $= 16\ 000\ kgCO_2eq$
$em_{11, BM_x, CA_{20}} = em_{EoL} = 500\ kgCO_2eq$

### 3.3.1 Spare parts

Spare parts are not included in the existing VCC C40 LCA but are included in the BM-LCA system boundary to be able to perform a more complete assessment of the business models. Thus, data collection and calculation of spare parts in relation to  $q_{BM_xBY_iCA_j}$  was performed. This was done by combining historical company-specific data and estimations from experts within the field of spare parts at VCC. Emissions from spare parts have been allocated accordingly to how much spare parts are being replaced per car age.

During the warranty period, VCC does not receive any revenues from spare parts. After the Warranty period, spare parts become revenues for VCC. At both times, spare parts are nevertheless causing environmental impact. There is no difference in the relative amounts of produced spare parts for the different business models. However, in the computational excel model, there is the possibility to make changes in the spare part activity for the different business models.

### 3.4 Life cycle impact assessment

Impact results are calculated based on inventory data. The calculated impacts aim at presenting core results, CO<sub>2</sub>eq emission per contribution margin, as well as additional information that creates a better understanding of the core results.

In Figure 12, the total amount of greenhouse gas emissions from the five business models over their entire business period is compared with one another based on the set contribution margin of Partner sales. Compared to Partner sales, Direct sales are reduced to 91% of the total CO<sub>2</sub>eq, Flex 77%, Fix 66% and Multicycle 55%, which can be seen by the normalized values in Figure 12 and Table 22.

Figure 12 - Normalized results for Partner sales

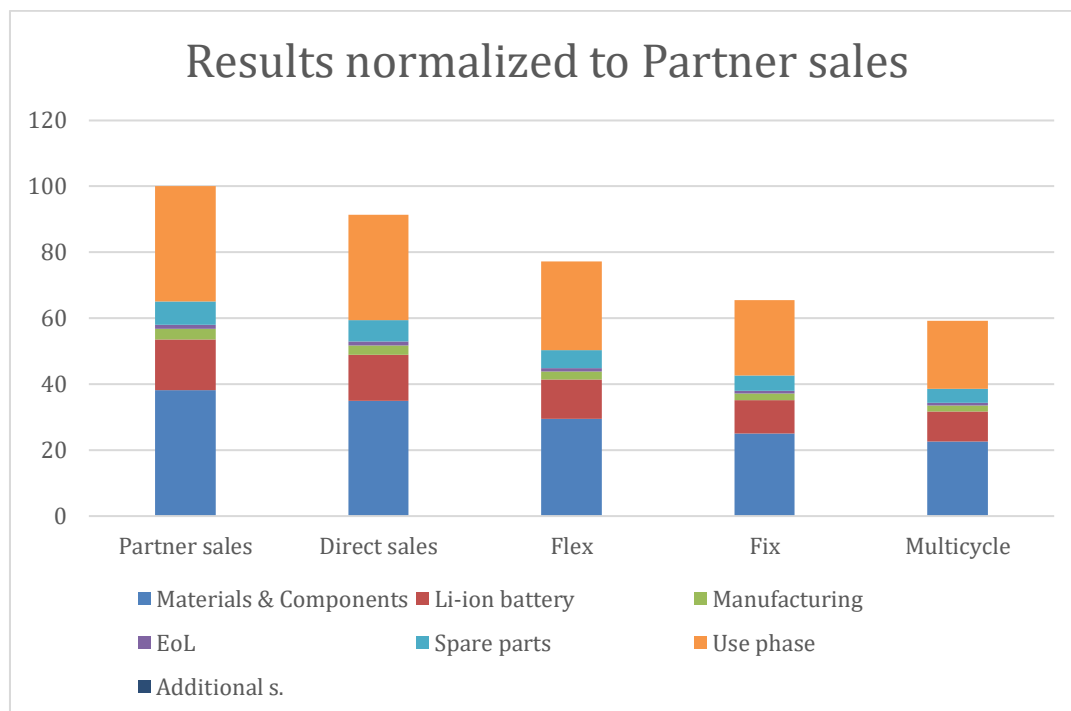
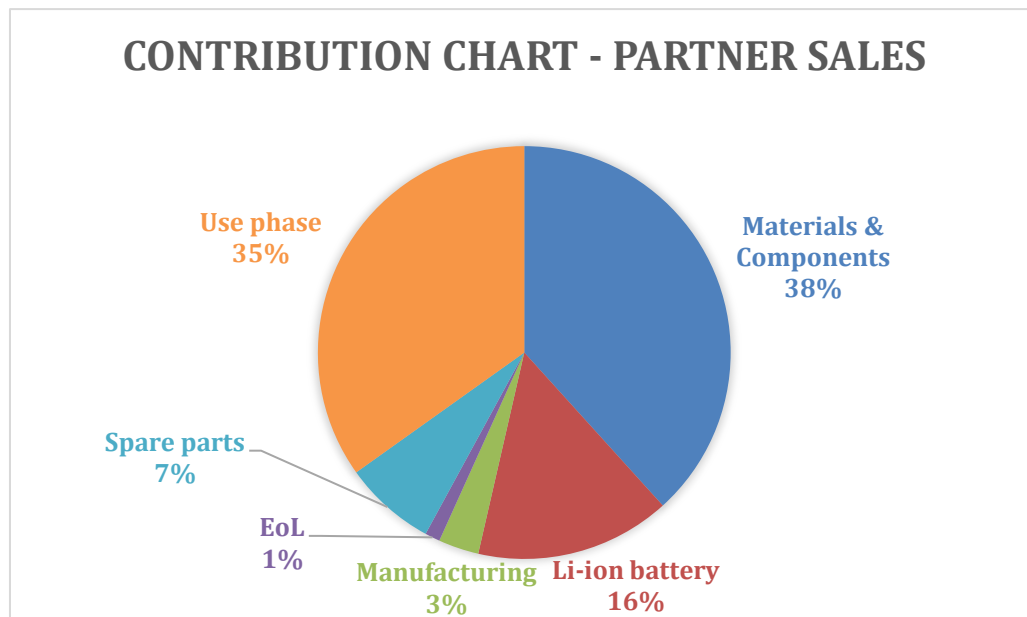


Table 22 - Summary table

Business model	CO <sub>2</sub> eq /CM compared to Partner sales
Partner sales	100%
Direct sales	91%
Flex	77%
Fix	66%
Multicycle	56%

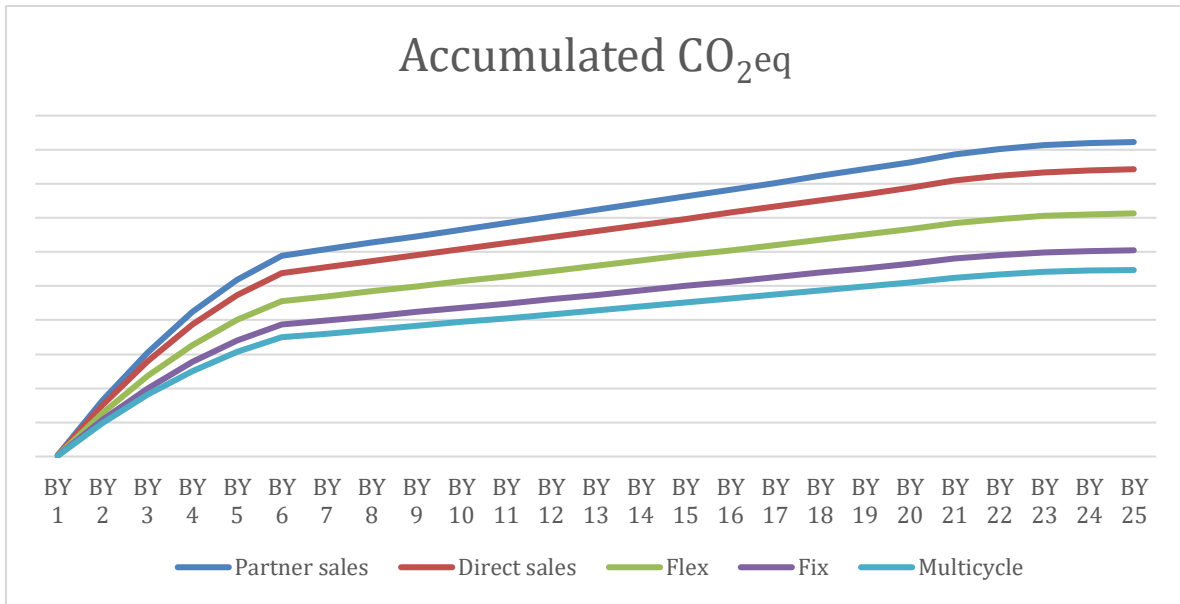
Out of the total CO<sub>2</sub>eq for Partner sales, 38% comes from extraction and refining of raw material. With the same EU-28 electricity mix as the initial LCA report, 35% of the emissions come from the use phase. 16% comes from the production of li-ion battery modules, 7% from spare parts, 3% from manufacturing, and 1% from end-of-life management, see Figure 13. Since the cars are dealt with and used similarly by the users between the different business models, there is no variation in the distribution of emissions between them. Although some business models might enable a different solution for managing spare part usage in their cars in the future, this is not done today.

Figure 13 - Contribution chart - Partner sales



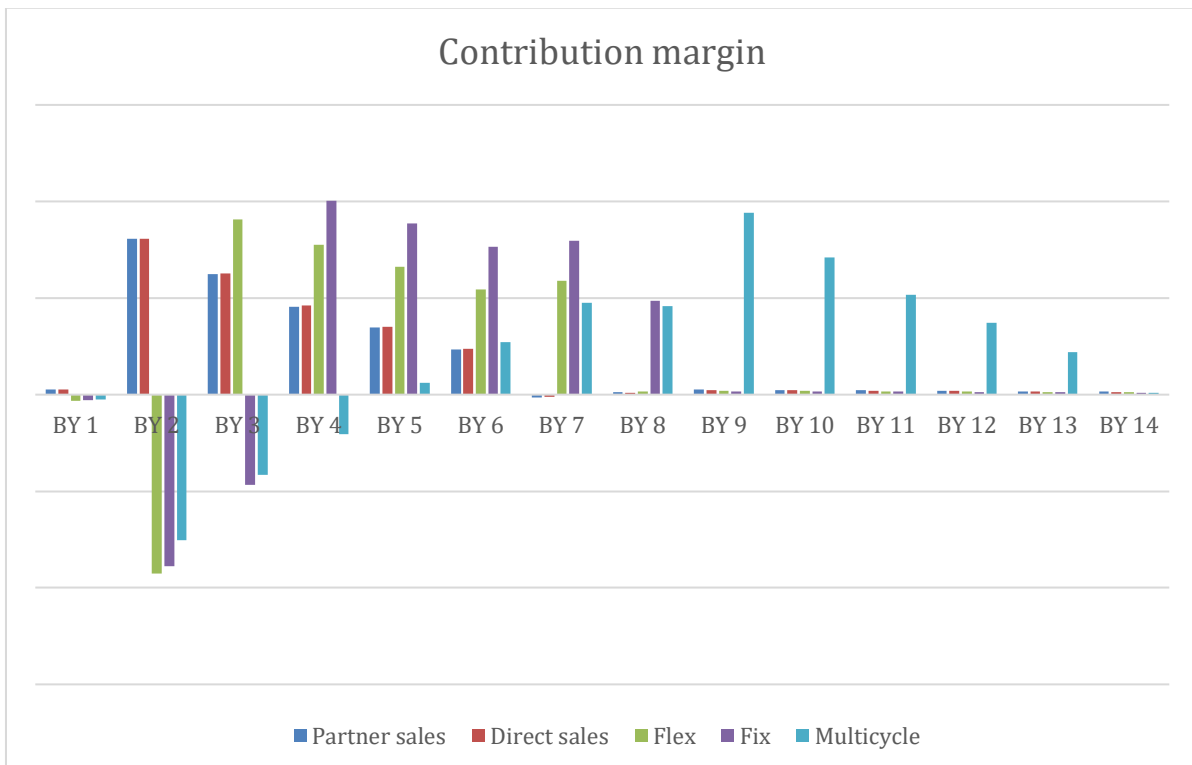
In Figure 14, the environmental impact per business year is accumulated over the entire business period. The changed slope of the curve is due to a changing mix of cars with different ages for each BY. The first part of the curve, BY 1-6 represents the years including the production of cars and the use phase. BY 6-20 represents the years including cars with only use phases. BY 20-25 represents the years including cars with use phases and end-of-life management.

Figure 14 - Accumulated tCO<sub>2</sub>eq per business year



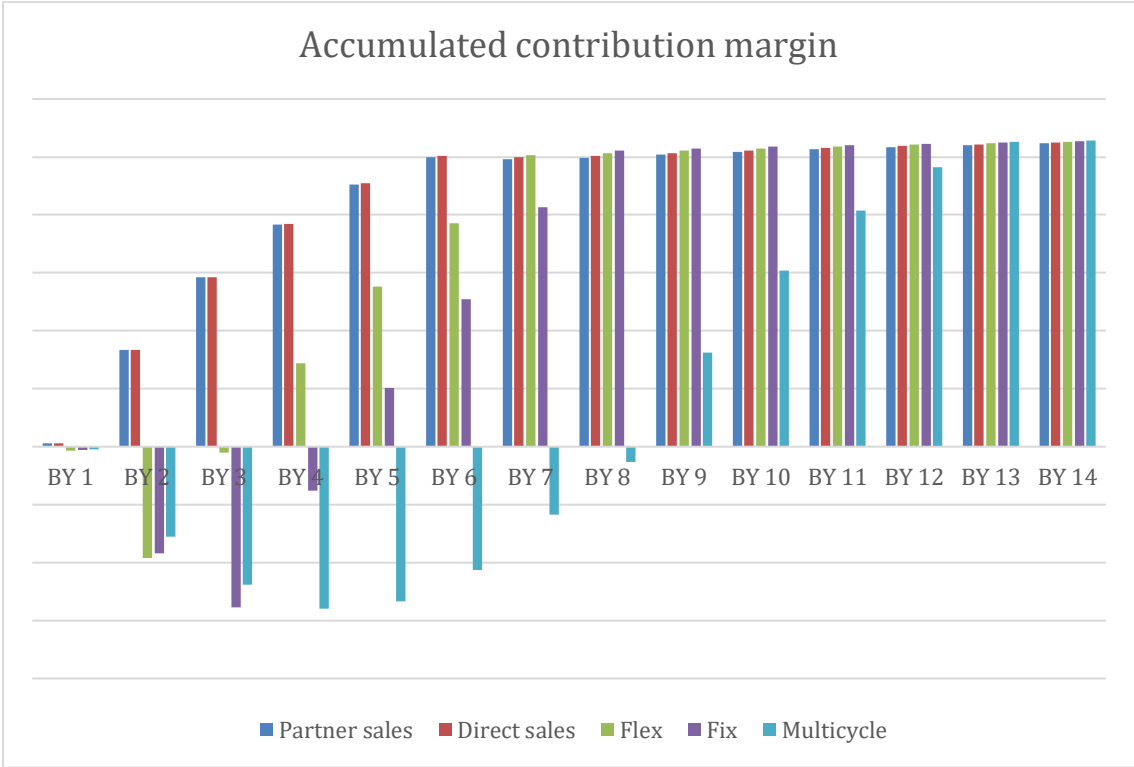
Additional to the previously performed BM-LCIA, complementary results mainly focused on the economic performance of the business models are presented in this report. Although the contribution margin is set to the same level for each business model, there is a variation in when the revenues and costs occur. In Figure 15, the contribution margin per BY is shown. Both Partner sales and Direct sales generate their main revenues at the same time as their main costs. Flex, Fix and Multicycle generate both monthly revenues and revenues at the end of the subscription when the used car is sold, while the main costs are at the beginning of the system.

Figure 15 - Contribution margin per business model per business year



In Figure 16 the accumulated contribution margin can be seen. Both Partner sales and Direct sales have a positive accumulated contribution margin from the start and reach the final decided contribution margin value at BY 6. Flex has a negative accumulated contribution margin until BY 3 and reaches the final value at BY 7. Fix also has a negative accumulated contribution margin until BY 4 and reaches the final value at BY 8. Since the cars are not sold until 8 years after their introduction, Multicycle has also a negative accumulated contribution margin until BY 8 and reaches the final value at BY 13.

Figure 16 - Accumulated contribution margin



### 3.5 Interpretation

In the following section, an analysis of the results, checking uncertain data and how the input parameters change the results of the business models is performed. Thanks to the coupling equations, it is possible to alter both environmental and economic parameters to investigate their influence on environmental performance. One parameter at the time has been changed and evaluated, the model allows however for multiple parameters to change at the same time. Table 23 shows which and how the parameters are changed, and how the new result is compared to the respective business model without any changes. A percentage above 100% is an increase of CO<sub>2</sub>eq per CM. 100% indicates that the change in parameter does not affect the business model’s CO<sub>2</sub>eq per CM. A percentage lower than 100% means a reduction of CO<sub>2</sub>eq per CM.

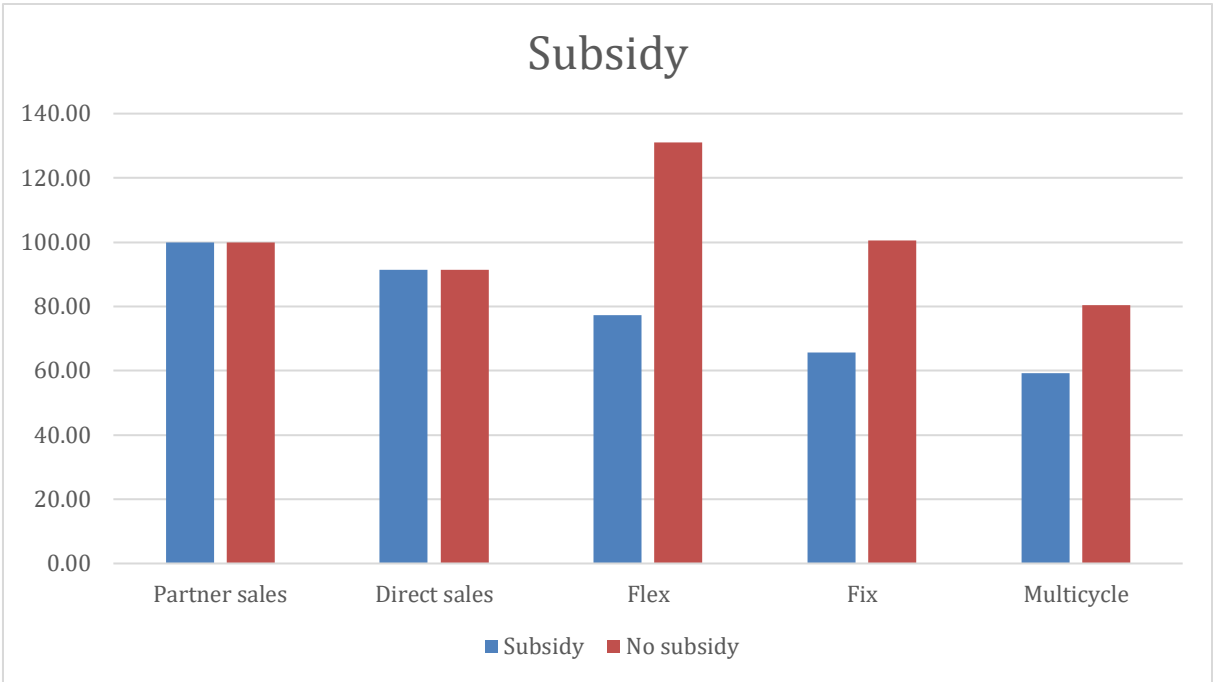
Table 23 - A summary of sensitivity analysis, % change of the amount of CO<sub>2</sub>eq compared to the same business model without changed parameter

Sensitivity category	Parameter changed	How the parameter was changed	Partner sales % change	Direct sales % change	Flex % change	Fix % change	Multicycle % change
Altering revenues	Subsidy	No subsidy	100%	100%	169%	153%	143%
	Used car price	+20%	100%	100%	71%	77%	79%
		-20%	100%	100%	166%	142%	115%
Altering costs	Components and battery costs	+20%	178%	167%	151%	140%	133%
		-20%	69%	71%	75%	78%	80%
	Manufacturing costs	+20%	103%	103%	102%	102%	102%
		-20%	97%	97%	98%	98%	98%
Altering financial factor	Discount rate	2.5%	108%	107%	114%	118%	135%
		5%	115%	115%	129%	140%	185%
		10%	130%	129%	164%	198%	385%
Altering CO <sub>2</sub> eq-intensity	Electricity mix	EU-27 2020	86%	86%	86%	86%	86%
		Sweden 2020	66%	66%	66%	66%	66%
		Global grid mix	118%	118%	118%	118%	118%
	CO <sub>2</sub> eq from battery and components	+20%	111%	111%	111%	111%	111%
		-20%	89%	89%	89%	89%	89%
Altering product factors	Fuel efficiency	+20%	107%	107%	107%	107%	107%
		-20%	93%	93%	93%	93%	93%
	Car lifetime	+50%	148%	148%	148%	149%	149%
		-50%	91%	91%	91%	91%	91%
Altering functional unit	Business period	5years	66%	66%	109%	297%	N/A <sup>1</sup>
		10years	76%	75%	75%	74%	123%

<sup>1</sup>due to negative CM, the results from Multicycle with a business period of 5 years are not possible to calculate.

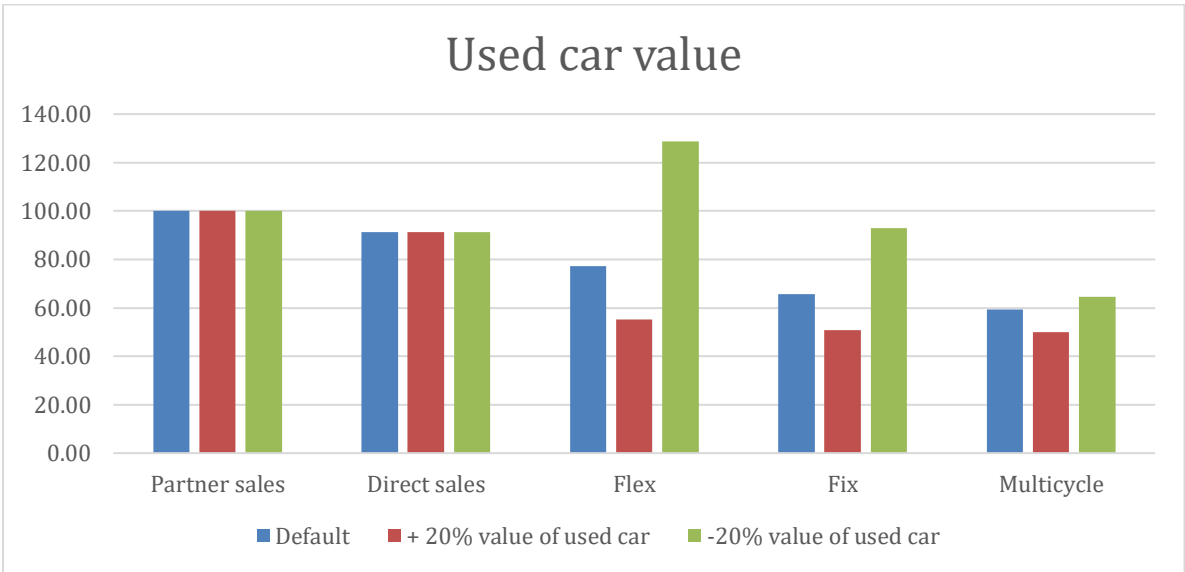
The subsidy is currently a revenue only given to Flex, Fix, and Multicycle from the government since VCC is the owner of the car. In the nearby future, there are considerations of reducing and removing it entirely, therefore, it is of interest to change this parameter and check the new result. Removal of subsidy would negatively affect the three business models, making Partner sales and Direct sales more competitive, see Figure 17.

Figure 17 - Subsidy



The value of used cars depends on the current market and is out of VCCs scope to adjust. Issues with global production can lead to fewer cars on the market and thus fewer used cars, triggering the price for used cars. A 20% increase in value reduces the relative emissions for Flex, Fix, and Multicycle by 29%, 23%, and 11% respectively. A 20% decrease punishes Flex the hardest, resulting in a 66% increase in relative emissions per contribution margin, see Figure 18. Fix and Multicycle are also affected, however not to the same extent since they have a higher rate of subscription fee revenues compared to sold used car revenue.

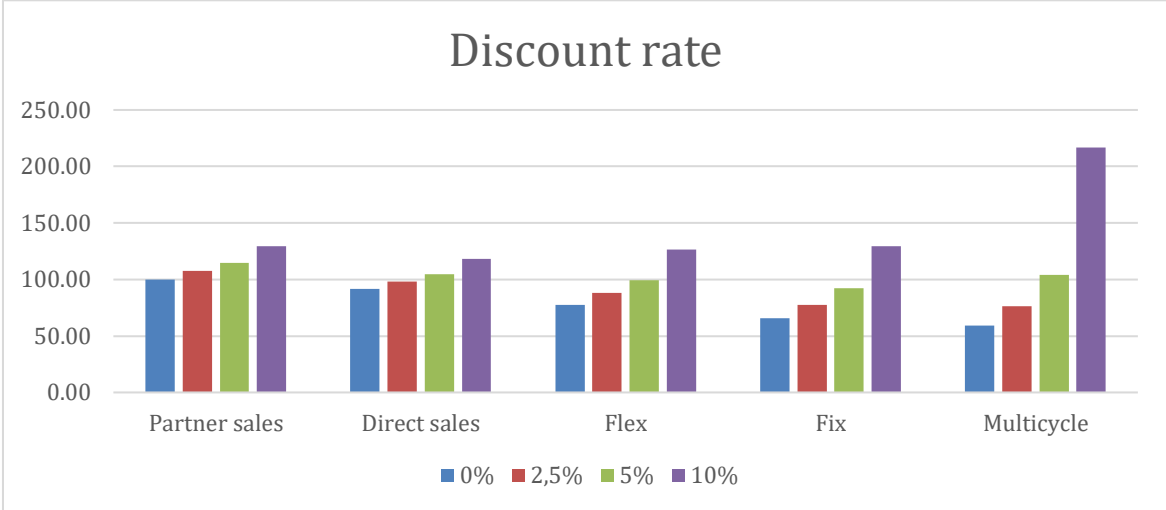
Figure 18 - Used car value



A discount rate is argued to play a significant role in business decisions since when revenues and costs occur are vital for an organization's cash flows. Three discount rates with values of

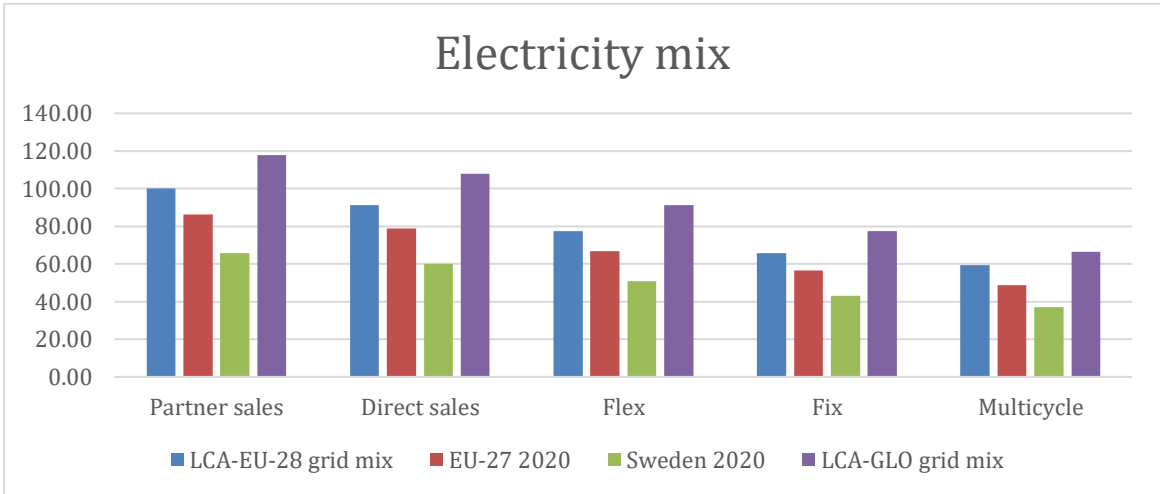
2.5% (red), 5% (green) and 10% (purple) have been tested compared to 0% (blue) discount rate, see Figure 19. With a higher discount rate, business models where revenues appear later than the costs, are negative for the result. With a rate of 10%, Flex and Fix have similar results as Partner sales. Multicycle is the most affected business model, with an almost twofold amount of gCO<sub>2</sub>eq/f.u compared to Partner sales.

Figure 19 - Discount rate



During the lifetime of the car and the chosen business period, the electricity mix will probably increase its share of low-carbon intensive electricity. With a specific Swedish energy mix, all business models reduce their relative emissions by 34% compared to their respective business models with the EU-28 grid mix taken from the initial LCA report, see Figure 20. However, the absolute decrease is bigger for Partner sales since it requires more produced cars to reach the same contribution margin compared to the other business models.

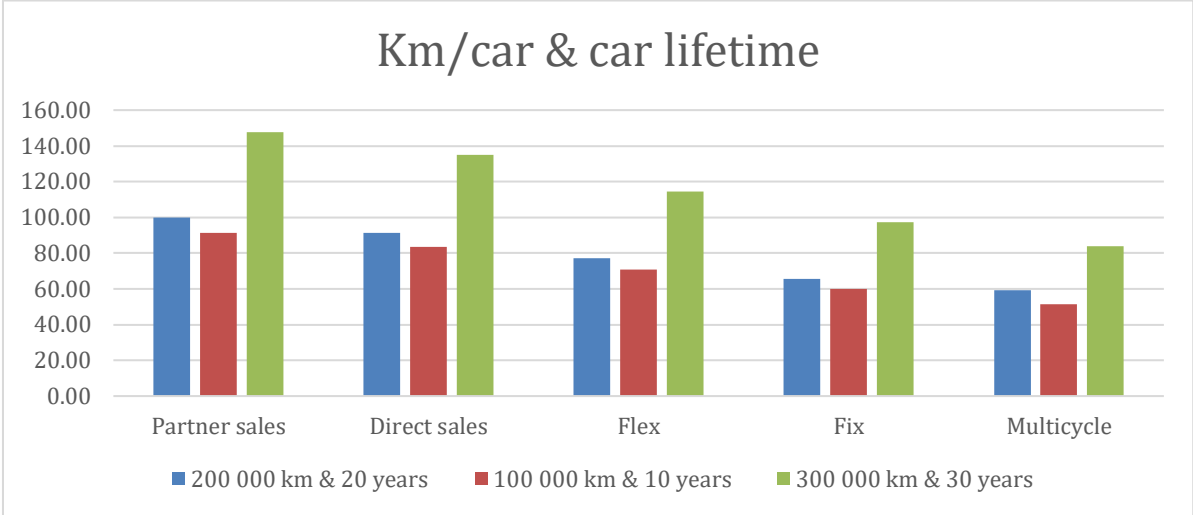
Figure 20 - Electricity mix



Although the existing C40 LCA had a functional unit of 200 000 km, it can be argued that the technical lifetime of a car can be both longer and shorter. A shorter lifetime of 10 years reduces the use phase emissions by 50% while keeping almost all the revenues except some

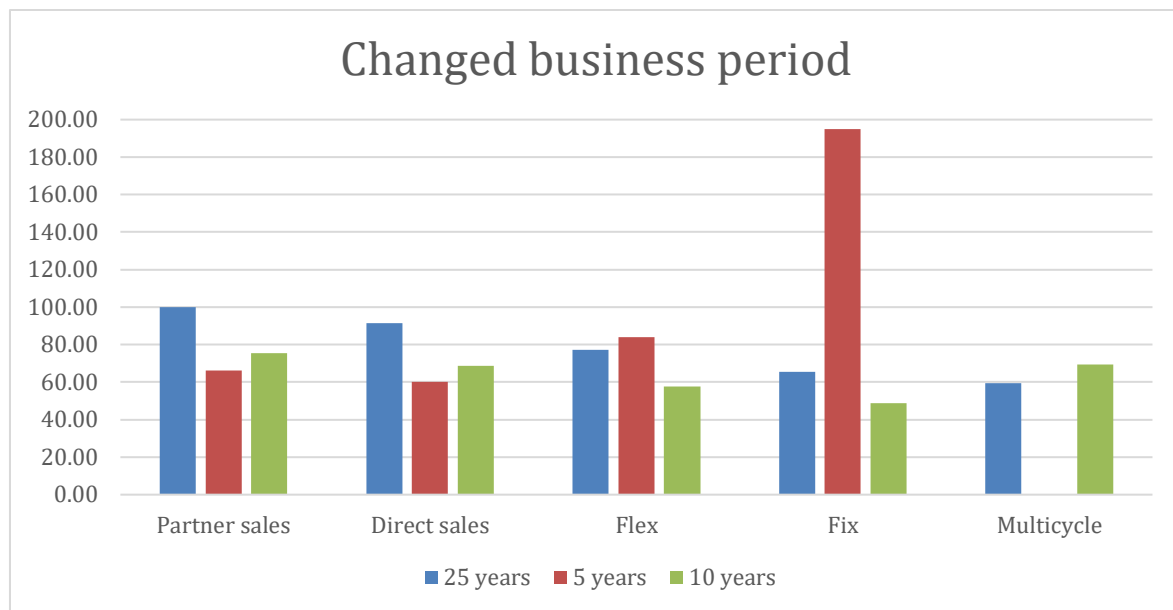
spare part sales. Therefore, the BM-LCA result is better for this shorter lifetime. On contrary, increasing the lifetime by 50% results in 50% more emissions from the use phase, with insignificant revenues, resulting in a worse BM-LCA result, see Figure 21. When looking at the functional measure of CO<sub>2</sub>eq per km the opposite relation is true. Decreasing the lifetime of the vehicle leads to a worse functional environmental performance while increasing the lifetime leads to a better functional environmental performance.

Figure 21 - Km / car & car lifetime



It was assumed by the authors that with a short business period, the assessment would not include all relevant life cycle activities. In this case, the business period was changed to the first five and ten years from start of production, see Figure 22. It is however in the model also possible to analyze a different segment. Looking at the first ten years, all business models improve their environmental performance except Multicycle. Looking at a five-year business period reduces the impact of Partner sales and Direct sales while increasing the relative impacts of Flex and Fix. Since Multicycle has a negative contribution margin until year 8, the results are not applicable.

Figure 22 - Business period



### 3.6 Conclusion of the BM-LCA study of the five business models

Finally, based on the impact assessment and interpretation, conclusions and recommendations can be drawn. The conclusions and recommendations on the environmental performance of the assessed business models are presented below. This is the last part of the BM-LCA study that is part of this thesis report.

The main reason why some business models had better environmental performance than others is that they required different amounts of produced cars to obtain the set level of contribution margin. Mainly the economic parameters influenced the outcome, and how the environmental performance of the business models was affected by the most significant parameters are described below.

Partner sales were selected as the reference model since it is by far the dominating business model of today. Direct sales, which have similar physical flows, but attain revenues directly from the customer instead of from the dealer are more profitable. The Direct sales model, therefore, performs better than Partner sales when assessing the current state as well as in all sensitivity scenarios tested. The environmental impact of the Direct sales business model is 91% compared to Partner sales and together with the results from the sensitivity analysis, it can be said that the Direct sales business model has undoubtedly better environmental performance compared to Partner sales.

The Flex business model has a better environmental performance compared to Partner sales and Direct sales. Flex is however sensitive to changes in subsidies and used car value. Removing the 70 000 SEK governmental subsidy results in a less favorable environmental performance of the Flex business model changing the ranking so that Partner sales and Direct sales environmental performance is better than Flex. Flex is also sensitive to changes in used car values. A 20% decrease in value makes the model far worse compared to Partner sales and Direct sales. Both these two changes are outside the company's influence and are therefore a risk.

The Fix business model has similar results as Flex but differs in some results since Fix has a higher share of revenues from subscription fees compared to sales of used cars. Fix performs better than Partner sales, Direct sales, and Flex in the assessment as well as on all sensitivity tests except for using a high discount rate and a short business period. Removing the subsidy reduces the environmental performance, not as much as for Flex, however, resulting in an environmental performance similar to Partner sales. Fix is not as sensitive to the value of used cars as the Flex model. With a 20% reduction in used car value, the Fix model is still better compared to Partner sales but worse than Direct sales. The Fix model is reliant on a subsidy but is overall less sensitive to outside influences compared to the Flex model.

Multicycle is the business model with the best environmental performance. This is also true for all sensitivity scenarios except when using discount rates higher than 5% or looking at short business periods. A no subsidy scenario does not increase the relative result as much as for Flex and Fix, resulting in maintained better results compared to Partner sales and Direct sales. Neither does the value of used cars affect the Multicycle as much as it does for Flex and Fix. External influence is therefore less of an issue for the Multicycle model.

To summarize, it is more favorable to sell cars directly to customers instead of to dealers, favoring the Direct sales model above Partner sales. Additionally, it would be advised that in parallel to Direct sales, with caution of change in parameters of external influence, increase the share of the subscription-based business models. Multicycle followed by Fix is the preferred subscription business model from a BM-LCA perspective. It is however important for the implementation of the subscription-based business models to be aware that the major revenues will be postponed, up to several years, as the sale of the car is later into the future compared to the non-subscription business models. The consequences of this shift in cash flows must be understood to give further recommendations.

## 4 Exploration – BM-LCA as a tool for Business Model Innovation

This part of the report will explore the possibility to use BM-LCA as a tool for business model innovation.

The BM-LCA computational excel model in this study was built with the possibility to alter several product and business parameters and instantly view the changes in environmental performance from these changes. This possibility was used when performing the sensitivity analysis, see Interpretation, but can also be used when working with sustainable business model innovation. While input parameters were changed one by one in the sensitivity analysis it might be of interest to change multiple parameters at the same time when working with sustainable business model innovation. Commonly, changing one parameter leads to consequences, and changes in other parameters are needed as well to create realistic scenarios. An example is a change in spare part offerings, from selling mainly new parts to selling a mix of new, remanufactured, refurbished, repaired, and reused (4R). Since there is an increase in market offers, the retention curve will most likely increase consequently. The coupling equations and the structure of the computational excel model allow for changes in multiple parameters at the same time, and the results can be viewed as exploring different possible future scenarios. Variable parameters in this model are found in Table 24 below.

Table 24 - Variable parameters

General parameters	CO <sub>2</sub> eq intensity	Rev & cost
Km per car lifetime	CO <sub>2</sub> eq material & components	Subsidy
Production per Business Year	CO <sub>2</sub> eq Li-ion battery	Discount rate
4R spare part distribution	CO <sub>2</sub> eq Manufacturing	Spare parts covered by insurance during the subscription period
Retention per car age	Fuel efficiency	Cost of sales spare parts
Warranty spend	Electricity mix	Revenue spare parts
	CO <sub>2</sub> eq per kg spare parts	Additional services
	Additional services	Rev 1 to rev 11
		Cost 1 to cost 18

An example of a business model simulation is the performed BM-LCA on Multicycle, as that is a derivative from Flex where all cars are sold directly after the first subscriber ends its subscription. The Multicycle is assessed with expert estimations on the total cost of changing subscribers, a total of three subscribers over eight years, and a declining subscription fee for older cars. Shifting these parameters and other variable parameters can give indications of the potential environmental performance.

The results, communicated in dashboards, consist of a combination of graphs and numerical values in tables. The main numerical outcome of this BM-LCA is the measure of CO<sub>2</sub>eq per contribution margin during the business period. Some additional information was added to increase the possibility of taking well-informed decisions. The following information is part of the dashboards shown in Figure 23.

- CO<sub>2</sub>eq per SEK CM
- CO<sub>2</sub>eq per CM in reference business model including contribution distribution
- Contribution chart of business model activities for Partner sales
- CM per business year – per business model
- Accumulated CM per business year
- CO<sub>2</sub>eq per SEK turn-over
- Total fleet distance
- Accumulated tons of CO<sub>2</sub>eq per business year
- CO<sub>2</sub>eq per km

Figure 23 - Dashboard comparing business models



A conventional LCA focuses on environmental impacts connected to a function of a product or service while BM-LCA focuses on the environmental performance of the entire business model. Both measures might be of interest when developing sustainable business models. A business model where the impacts of the product per function are increased while the impacts per profit or contribution margin are decreased is doubtfully more sustainable, at least not from a functionality perspective. Vice versa, where impacts per product function are decreased while impacts per profit are increased might neither be viewed as more sustainable, at least not from a business perspective. It can therefore be seen as important to complement the impact per contribution margin measurement with more traditional functional focused LCA measurements.

Economic measurements related to the timing of revenues and costs are also of interest to understanding cash flows and the economic implications of changes in business models. A service-oriented business model often implies revenues spread over a longer period which can lead to a mismatch in revenues and costs. Understanding, and overcoming such implications, are important to be able to move from theoretical business models to business models that work in practice.

BM-LCA results can increase understanding and collaboration between disciplines by including environmental, economic as well as combined measures. While the multi-disciplinary approach might be a challenge, when collecting data and modeling, the results can hopefully act as a bridge between specialists. This might be seen as a secondary outcome but is of great importance to making a reality of sustainable business model innovation. While the inclusion of economical outcomes is necessary for companies to bet on new business models it is also of great importance to include environmental outcomes to safeguard environmental performance. BM-LCA as a tool for business model innovation has the potential to help organizations take a well-informed business decision considering both environmental, economical, and combined performance.

## 5 Evaluation of BM-LCA in this study

This part of the report focuses on the usefulness of the BM-LCA methodology and results as well as the feasibility to perform the BM-LCA study. The assessment of the usefulness of the method and results are based on feedback from VCC. The evaluation of the feasibility of the BM-LCA relates to the work process and is discussed and evaluated by the authors of this report.

### 5.1 Evaluation of the usefulness of BM-LCA for VCC

To assess the usefulness of the BM-LCA study, a workshop was performed with employees from VCC. The persons present at the workshop had positions within circular economy, life cycle management, sustainability of VCC businesses, after-market, and business.

Input to the evaluation was collected from discussions and feedback at a workshop at VCC. This part of the project would have benefited from a more thorough and structured approach with for example interviews, questionnaires, and workshops. This was not possible due to time constraints and it was considered that some feedback is better than none.

The workshop at VCC started with a brief introduction and background to the BM-LCA method followed by a presentation of the input parameters affecting the results. The results were presented and some modifications in input parameters illustrated the possibility to use the BM-LCA model for business model innovation.

And now to the actual feedback. It was clear that it is of interest to measure the environmental performance of business models. It was not that clear that the result of the BM-LCA, presented as CO<sub>2</sub>eq per SEK CM, is seen as the best way to do this. It is unclear if this uncertainty was due to a lack of time to think things through or if there are other reasons. There were however no suggestions on measures that better can capture the environmental performance of business models.

One of the clearest feedback items was that the fixed contribution margin used as a basis for comparison of business model environmental performance was disturbing to persons on the business side. It was clear that the goal at VCC is to reduce carbon emissions while at the same time growing the business. The feedback is no surprise but still valuable. Especially if BM-LCA aims at gathering business and environmental persons to buy in on the same measures. The fixed contribution margin for all business models became a hick-up even when it was described that the measure gCO<sub>2</sub>eq per SEK contribution margin and normalized results can be seen as measures that are not bound to a fixed contribution margin. It was discussed if it is better to use a fixed production volume or a fixed carbon budget instead of a fixed contribution margin, but these possibilities were not considered relevant due to other reasons. A conclusion from this feedback is that it might be a good idea to focus on measures where it is possible to scale the businesses and not mention fixed business value (e.g. contribution margin or profit) if there is an intention and will to bring along the business side of the company.

The participants were free to ask questions and comment during the whole session and the go-through of the input parameters resulted in several discussions, comments, and questions. This was most obvious for the inclusion of spare parts in addition to the existing product LCA

used in this study. Discussions tended to evolve around the correctness of individual values and parameters as well as general thoughts related to the parameters used in this study.

While environmental performance is of great interest at VCC, the same goes for profitability. Since contribution margin is used in this study, some of the costs included in a profit measure were not accounted for. As new business models often require investments and other increased costs, compared to prevailing business models, it is of interest to include these increased costs in the analysis of the business models. A higher contribution margin is therefore often required for new business models compared to existing business models.

One of the business models, multicycle, is not in use today. The inclusion of this business model in the assessment was actively discussed and it was clear that optimization of input parameters, such as how old a car is when sold and the number of change of subscribers for one car, leading to an optimal environmental and economic performance was of interest. It could be of interest to check if BM-LCA, as a tool for business model innovation, could help in this optimization of profitability while at the same time safeguarding environmental performance.

Another input was that it is often of interest to change multiple parameters at the same time. An example of this is input regarding the distribution of spare parts that are new, remanufactured, refurbished, repaired, and reused. Changing this distribution goes hand in hand with increasing the retention curve for spare parts which means that VCC sells a larger part of the total spare parts used during the car's lifetime. This might also be the case for changing the CO<sub>2</sub>eq-emissions from for example aluminum as this might lead to a higher material cost.

Assessing a combination of the environmental and economic performance of business models is not as straightforward as measuring environmental performance from a functional perspective. A more thorough evaluation is needed to understand if BM-LCA is of interest to VCC when it comes to assessing and innovating business models with environmental performance in focus. VCC was interested in looking more into the computational excel model to be able to better understand the results and to see how changes in input parameters affect the results.

## 5.2 Evaluation of the feasibility of BM-LCA

The fact that BM-LCA only is performed on one case before this study, together with differences between this study and the prior study, made it difficult to estimate the time needed to complete different steps of the study. At the planning stage of this project, it was not possible to know if the calendar time and work time available would be enough to complete the BM-LCA study. The distribution between different tasks as well as the total time needed will differ between studies, but it might still be of interest to understand and reflect on the work process in this study. Figure 24 displays both work weeks spent and calendar time. The total work time spent on each BM-LCA activity corresponds to work time spent by two persons, i.e. one week of work in Figure 24 equals two-man weeks of work.

Figure 24 - Work time spent over BM-LCA activities and weeks

BM-LCA activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	total work time
Understand product LCA																	1 week
Complement product LCA																	4 weeks
Understand BM's & create flowchart																	2 weeks
Collect & process business data																	5 weeks
Modelling																	3 weeks
Results & Interpretation																	1 week

Of the total 16 work weeks, 4 weeks were spent on complementing the product LCA with CO<sub>2</sub>eq emissions from spare parts. This process required information and data from different persons at VCC and modeling in Excel to create data that was used as input in the BM-LCA model. Complementing the existing LCA with the spare part required about 25% of the total time spent on the BM-LCA. Including emissions related to spare parts to the existing BM-LCA resulted in a more complete assessment of the business models as well as the possibility to set different 4R-distributions for the different business models when exploring business model innovation opportunities.

Collecting and processing business data was the most time-consuming activity in this study, both from a work time and calendar time perspective. Reasons for this include that information from several persons was needed and that the structure and content of the received business data did not match the business models. This led to a need to question, process, and ask for more data and clarifications. Another reason was that business data had to be requested post by post for some of the business models instead of using existing economic reports and business cases as the starting point. The time spent on collecting and processing business data could probably be minimized if the persons collecting the data are part of the organization and if received data for different business models was more coherent regarding structure and cost/rev posts. A lot of the time was spent processing data and to request more information. This was considered necessary to get a fair evaluation of the different business models. The functional unit in this study is based on contribution margin and rather small errors in economic data can have large effects on contribution margin. It was therefore considered important to be confident regarding the monetary data used in the study.

Modeling, including coupling equations, is estimated to be three intensive weeks. This part of the study could be performed in a rather short period due to information and data collected in earlier activities. The modeling was performed in Excel using the coupling equations. It is estimated that about 1 week of this time was spent including an input part where variables can be changed with instant changes in the results, presented as a dashboard. Some additional

time was also spent on including the possibility to add additional services that could be of interest when using the computational excel model for business model innovation purposes.

Results including interpretation were performed in approximately 1 week time. This includes the sensitivity analysis which could be performed rather quickly due to the possibility to change parameters in the excel model. Increasing the time used for this part would be beneficial. In the case of this study, it could be argued that the time spent on complementing the LCA with spare part data could be better spent on the activities of modeling and working with the results and interpretation.

A lot of the activities were performed in parallel and iterative. Information and knowledge acquired from one activity often led to the understanding that more information is needed within another area. The understanding of business models and collection of business data was to a large extent an integrated process.

To conclude, the work process of conducting the BM-LCA study was time-heavy on activities related to the collection and processing of business data and complementing the LCA with spare part data. The time needed to collect business data could probably be reduced a lot if the persons conducting the BM-LCA are part of the organization, if the company was smaller, and if business data for the different business models were received in the same structure/format.

A car is a complex product and so is the spare part provision during a car's lifetime. Complementing the LCA with spare part data made the time plan challenging. Skipping this part would however make the assessment less complete but more time could, on the other hand, be spent on modeling and on writing the BM-LCA study. Starting with a few contacts at VCC, the number of persons that helped in providing information increased over time. Contacts and a bit of luck were both parts of finding persons that could provide the requested information.

## 6 Discussion

In the following chapter, the reliability of the results, methodological deviations, usability of the method for business model innovation, and what knowledge gaps BM-LCA studies might fill is discussed.

### 6.1 Reliability of results

A core starting point is that the purpose of a company's business model is to create business value, for example, profit (Böckin et al., 2022b; Nosratabadi et al., 2019). With that said, environmental impact per profit is a reasonable way to measure business models' environmental performance from a company perspective, which is the used measure in the BM-LCA method. It is discussable whether business models also can create business value in other ways, such as an increase in users and market share. It is however assumed that the assessed business models' purpose is to make an immediate profit and the results are therefore justifiable.

Using contribution margin instead of profit excludes for example overhead costs. Since these costs are not accounted for, it is hard to tell precisely how the result would be affected. It is nevertheless clear that with more costs, the profit margin would decrease and the result would be more sensitive to changes in input parameters.

The results and sensitivity analysis in this BM-LCA study made it clear that it is important to complement the environmental impact per contribution margin measure with measures of environmental impacts per product function. Changes in some parameters lead to better environmental performance of the business model but at the same time worse environmental performance for the product function. This is true for an increased car lifetime where the environmental impacts per function are reduced while the BM-LCA measure of environmental impact per contribution margin is increased. The reason for this somehow conflicting result is due to increased use phase emissions but a low increase in contribution margin during the extended lifetime. The relatively low increase in spare part revenues is due to the currently low retention for VCC spare parts for older cars.

When parameters altering the contribution margin but not the emission per function are changed, the result measuring environmental impact per contribution margin will be altered while the environmental impact per function of the product will remain the same. Another way to put it is that if the contribution margin is increased the environmental performance of the business model might be considered to improve if the function of the business model is to generate profit. It is however of interest to also understand that actual emissions from the function of the product will remain the same. An example of this phenomenon in this study relates to a subsidy of 70 000 SEK received by the first owner of an electric car. With the subsidy in place, the subscription-based business models' environmental performance is better than the Partner sales and Direct sales models. A withdrawal of this subsidy would however change the ranking of the environmental performance of the business models in favor of the Partner sales and Direct sales business models. The above examples aim at stressing the importance of understanding environmental performance from multiple perspectives, in this case from a business model and product function perspective. This is to better understand the comparison of environmental performance between business models and to avoid greenwashing. It could for instance be questioned if a business model with less

environmental impact per contribution margin but higher environmental impact per function can be considered more environmentally friendly than a business model where the opposite is true.

Since some businesses have low margins, an increased cost or revenue can have large effects on contribution margin and profit. When using contribution margin or profit as a functional unit, it is therefore specifically important to have high confidence in the collected data. A less influenceable economic functional unit might be total revenues which is a measure that is insensitive to cost changes and less sensitive than contribution margin or profit for changes in revenue. It is however discussable if revenue can be considered the aim of the business model. This might be true for some emerging business models for a certain period but seldom in the long run.

The sensitivity analysis includes a change in the car's lifetime. If looking at the functional environmental performance (CO<sub>2</sub>eq/km) in addition to the business model environmental performance (COeq/SEK CM) it can be seen that the change in vehicle lifetime affects these two measures in different directions. Increasing the lifetime from 20 to 40 years leads to better functional environmental performance but a worse business model environmental performance. Decreasing the lifetime from 20 to 10 years leads instead to a worse functional environmental performance but a better business model environmental performance, as a higher share of revenues is obtained in the first 10 years. This is seen as important since it can be argued that it is doubtful to claim that a business model's environmental performance improves while the functional environmental performance gets worse. A possible solution to this dilemma is to base decisions on both business models and functional environmental performance.

## 6.2 Methodological deviations from previous BM-LCA study

Some methodological deviations from the previous BM-LCA study were made, the deviations and the effects of these are discussed in this chapter.

*Contribution margin of the Partner sales business model for a business period of 25 years from start of production* is the functional unit in this study. Contribution margin was chosen instead of profit as overhead costs were not assigned to a specific car model at VCC. As the environmental performance of the business models is based on the measure of environmental impact per contribution margin it is important to discuss the implications of choosing this measure compared to profit. If the business model aims to deliver contribution margin, this measure can be considered the most relevant. A problem when comparing different business models based on contribution margin is that the different business models might have different levels of overhead costs etcetera to cover. This might be true for the subscription-based business models in this BM-LCA study that have additional overhead costs compared to the sale models. Contribution margin is however considered the better choice compared to profit in this study, but it is important to understand discussed implications when comparing the environmental performance of business models.

When introducing new business models to the market it is not obvious that the business model aims to generate profit or contribution margin, at least not for a certain period. The focus can instead be to grow the revenue and customer base. The economic measure used in

BM-LCA studies with business models with other kinds of focus has to be modified accordingly. It might be reasonable to use a combination of environmental impacts per revenue together with impacts per product function for business models in this phase. Another consideration regarding emerging business models is if the assessment should look at present data or at forecasted data for a point in the future when the model has reached a desired volume and state. It is otherwise a risk that novel business models will be disqualified if compared to more mature business models. Disqualifications of novel business models based on assessments of the present state should be avoided in cases where the environmental performance of the business model will improve over time.

Another deviation from the methodology is how the product volumes for business models 2-5 were calculated. Instead of calculating the number of required products for business model 2-5 from a set level of profit, the different profit levels were first calculated for all the business models based on the same amount of produced products. Thereafter, the profit levels were scaled to the profit level of business model 1. With the same factor as the profit level had to be scaled to meet the profit level of business model 1, the amount of produced products was also scaled. This creates the same results as in the original methodology but was in the setting of the computational excel model more feasible. It is important to understand that scaling business models is not possible when there are fixed or semifixed costs and impacts that are not expressed per product and thus not scalable. It is however not the case in this study as contribution margin was used and scaling is therefore feasible.

### 6.3 Usability of BM-LCA for innovation of business models

Building the life cycle inventory and collecting economic data have been thoroughly performed with mainly specific company data. Both the existing LCA report and the included spare parts part were company-specific. The inclusion of spare parts improved the completeness of both the product system and the BM-LCA study. Being consistent and certain of the choices of the economic data has also been important to generate reliable and usable results.

The product system structure is close to identical for all the assessed business models in this study. The consequence is that it is the monetary flows that lead to the difference in the BM-LCA result (CO<sub>2</sub>eq per contribution margin). This makes the BM-LCA method, including the coupling equations, a potentially overcomplicated method looking at the outcome of the computational excel model. The effort put into the coupling equations and modeling in Excel can however be of use when applying the computational excel model for sustainable business model innovation. Where the model can be used when changing environmental and monetary parameters for all business models individually and getting instant results, which creates possibilities to develop business models with improved environmental performance.

BM-LCA studies combine environmental and economic evaluation leading to potential interest in the results from business oriented as well as environmental-oriented functions. The fact that a certain level of economic performance as a baseline for environmental comparison is used became however a barrier to attracting business-oriented persons to buy in on the results. This is not at least true when working with business model innovation in profit-driven companies. A conclusion from this study is therefore to focus on results that are not related to a fixed level of contribution margin. The most appropriate measure in this study to use

when presenting results would therefore be gCO<sub>2</sub>eq per SEK contribution margin and a normalized comparison of the environmental performance of the business models.

BM-LCA can be used both when assessing existing business models and forecasting the environmental performance of future business models. In the case of a mature company, BM-LCA can guide the transition to a more environmentally friendly business model mix as well as to which new business models to implement. When experimenting with new business models it is important to decide at what scale and/or point of time in the future to use as a base for the assessment to not disqualify novel business models in comparison with well-established and optimized business models. In the case of emerging companies, BM-LCA can help make informed decisions on which business models to bet on.

#### 6.4 BM-LCA to fill the knowledge gaps found in the literature

It was evident from the literature research that assessment tools for current business models and tools for business model innovation are wanted. That evidence goes hand in hand with the result from (Das et al., 2022) that to avoid lock-ins of suboptimal business models, assessment of them in explorational stages is necessary. Companies generally measure the current environmental performance of business models, however, they have no tools for assessing explorative business models. Based on the BM-LCA study, it can be concluded that it is feasible to conduct an environmental assessment of business models and also to use the method as a tool for business model innovations.

BM-LCA is a promising tool for assessments of business models' environmental performance. Measuring the environmental performance of current and prospective business models is essential to safeguard environmental concerns and avoid lock-ins in business models with poor environmental performance (Das et al., 2022; Nosratabadi et al., 2019). The lack of research on evaluation of business models from a sustainability perspective (Nosratabadi et al., 2019), the lack of evaluation in practice (N. Bocken et al., 2019), and the increased focus on sustainable business models, not at least so-called circular business models, indicate a need of assessment tools focusing on the business model. Knowing the environmental performance is essential when promoting business models internally and to the market. BM-LCA can thereby help companies make well-informed decisions when implementing new business models and pushing for changes in the current business model mix to steer towards a more sustainable path.

Addera till diskussionen att utveckling av terminologi gällande tidsdefinitioner behövs.

## 7 Conclusion & further research

This study shows that it is possible to perform a BM-LCA on complex products with a long lifetime and emissions during the use phase. Some methodological deviations compared to the previous BM-LCA was needed due to the product and business model structure, it was however feasible to obtain the result. The study also shows that it is possible to build on an existing LCA as input to the BM-LCA. Further, the computational excel model which is based on the BM-LCA method is a good tool for business model innovation. It was not possible to draw any general conclusions regarding the usefulness to VCC due to time constraints.

For future research, it would be of interest to study when and where in the process of innovating for sustainable business model, different measurements are useful. Answering this question could give guidance to when it is reasonable to measure environmental performance based on profit, and when it is relevant to assess the environmental performance separated from the profitability.

Secondly, it would be of interest to conduct and evaluate BM-LCAs on business models labeled as sustainable or circular by the companies, where there are more clear differences within the product systems compared to this case.

## Reference list

- Amatuni, L., Ottelin, J., Steubing, B., & Mogollón, J. M. (2020). Does car sharing reduce greenhouse gas emissions? Assessing the modal shift and lifetime shift rebound effects from a life cycle perspective. *Journal of Cleaner Production*, 266, 121869. <https://doi.org/10.1016/J.JCLEPRO.2020.121869>
- Baumann, H., Böckin, D., Goffetti, G., Tillman, A.-M., & Zobel, T. (2022a). Switching the focus from product function to business profit: Introducing Business Model LCA (BM-LCA). *Proceedings of the 10th International Conference on Life Cycle Management, LCM2021. In E3S Web of Conferences, Forthcoming*.
- Baumann, H., Böckin, D., Goffetti, G., Tillman, A.-M., & Zobel, T. (2022b). Switching the focus from product function to business profit: Introducing Business Model LCA (BM-LCA). *E3S Web of Conferences*, 349, 06004. <https://doi.org/10.1051/E3SCONF/202234906004>
- Baumann, H., & Tillman, A.-M. (2004). *The hitchhiker's guide to the lca* (1:10). Studentlitteratur.
- Bocken, N. M. P., Schuit, C. S. C., & Kraaijenhagen, C. (2018). Experimenting with a circular business model: Lessons from eight cases. *Environmental Innovation and Societal Transitions*, 28, 79–95. <https://doi.org/10.1016/J.EIST.2018.02.001>
- Bocken, N. M. P., Short, S. W., Rana, P., & Evans, S. (2014). A literature and practice review to develop sustainable business model archetypes. *Journal of Cleaner Production*, 65, 42–56. <https://doi.org/10.1016/J.JCLEPRO.2013.11.039>
- Bocken, N., Miller, K., & Evans, S. (2016). *Assessing the environmental impact of new Circular business models MAESTRI-Total Resource and Energy Efficiency Management System for Process Industries View project Circular economy View project*. <https://www.researchgate.net/publication/305264490>
- Bocken, N., Strupeit, L., Whalen, K., & Nußholz, J. (2019). A Review and Evaluation of Circular Business Model Innovation Tools. *Sustainability 2019, Vol. 11, Page 2210, 11(8)*, 2210. <https://doi.org/10.3390/SU11082210>
- Böckin, D., Goffetti, G., Baumann, H., Tillman, A.-M., & Zobel, T. (2022a). *Environmental assessment of two business models-a life cycle comparison between a sales and a rental business model in the apparel sector in Sweden*. [https://www.researchgate.net/publication/344784823\\_Environmental\\_assessment\\_of\\_two\\_business\\_models\\_-\\_A\\_life\\_cycle\\_comparison\\_between\\_a\\_sales\\_and\\_a\\_rental\\_business\\_model\\_in\\_the\\_apparel\\_sector\\_in\\_Sweden](https://www.researchgate.net/publication/344784823_Environmental_assessment_of_two_business_models_-_A_life_cycle_comparison_between_a_sales_and_a_rental_business_model_in_the_apparel_sector_in_Sweden)
- Böckin, D., Goffetti, G., Baumann, H., Tillman, A.-M., & Zobel, T. (2022b). Business model life cycle assessment: A method for analysing the environmental performance of business. *Sustainable Production and Consumption*, 32, 112–124. <https://doi.org/10.1016/J.SPC.2022.04.014>
- Brandtner, P., & Freudenthaler-Mayrhofer, D. (2020). *Business Model Innovation in the Automotive Industry-Socio-cultural Trends in Generation Y & Z T2T InnoNet-Talent-2-Talent Innovation Network View project InnoStrategy 2.0-Facilitating Corporate Foresight and Strategic Frontend of Innovation with Enterprise 2.0 View project Business Model Innovation in the Automotive Industry-Socio-cultural Trends in Generation Y & Z*. <https://www.researchgate.net/publication/342303180>
- Calado, E. A., Leite, M., & Silva, A. (2019). Integrating life cycle assessment (LCA) and life cycle costing (LCC) in the early phases of aircraft structural design: an elevator case

- study. *International Journal of Life Cycle Assessment*, 24(12), 2091–2110.  
<https://doi.org/10.1007/S11367-019-01632-8/FIGURES/13>
- Carbon footprint report Volvo C40 Recharge. (n.d.). Retrieved May 17, 2022, from  
<https://www.volvocars.com/images/v/-/media/Market-Assets/INTL/Applications/DotCom/PDF/C40/Volvo-C40-Recharge-LCA-report.pdf>
- Comin, L. C., Aguiar, C. C., Sehnem, S., Yusliza, M. Y., Cazella, C. F., & Julkovski, D. J. (2020). Sustainable business models: a literature review. *Benchmarking*, 27(7), 2028–2047.  
<https://doi.org/10.1108/BIJ-12-2018-0384/FULL/PDF>
- Das, A., Konietzko, J., & Bocken, N. (2022). How do companies measure and forecast environmental impacts when experimenting with circular business models? *Sustainable Production and Consumption*, 29, 273–285. <https://doi.org/10.1016/J.SPC.2021.10.009>
- Ding, N., Pan, J., Zhang, Z., & Yang, J. (2019). Life cycle assessment of car sharing models and the effect on GWP of urban transportation: A case study of Beijing. *Science of The Total Environment*, 688, 1137–1144. <https://doi.org/10.1016/J.SCITOTENV.2019.06.111>
- Fernandes, S. da C., Pigosso, D. C. A., McAloone, T. C., & Rozenfeld, H. (2020). Towards product-service system oriented to circular economy: A systematic review of value proposition design approaches. *Journal of Cleaner Production*, 257, 120507.  
<https://doi.org/10.1016/J.JCLEPRO.2020.120507>
- Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E. U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., Romero Lankao, P., Siriban Manalang, A., & Sewerin, S. (2011). *Decoupling Natural Resource Use and Environmental Impacts from Economic Growth*.  
<https://wedocs.unep.org/xmlui/handle/20.500.11822/9816>
- França, W. T., Barros, M. V., Salvador, R., de Francisco, A. C., Moreira, M. T., & Piekarski, C. M. (2021). Integrating life cycle assessment and life cycle cost: a review of environmental-economic studies. *The International Journal of Life Cycle Assessment* 2021 26:2, 26(2), 244–274. <https://doi.org/10.1007/S11367-020-01857-Y>
- Goffetti, G., Böckin, D., Baumann, H., Tillman, A.-M., & Zobel, T. (2022). Towards sustainable business models with a novel LCA method. *Business Strategy and the Environment*, *Doi: 10.1002/Bse.3005*. <http://mc.manuscriptcentral.com/bse>
- Gradin, K. T., & Björklund, A. (2021). The common understanding of simplification approaches in published LCA studies—a review and mapping. *International Journal of Life Cycle Assessment*, 26(1), 50–63. <https://doi.org/10.1007/S11367-020-01843-4/FIGURES/5>
- Grieger, M., & Ludwig, A. (2019). On the move towards customer-centric business models in the automotive industry - a conceptual reference framework of shared automotive service systems. *Electronic Markets*, 29(3), 473–500. <https://doi.org/10.1007/S12525-018-0321-6/TABLES/6>
- Harris, S., Martin, M., & Diener, D. (2021). Circularity for circularity’s sake? Scoping review of assessment methods for environmental performance in the circular economy. *Sustainable Production and Consumption*, 26, 172–186.  
<https://doi.org/10.1016/J.SPC.2020.09.018>
- Harris, S., Mata, É., Plepys, A., & Katzeff, C. (2021). Sharing is daring, but is it sustainable? An assessment of sharing cars, electric tools and offices in Sweden. *Resources, Conservation and Recycling*, 170, 105583.  
<https://doi.org/10.1016/J.RESCONREC.2021.105583>

- Khan, I. S., Ahmad, M. O., & Majava, J. (2021). Industry 4.0 and sustainable development: A systematic mapping of triple bottom line, Circular Economy and Sustainable Business Models perspectives. *Journal of Cleaner Production*, 297, 126655. <https://doi.org/10.1016/J.JCLEPRO.2021.126655>
- Lüdeke-Freund, F., Carroux, S., Joyce, A., Massa, L., & Breuer, H. (2018). The sustainable business model pattern taxonomy—45 patterns to support sustainability-oriented business model innovation. *Sustainable Production and Consumption*, 15, 145–162. <https://doi.org/10.1016/J.SPC.2018.06.004>
- Luthin, A., Backes, J. G., & Traverso, M. (2021). A framework to identify environmental-economic trade-offs by combining life cycle assessment and life cycle costing – A case study of aluminium production. *Journal of Cleaner Production*, 321, 128902. <https://doi.org/10.1016/J.JCLEPRO.2021.128902>
- Mahut, F., Daaboul, J., Bricogne, M., & Eynard, B. (2017). Product-Service Systems for servitization of the automotive industry: a literature review. *International Journal of Production Research*, 55(7), 2102–2120. <https://doi.org/10.1080/00207543.2016.1252864>
- Masson-Delmotte, V., Zhai, P., Chen, Y., Goldfarb, L., Gomis, M. I., Matthews, J. B. R., Berger, S., Huang, M., Yelekçi, O., Yu, R., Zhou, B., Lonnoy, E., Maycock, T. K., Waterfield, T., Leitzell, K., & Caud, N. (2021). *Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change Edited by*. [www.ipcc.ch](http://www.ipcc.ch)
- Nosratabadi, S., Mosavi, A., Shamshirband, S., Zavadskas, E. K., Rakotonirainy, A., & Chau, K. W. (2019). Sustainable Business Models: A Review. *Sustainability 2019, Vol. 11, Page 1663*, 11(6), 1663. <https://doi.org/10.3390/SU11061663>
- Planing, P. (2018). Towards a circular economy - How business model innovation will help to make the shift. *International Journal of Business and Globalisation*, 20(1), 71–83. <https://doi.org/10.1504/IJBG.2018.088665>
- Santa-Maria, T., Vermeulen, W. J. V., & Baumgartner, R. J. (2021). How do incumbent firms innovate their business models for the circular economy? Identifying micro-foundations of dynamic capabilities. *Business Strategy and the Environment*. <https://doi.org/10.1002/BSE.2956>
- THE 17 GOALS | Sustainable Development. (n.d.). Retrieved February 3, 2022, from <https://sdgs.un.org/goals>
- Ward, J. D., Sutton, P. C., Werner, A. D., Costanza, R., Mohr, S. H., & Simmons, C. T. (2016). *Is Decoupling GDP Growth from Environmental Impact Possible?* <https://doi.org/10.1371/journal.pone.0164733>
- Wells, P. (2013). Sustainable business models and the automotive industry: A commentary. *IIMB Management Review*, 25(4), 228–239. <https://doi.org/10.1016/J.IIMB.2013.07.001>

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS  
DIVISION OF ENVIRONMENTAL SYSTEMS ANALYSIS  
CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden  
[www.chalmers.se](http://www.chalmers.se)



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