Does recycling equal decoupling?

A Business Model-LCA case study of a novel recycling service for tissue products, on two different markets

Master's thesis in Industrial Ecology

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SUMMARY

Circular business models are commonly assumed to facilitate the transition to a more circular and sustainable economy (Böckin et al., 2022). However, the actual environmental performance of these business models is seldom properly assessed. Therefore, Böckin et al. (2022) introduced the methodology of business model life cycle assessment (BM-LCA), which serves to quantitatively assess and compare the environmental impacts of business models themselves.

Previous studies employing the BM-LCA methodology have examined circularity and servitisation in business models, and explored the potential for business model innovation, but call for further applications of the method (Baumann, 2023; Goffetti et al., 2022). In this study, BM-LCA is applied to investigate a novel closed-loop recycling service for a single-use tissue product, deployed by a multinational hygiene products company. The aim is to assess the potential of the recycling service to lead to decoupling of environmental impact from the economic performance of the company's business models around the given tissue product.

The study considers four different business model scenarios on the German and Swedish markets respectively, based on the actual production and business models in these markets. The study frames different scales of the recycling loop, firstly, the theoretical scenario of 100% closed-loop recycling, and secondly, the recycling service's maximal practically feasible capacity in Germany of 20%. The third scenario represents the linear production from externally purchased recovered waste paper, while the fourth represents the linear production from 100% fresh wood based fibre.

The study considers two impact categories, Global Warming Potential (GWP) and Forest Area. The impact assessment and sensitivity analysis cater for concluding that the recycling service contributes to decoupling of the total environmental impact (taking both impact categories into account) from economic performance, compared to the linear business model scenarios. The decoupling potential is unambiguous with regards to the forest area impact category. The 100% recycling loop scenario also has the lowest GWP impact score, but the difference to the second and third scenario is marginal. In fact, the second scenario (20% recycling loop) has slightly higher GWP impact than the third scenario, in which there is no closed-loop recycling. This offers some ambiguity regarding the decoupling potential of the recycling service with regards to GWP impact.

The study explores the environmental hotspots of the business models scenarios and how they differ between markets. In Sweden, the greatest share of the GWP impact derives from upstream production, while on the German market, the hotspot is the production processes themselves. A sensitivity analysis of specific market parameters shows that the environmental performance of the circular business model scenarios is highly dependent on i.e. revenue margins, energy prices, electricity mix and waste management system.

Keywords: Life cycle assessment, Business model, Circular business model, Tissue product, Market analysis

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Content pages

1 Introduction

The exponential growth of the global population and economy during the last century has been coupled with environmental impacts (Fischer-Kowalski et al., 2011). These impacts have led up to the situation the world faces today, with severe environmental issues. Decoupling of economic output from environmental impacts is commonly proposed as the way forward. This concept is often considered at a macro scale (Böckin et al., 2022). However, changes at a macro scale require micro scale changes, i.e. at business model level. Böckin et al. (2022) identified a lack of means to measure the level coupling between the economic output and environmental impacts of business models, in response to which the authors proposed the business model life cycle assessment (BM-LCA) methodology. This method could potentially help guide businesses towards decoupling.

1.1 Background

This study revolves around exploring the merits and drawbacks of the BM-LCA method by applying it to a real business case. In this section, said method and the case study will be introduced.

1.1.1 Business model life cycle assessment (BM-LCA)

Life cycle assessment is commonly used to assess the environmental impacts of products (or services) (Böckin et al., 2022). Through firstly determining the physical flows of energy, material, waste and emissions caused throughout a product's life cycle, its environmental impacts are quantified by converting these flows to contributions to different types of impact. The environmental impacts are quantified in relation to the functional unit, which is a measure of the intended function of the product. This allows for comparison of the environmental impacts of different alternatives, which serve the same function to the user (Baumann & Tillman, 2004).

Business model life cycle assessment (BM-LCA) extends the life cycle assessment (LCA) methodology to the assessment of business models, by shifting functional unit and coupling the monetary flows in a business model to the physical flows in the associated product system (Böckin et al., 2022). The functional unit in BM-LCA is economic and typically represents the profit the business model generates. As companies deploy business models to make profit, this novel functional unit captures the function of business models themselves. The functional unit, a certain profit level of a business model, (usually) corresponds to certain physical flows. Said coupling of monetary and physical flows expresses this relation. The BM-LCA results are the environmental impacts of the physical flows (as quantified in conventional LCA) corresponding to a certain profit level of a business model. This is a measure of the business model's level of decoupling, and what the terms "environmental impact" or "environmental performance" of a business model will refer to throughout the report.

Proposed in 2022, BM-LCA is a novel tool (Böckin et al., 2022). As of 2023, two BM-LCA studies had been carried out while three were ongoing (Baumann, 2023). From these studies, the methodology appears to fill a knowledge gap by providing a means to assess the environmental performance of business models themselves. Further, Goffetti et al. (2022) explore the method's potential to guide business model innovation, towards more decoupled business models. Goffetti et al. (2022) also show how sensitivity analysis of BM-LCA results may provide insight to how business models' environmental performance depends on business and technical parameters. Böckin et al. (2022) propose that the market dependency of the BM-LCA results could be explored by means of such sensitivity analysis. Both Böckin et al. (2022) and Gofetti et al. (2022) call for further studies which apply the method on different types of business models, to better understand its merits and drawbacks.

1.1.2 The case: A novel recycling service for a single-use tissue product

An international hygiene products company has launched a closed-loop recycling service for a single-use tissue product. The given single-use product is normally disposed of as general waste, only a very small fraction is recycled. In this sense, the recycling service is innovative. Through the recycling service, the products are recovered after use, and through a series of processes, the paper fibres in the used products are made use of again in new single-use products (of the same type, and other similar products). The same recycling processes also takes recovered paper from other sources as input, and the company also produces the same type of single-use tissue product with fresh wood-based paper fibres. These constitute two different modes of production, in comparison to which the recycling service provide paper fibres for a very small share of the production. Greater detail regarding the company's production and the corresponding business models will follow in Chapter 3 BM-LCA: Application to the case study.

The recycling service cannot be considered a business model in itself as the clients don't pay for the manufacturer's take-back. The clients merely buy the single-use products and agree to dispose of them separately. The company has examined the environmental performance of the recycling service through LCA. The LCA shows that the recycling service lowers the environmental impact per product, compared to their other business models around the same type of products. This must not imply that the recycling service makes their business models more decoupled though, as the service leads to altered monetary flows as well as material flows. Further, the company offers the service on different markets. In these markets, the material flows related to the company's production and the recycling service might differ, both because of variations in the company's own processes (*foreground system*) and variations in the *background system*, i.e. the energy and waste management systems. The monetary flows likely also differ across markets, due to changes in costs and revenues in the foreground and background system (i.e. energy costs).

1.2 Aim and research questions

The aim of the study is to assess whether the company's novel recycling service for the single-use tissue product could contribute to decouple its business models around the product, on different markets, by applying BM-LCA. That is, analysing if the service could lower the business models' environmental impacts while maintaining the level of economic performance.

The study seeks to examine the market dependency of the environmental performance of the recycling service and the company's business models around the product. By conducting sensitivity analysis of the BM-LCA results to explore said market dependency, the study addresses one of the areas of further research around BM-LCA suggested by Böckin et al. (2022). Moreover, the study aims to analyse the service's and business models' environmental hotspots, and how their environmental impact varies with different economical and technical parameters, by means of sensitivity analysis.

This BM-LCA study serves to test the company's sustainability claims regarding the recycling service. By presenting another application of BM-LCA in a new industry and exploring the method's usefulness, the study addresses the pleads from Böckin et al. (2022) and Goffetti et al. (2022), and strives to add to the nascent field of research around BM-LCA.

The aim can be condensed to the following five research questions:

1. Can the recycling service contribute to decouple the company's business models around the product?
2. What are the environmental hotspots of the recycling service and the company's business models?
3. What economic and technical parameters most significantly affect the environmental performance of the recycling service and the business models?
4. How does the environmental performance of the recycling service and the business models vary across different markets, and which parameters are determinant?
5. How (well) does BM-LCA and sensitivity analysis serve to answer the four former research questions?

1.3 Method and boundaries of the study

To obtain an overview of the BM-LCA methodology and concepts relevant to the study, an initial literature study was conducted. Among the topics that were deemed relevant were *circular economy*, *decoupling*, (*circular) business models*, *markets* and *market dependency of business models' environmental performance*. These topics were explored by searching databases of scientific publications with relevant keywords. As there is yet little literature on BM-LCA, all found publications on the subject were read, starting from Böckin et al. (2022) where the methodology is proposed and explained in detail.

The main method for conducting the case study and answering the research questions is BM-LCA. However, to apply BM-LCA as to answer the research question, information about the company's production and business models had to be gathered. After learning about the production and the recycling service on different markets, one had to decide which business model *scenarios* in which markets to assess.

Merely assessing the company's actual production would not serve to answer the first research question, whether the recycling service could contribute to decoupling. This led to constructing business model and product system *scenarios*, which BM-LCA was applied to. In this manner, the company's actual business models were altered and made compatible to compare in terms of their level of decoupling, and what influence the recycling service can have. A limitation of this approach is that the results in a sense are more uncertain, as the data for the constructed scenarios by nature are uncertain as they are extrapolated from the actual business models.

To be able to obtain the data required to construct scenarios sufficiently accurate to reflect market differences in their environmental performance, the study was limited to consider the business models on the Swedish and German markets. Looking into the actual production on two different markets allows for exploring market differences in the foreground system (the company's own processes). If the study would have considered more markets in this manner, these differences in the foreground system could have been explored more exhaustively. Market differences in the background system are easier to investigate as no data needs to be provided by the company. Sensitivity analysis of the BM-LCA results with respect to technical and economical parameters that vary, or are likely to vary, across markets is conducted to analyse how the market variations in the background system affect the business model scenarios level of decoupling.

The course of action of constructing the business model scenarios and applying BM-LCA is accounted for in Chapter 3, the results of which allows to answer the first and second research question. The sensitivity and market analysis in Chapter 4 Sensitivity analysis cater for answering the third and fourth research question respectively. The fifth research question is of more exploratory nature and is discussed in conjunction with the limitations of applying BM-LCA in this study, in Chapter 6 Discussion.

2 Theory

2.1 Decoupling

It is generally well-understood that a development where the resource use and environmental impacts decrease globally while the economic activity increases, allowing for elevated living standard, is desirable (Fischer-Kowalski et al., 2011). As economic growth has historically been coupled with environmental impact, decoupling is the term for breaking this bond, to achieve a desirable development. Decoupling can either refer to using less resources per unit economic output, or reducing the environmental impact of resources use or economic growth. These two aspects of the term are called resource decoupling and impact decoupling. Decoupling can either be relative or absolute, where relative decoupling refers to an increase in the efficiency of material use (Ward et al., 2016). Hence, there is still a growth of material and energy consumption needed for economic growth. Absolute decoupling instead describes a situation where the resource use is stable or declining while economic growth is still occurring.

An important aspect to consider in the discussion around decoupling is the concept of growth (Fischer-Kowalski et al., 2011). Fischer-Kowalski et al. (2011) argue that environmentalists are inclined to think of economic growth in terms of increasing physical throughput through the economy. This type of growth entails increasing exploitation of natural resources, land area and energy use, and is not desirable. Businesses and governments on the other hand tend to focus on strictly economic growth, where monetary value is measured through performance indicators such as GDP. Such growth is conceptually possible to separate from physical growth of the economy, while the feasibility of such a separation remains debated. There are multiple examples of countries that have been able to show relative decoupling, increasing productivity of energy and material use (Ward et al., 2016). However, Ward et al. (2016) report that there are no indications of absolute decoupling occurring on a global scale.

Böckin et al. (2022) state that the concept of decoupling is mainly treated at macro levels, e.g. country level. Meanwhile, the business models deployed within a country in a sense “make up” the macro level economy, and are “shaping the production and consumption systems”, as described by Böckin et al. (2022). The authors note that other studies propose decoupling at firm level as areas which need further research. According to Goffetti et al. (2022), their BM-LCA case study might be the first verification of decoupling at firm level.

2.2 Circular economy

Böckin et al. (2020) describe that a “circular economy aims at decoupling value creation from resource throughput”. The purpose of circular economy is to address global issues like climate change, biodiversity loss and pollution (Ellen MacArthur foundation, n.d), which the throughput of resources through the global economy arguably has caused. In a circular economy, the resource extraction and generation of waste is minimized.

While the goal of circular economy is decoupling, the means to achieve this can be referred to as strategies for increased resource efficiency (Böckin et al., 2020). Such strategies either contribute to close loops of resource use, narrow them or slow them down, or a combination of these (Bocken et al., 2016). These strategies have been listed and organised in order of priority in so-called R-frameworks (Böckin et al., 2020). The 9R-framework, as described by Potting et al. (2017), list the following measures, in order of decreasing priority: Refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover.

Higher priority means the measure should be “more circular”, in the sense that it contributes more to decreasing the throughput of resources.

Strategies connected to the useful application of materials are recovery and recycling (Potting et al., 2017). Recovery refers to incineration of materials with energy recovery. Recycling is the processing of waste material which provides raw material that can be used again, thus contributing to closing resource use loops (Bocken et al., 2016). These two strategies should only be applied if a product, or its parts, can no longer remain in use by means of the strategies repurpose, remanufacture, refurbish, repair and reuse (Potting et al., 2017). All of these measures aim to extend products’ lifetimes and thus slow down the flow of resource use. Repurposing refers to using discarded products or parts in new products with different functions. Refurbishing aims to restore a worn-out product to its former glory, and repairing restores the functionality of a broken product. Reuse means to redistribute a product to a new user instead of discarding it as waste.

Finally, the purpose of reduce, rethink and refuse is to develop smarter product use and manufacturing (Potting et al., 2017). These are assigned higher level of priority than the previously discussed strategies as they address the root cause of resource throughput, and could narrow the loops of resource use (Bocken et al., 2016). These strategies mean to reduce the raw materials use in manufacturing processes or use phase of products, rethinking the use of products through e.g. multifunctional products or sharing products, and to refuse raw material intensive products.

As a part of the European Union Green Deal strategy to become the first climate neutral union in the world by 2050, the European Commision adopted a new circular economy action plan in 2020 (European Commission, 2020). The action plan consists of a strategy for scaling the circular economy and decoupling economic growth from raw material extraction. The strategy strives to provide a common framework for mainstream actors to deploy sustainable production, reduced material extraction, servitisation, and sustainable business models, and thus adhere to the principles of circular economy. The transition plan includes increased resource efficiency, reducing the climate footprint and doubling the circular material use rate. The aim is to reduce the large impact of resource extraction, which makes up half of the total climate change impact and 90 percent of biodiversity loss and water stress.

2.3 Business models

To describe the different functions and parts of a business, and how they operate towards being profitable, the concept of business models has been introduced (Ovans, 2015). What fits into the concept has many different interpretations. The most basic definition is “how a business makes money”, and Böckin et al. (2022) argue this is the main function from a company’s perspective. The term can also refer to the former definition for specific products and services, on particular markets, with varying level of detail regarding the *how* the business operates to turn a profit (e.g. costs and revenues) (Ovans, 2015). The function, from a customer perspective, of the product or service provided through a business model is one of the components making up the business model, but the associated production, purchasing, marketing, pricing and distribution also affect the business model’s profitability (Reim et al., 2015). The classic product-sales business model is referred to as a linear business model (Böckin et al., 2022).

2.3.1 Circular business models

As alternatives to linear business model, different types of sustainable business models have been proposed (Böckin et al., 2022). Product-service system is one such group of business models, in which the value proposition to the customer consists of a service. Circular business models are another such group. While the term does not have fixed definition (Böckin et al., 2022), Geissdoerfer et al. (2018) describe that these business models employ strategies for resource efficiency (described earlier) to adhere to circular economy principles and slow down, narrow, or close loops of resource use. With this definition, circular business models by construction contribute towards a more circular economy. Consumer behaviour and acceptance is one important factor to consider regarding circular business models as they affect whether the business models work as intended (Elzinga et al., 2020), which could influence both their profitability and environmental impacts. Particularly relevant for this study is recycling behaviour. Thomas & Sharp (2013) note that the mechanisms of why some people participate in recycling while others do not are not yet fully understood.

2.3.2 Markets

According to a dictionary definition, the well-established concept of markets fits two perspectives. Firstly, the people that has a demand for something and the physical domain where it is sold. Secondly, a market is the business or trade of particular products or services (Cambridge University Press, n.d). A market is in essence where the exchange of goods takes place between a seller and a buyer, in a country or region for example (Encyclopaedia Britannica, n.d).

Companies tend to expand their business into new markets based on previous success of their business models. The norm is to copy the original business model and deploy it on the new market. However, case studies on the expansion of bike-sharing indicate that external market factors affect the profitability of business models when introduced on a new market (Han et al., 2022). In fact, sustainable business models appear more subjected to external factors than generic business models because of increased market pressure and sustainability demands in different countries (Weinzettel & Kovanda, 2015). Han et al. (2022) identifies seven categories of external factors influencing whether the implementation of a circular business model on a new market is successful (from a company’s perspective). The identified categories are regulatory factors, market, supply and partner network, socio-cultural factors, technology and infrastructure, knowledge and information, and environmental factors. However, the perspective of how external factors on different markets affect the *environmental performance* of business models appears to be unexplored in current research.

2.3.2.1 Market variations: Electricity mix, energy prices and waste management

Environmental impacts are often categorised by sector. In the European Union, the sectors with the highest greenhouse gas emissions are energy, industry, and transport (European Environment Agency, n.d.). Waste is also a large contributor to greenhouse gas emissions. Emissions, and the sectorial shares of emissions, vary between countries (Tavares, 2024).

Emissions from electricity differ widely among countries depending on the energy source (Council of the European Union, n.d.). In the European Union, the electricity mix consists mainly of renewable energy, fossil fuels and nuclear power. Renewable energy sources include wind power, hydro, solar and biomass while gas, coal and oil make up the share of fossil fuels. The respective shares of these energy sources are notably different between European Union countries. Furthermore, the prices of different types of energy; electricity, fossil fuels and renewable fuels, fluctuate over time, within, and across markets (European

Commission, n.d.). These variations depend on factors such as competition, regulations, policies, taxation, and consumption patterns.

The emissions from waste handling also varies across the European Union (Zero Waste Europe, 2020). The main routes for solid waste disposal are landfilling, incineration and composting. There are differences between these waste routes in terms of greenhouse gas emissions. As waste management systems differ between countries (e.g. different landfill to incineration ratios), so do the emissions.

2.4 Environmental assessments

2.4.1 Life cycle assessment

To evaluate the potential environmental impact of products, it is necessary to use a life cycle perspective (Baumann & Tillmann, 2004). LCA is a commonly used method for such an assessment, which assesses the potential environmental impacts of all phases of a product's life cycle; raw material extraction, production, use and end-of-life. The LCA methodology is divided into four steps: goal and scope definition, inventory analysis, impact assessment and interpretation. An important concept of LCA is the functional unit to which all material flows are scaled to assess the environmental impact.

2.4.2 Environmental assessments of business models

Böckin et al. (2022) review the scientific literature on environmental assessments of business models and find that while many LCA studies claim to assess the environmental performance of business models, they merely assess their products. The authors argue that these studies are not sufficient assessments of the business models as they do not take the function of business models, generating profit, into account, only the function the product serves the user. The rationale is as follows: No matter how low environmental impact a product has, the business model it is provided through does not necessarily have a low impact. If a product needs to be mass produced a business model to reach a certain profit level, this can outweigh the fact that the product might have a low environmental impact itself, and cause the business model to have a high impact regardless. The economic performance of a business model does not only depend on the product and the function it provides its user either, as described earlier (Reim et al., 2015). Thus, the functional unit in conventional LCA cannot serve as proxy for business models' economic performance.

There are methods that consider the environmental impacts of business models, such as the business model canvas (BMC), proposed by Osterwalder & Pigneur (2010). There are also complementary methods such as circular BMC (Nussholz, 2018) and the triple-layered BMC (Joyce & Paquin, 2016). However, the perspective of these methods is to guide business model innovation towards lower environmental impact, through qualitative analyses. These methods neither assess business models' actual environmental performance nor provide quantitative based recommendations (Böckin et al., 2022).

Böckin et al. (2022) contend that there is a lack of methods for systematic assessment of business models' environmental performance. Nosratabadi et al. (2019) also found that there is a lack of means to assess sustainable business models. While the environmental impacts of circular business models remain unexplored, these business models enjoy great confidence as to their potential to contribute to sustainability transitions (Goffetti et al., 2022). Böckin et al. (2020) describe that the measures for resource efficiency incorporated in such business models might not lead to environmental benefits in all cases, as certain circumstances can make the impacts the measures entail outweigh their benefits. Meanwhile, claims that business models are sustainable can be used by companies striving for competitive advantage (Böckin et al., 2022). This context motivates the purpose and need for a method which quantifies the environmental impacts of business models, which BM-LCA is constructed to do.

2.5 BM-LCA

In BM-LCA, the environmental performance of a business model itself is assessed, through taking both the business model's economic performance and environmental impacts into account (Böckin et al., 2022). The result represents the environmental impacts the business model causes, given it provides a certain profit level. This indicates the business model's level of decoupling. The following section explains how the method is carried out.

2.5.1 The methodology

BM-LCA consists of five iterative steps as the methodology is described by Böckin et al. (2022). The methodology's main difference as compared to conventional LCA is the twofold goal and scope phase, which renders BM-LCA one more step compared to the four steps in LCA. The goal and scope phase is divided into a descriptive phase and a coupling phase. All activities in these two phases must be carried out for all the business models under assessment.

The descriptive phase of goal and scope accounts for the purpose of the study, which business models are assessed, which environmental impact categories are considered and the system boundaries (Böckin et al., 2022). It also covers which data sources are used and the data quality, and the most relevant characteristics of the product provided through the business model, as in conventional LCA. In contrast to conventional LCA, this phase includes descriptions of the business models under assessment, in terms of which monetary transactions and exchanges of goods take place to and from the company. The relation between customer transactions and physical exchanges of goods should be identified. While one transaction in linear business models corresponds to one product and associated physical flows, the relation in circular business models is not always as trivial. In i.e. rental business models, the relationship between one rental transaction and how many products need to be produced must be determined.

The coupling phase of goal and scope commence with defining the functional unit for the study, which should be the same for the business models under comparison (Böckin et al. 2022). The functional unit is a certain amount of profit generated in a given time period. To deduct the number of transactions required to reach the given profit level, an equation is set up with the profit level on one side and the costs and revenues and the number of transactions of the other side. Together with the relationship between the number of transactions and the amount of products produced, this equation couples the profit generated by the business model with the flows in the product system. Böckin et al. (2022) exemplify how such an equation can be constructed, in Equation 1 and Equation 2, using the cost structure suggested by Norris (2001). The profit is denoted, π, and the constant R represents the revenues. Costs, denoted, C, are categorised as direct, indirect and contingent costs. In Equation 1, the relationship between profit, costs, and revenues is framed as,

$$\pi = R - C_{direct} - C_{indirect} - C_{contingent} \quad (1)$$

In Equation 2, the costs and revenues are expressed in terms of the number of transactions, denoted t, and the coupling factors, f , associated with the costs and revenues (Böckin et al., 2022).

$$\pi = f_{revenue} \cdot t - f_{direct} \cdot t - f_{indirect} \cdot t - f_{contingent} \cdot t \qquad (2)$$

From latter equation, the number of transactions required to reach the desired profit level is derived, as expressed in Equation 3.

$$t = \frac{\pi}{f_{revenue} - f_{direct} - f_{indirect} - f_{contingent}} \qquad (3)$$

Lastly, the number of products needed for the number of transactions is determined through the relationship determined in the descriptive phase of goal and scope (Böckin et al., 2022). The environmental impact of this number of products is then assessed by carrying out the last three steps, as in conventional LCA; life cycle inventory analysis, impact assessment and interpretation.

2.5.2 Sensitivity analysis of BM-LCA results

The coupling between monetary flows and physical flows, and the economic functional unit, allow for sensitivity analysis of the BM-LCA results with respect to both business parameters and technical parameters (Böckin et al., 2022). Through varying these parameters and evaluating the effect on the BM-LCA results, sensitivity analysis can provide insight to how the business model's environmental performance depends on the parameters, and which are the most influential (Böckin et al., 2022). The study from Goffetti et al. (2022) exemplifies how such an analysis can be carried out. It showed that a rental-based business model for jackets had lower environmental impacts than a corresponding linear business model. However, their environmental performances were highly dependent on certain business parameters, to such a degree that the ordering of their relative performances could shift. Böckin et al. (2022) further propose sensitivity analysis as a means to model business complexities that would require a practically unfeasible level of detail if they were to be included as separate scenarios in a BM-LCA study, i.e. market differences.

2.5.3 Limitations of BM-LCA

The BM-LCA methodology merely quantifies the level of coupling between a business model's economic performance and its environmental impact (Böckin et al, 2022). It does not account for the absolute environmental impact a business model causes, which depends on business variables such as the *actual* number of transactions. Furthermore, one should observe that the economic functional unit has a large influence on the BM-LCA results. For example, if two business models were to provide products which serve the same function for the user, BM-LCA results could show better environmental performance for a business model with higher environmental impact per product given its profitability per product is high enough. In this case, given a fixed number of (actual) transactions, the absolute environmental impact of the business model which BM-LCA shows is more decoupled could be higher than the other business model's impact.

3 BM-LCA: Application to the case study

This section describes how the BM-LCA is carried out and its results. The interpretation phase of the BM-LCA is accounted for in the separate Chapter 4 Sensitivity analysis.

3.1 Goal and scope: Descriptive phase

The purpose of this BM-LCA study is to assess the company's recycling service as to the possibility it offers to decouple the company's business models around the single-use tissue product on the Swedish and German markets. To do so, four business model scenarios are constructed, for each of the two markets. These scenarios are based on the company's actual business models and production, which are accounted for in the following section.

3.1.1 The company's product systems and business models around the product

The company's actual production of the single-use tissue product can be divided into two types, here referred to as type *a* and *b*. These different modes of production are part of two different types of product systems and business models. In the type *a* production, the pulp used is made of fresh wood based paper fibres that come from forestry. The fresh fibre pulp is purchased externally (not produced in the company's own processes). The product system with type *a* production is displayed in Figure 1.

In the type *b* production, the company produces the pulp themselves, through a paper fibre recycling process. The input to this process is either recovered waste paper, either general waste paper grades like office paper or newspaper which is purchased externally, or the single-use tissue product, which is recovered through the novel recycling service. In the recycling service, the single-use products are brought back by truck to the company's production site after they have been used and disposed of separately. The company purchases this collection and transportation service by a logistics partner.

Regardless of the input to the recycling process in the type *b* production, it generates waste, in form of sludge, as a share of paper fibres are too short to be used in the production of new tissue. The sludge, which is a mixture of mainly short fibres and chemicals, is incinerated without energy recovery. The share of paper fibres provided to the type *b* production by the recycling service varies across markets and production sites, from zero to a small fraction. The type *b* production and the corresponding product system is visualised in Figure 2.

In both types of production, the manufacturing of the product generates waste, but much less than the recycling process in the type *b* production. Both the recycling and the manufacturing process require chemicals, water and energy use. Furthermore, the manufacturing requires inflows of material for the packaging of the products, which is bought from external suppliers. The product is then sold directly to the customer for a fixed price per *transaction unit* (a certain amount of products).

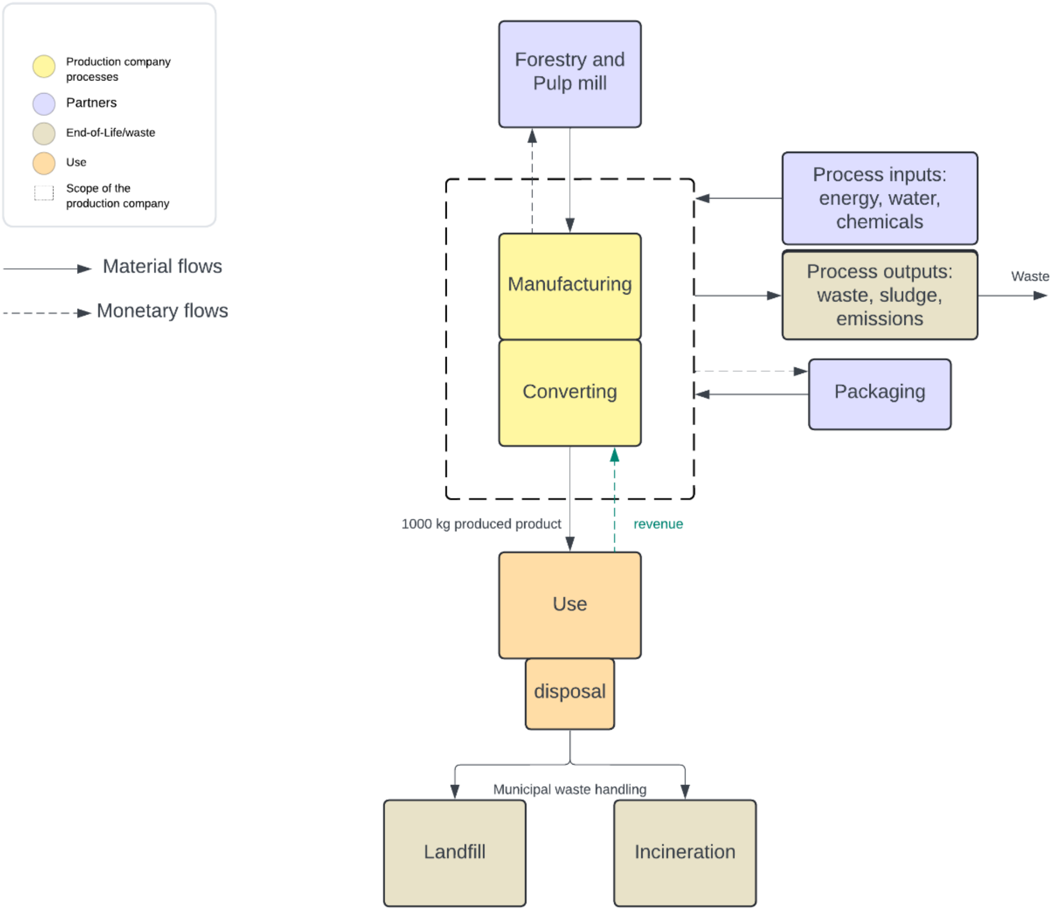

Figure 1. Flowchart type a production

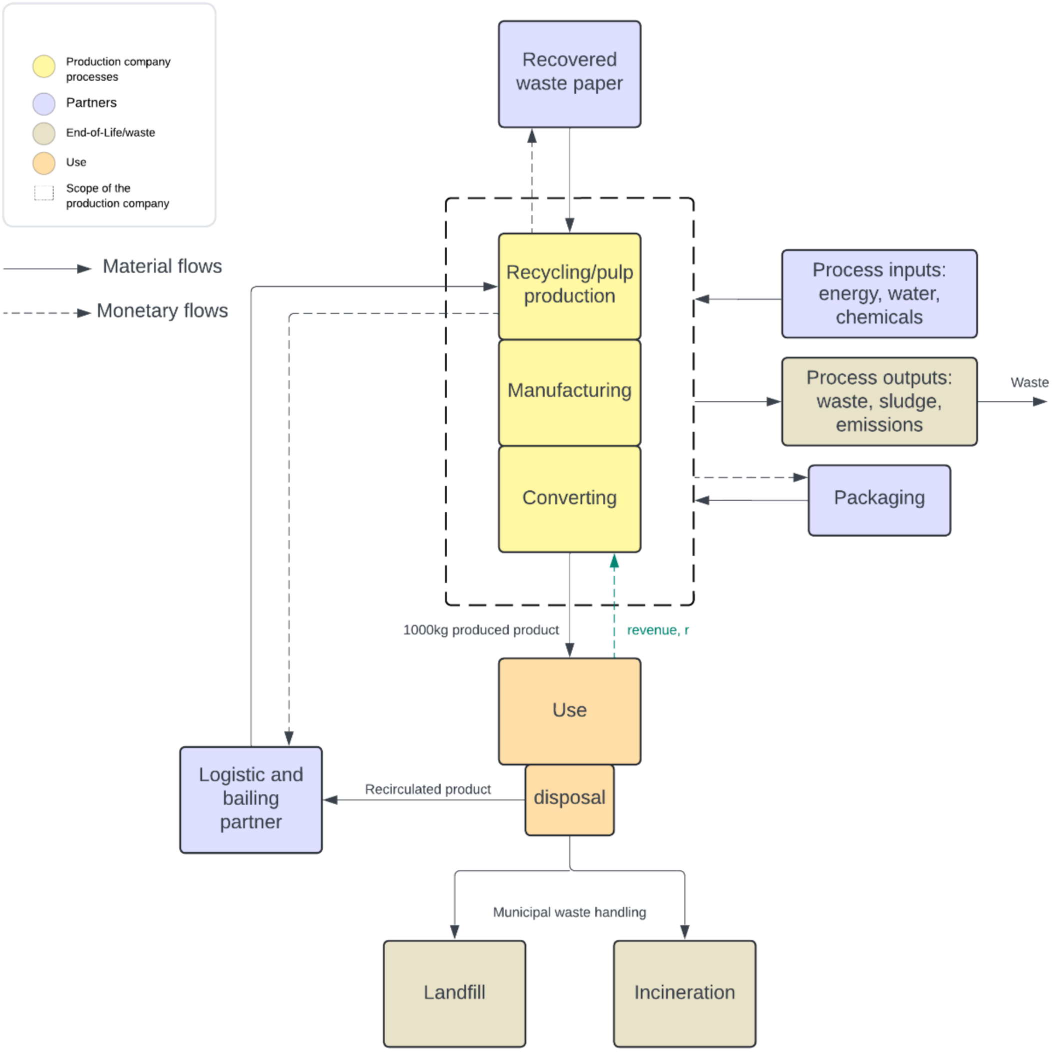

Figure 2. Flowchart type b production

3.1.2 The business model scenarios and modelling

In this section, four product systems with associated business models, referred to as scenarios, are presented. As these are set on the German and Swedish markets respectively, that makes for eight scenarios in total. They are denoted Scenario X G or S, where X is a number 1 to 4, and G represents Germany and S Sweden. In brief, Scenario 1 and 2 are circular business model scenarios where the recycling service accounts for 100% and 20% respectively of the pulp produced in the type *b* production. In Scenario 3, there is no recycling service, and recovered paper from other sources is the only input to the pulp production process in the type *b* production. Lastly, Scenario 4 represents the type *a* production, where fresh wood based paper pulp is used, and no recycling at all takes place.

The same type of single-use tissue product is provided through all the business model scenarios, but as the actual product that is produced in Germany and Sweden differ slightly, the German and Swedish scenarios are set to produce slightly different products accordingly. This choice was made in order to be able to use data on the actual production, provided by the company.

3.1.2.1 Scenario 1: The recycling service is deployed to its theoretical maximum

Scenario 1 is a model of the type *b* production where the recycling service is deployed to its theoretical maximum. All of the used products are recycled in the company's type *b* production, and they make up the vast majority of the input of paper pulp to the production process. This scenario does not reflect the company's actual type *b* production, further it is not practically feasible in the production in Germany. Thus, it is highly fictive.

Although 100% of the used products are recirculated back into the company's type *b* production in this scenario, the recycling and manufacturing processes entail material losses, thus additional input of *recovered waste paper* is necessary for the system to be in steady state. In Scenario 1, the amount of external input of *recovered waste paper,* to the otherwise closed system in terms of paper fibres, is small in comparison to in Scenario 2 and 3. As paper fibres are not infinitely recyclable, the external inflows of *recovered waste paper* in all said scenarios pose a demand for extraction of fresh wood based paper fibres. The environmental impact of this fresh wood based fibres should be taken into account, and for each scenario, the magnitude of this impact should be in relation to the amount of input of external *recovered waste paper.*

Based on the assumption that paper fibres can be recycled seven times (Broad, 2010), and that the upstream recycling of waste paper is in steady state, each such upstream recycling cycle require an inflow of at least 1/7 fresh paper, which has not yet been recycled. In accordance with the demand for external input of fresh paper to the upstream recycling, flows of recovered waste paper were in this study considered to consist of 1/7 fresh paper. The environmental impact of this fraction was taken into account for each of the inflows of recovered waste paper to Scenario 1, 2 and 3, thus reflecting their demand for fresh paper fibres.

The cost structure which was provided by the company is displayed in Table 1.

Table 1. Cost and revenue structure in Scenario 1

Cost and revenue structure in Scenario 1	Cost/Revenue	Associated physical flow
Revenue	R, Revenue when the product is sold	The product is transferred to a customer
Direct purchase cost	C1, Purchase cost of recovered paper	Input of recovered waste paper
	C2, Purchase costs of used single-use tissue products	Logistics and transportation of buyback of used single-use tissue products
	C3, Purchase cost of packaging materials	Packaging materials
Process costs	C4, Purchase cost of chemicals	Chemicals in production
	C5, Purchase cost of energy	Energy in production
	C6, Purchase cost of water and sludge	Water and sludge in production
	C7, Warehouse costs	Warehouse operating costs: rent, utilities etc.
Other costs	C8, Overhead/other costs	Additional costs of production

The product system and business model corresponding to Scenario 1 is displayed in the flowchart in Figure 3.

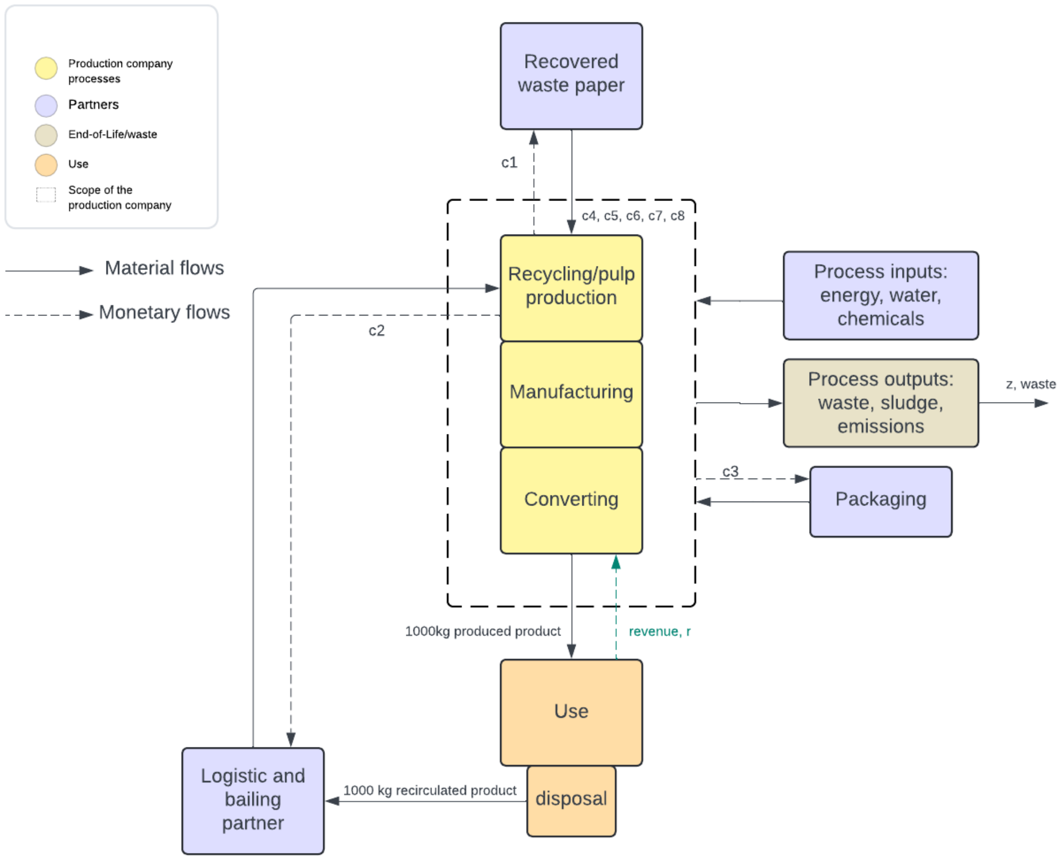

Figure 3. Flowchart Scenario 1

3.1.2.2 Scenario 2: The recycling service provides 20% of the pulp to the production

In the type *b* production in Germany, the recycling process consists of two parallel processes. One of them can have the single-use product as input while the other cannot and instead take other types of recovered paper as input. The assumptions regarding the environmental impact of upstream forestry of the recovered paper is the same as in Scenario 1, that 1/7 of the recovered paper is assumed to be produced from fresh wood based fibre. The capacity of the former recycling process is limited to 20% of total type *b* pulp production with the current infrastructure.

Scenario 2 represents the case in which the novel recycling serviced is deployed to its practical maximum (in Germany) and account for 20% of the produced pulp. For the Swedish production, no such practical limitation was given, but Scenario 2 is considered here as well. The scenario is fictive in the sense that it does not reflect the type *b* production in neither of the countries. The remaining 80% of the single-use products are disposed of as general waste in this scenario, meaning that the products either go to landfill or incineration. Figure 4 shows a flowchart of the Scenario 2 business model and product system. The cost structure for this business model is the same as for Scenario 1, thus given by Table 1.

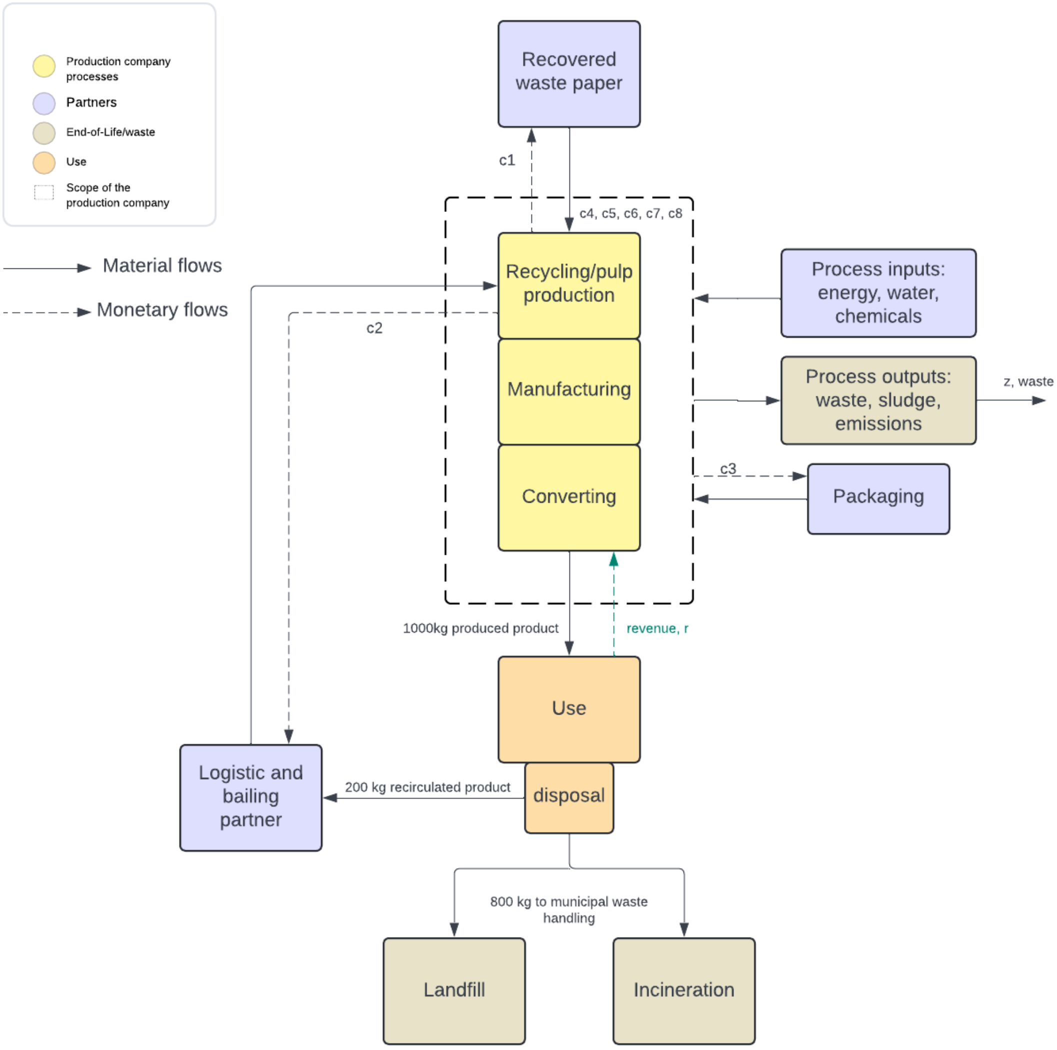

Figure 4. Flowchart Scenario 2

3.1.2.3 Scenario 3: Production with 100% recovered paper as input

As the recycling service in reality provides a small share of the paper fibres to the type *b* production in Sweden and Germany, Scenario 3 reflects reality rather well. This scenario serves as the "base case", which the other scenarios were constructed to be compatible to compare with, as accurate data was available for this case. All of the used products are disposed of as general waste in this scenario. Table 2 shows the cost structure of this scenario and Figure 5 displays the material and monetary flows related to the scenario.

Table 2. Cost structure in Scenario 3

Cost and revenue structure in Scenario 3	Cost/Revenue	Associated physical flow
Revenue	R, Revenue when the product is sold	The product is transferred to a customer
Direct purchase cost	C1, Purchase cost of recovered paper	Input of recovered waste paper
	C2, Purchase cost of packaging materials	Packaging materials

Process costs	C3, Purchase cost of chemicals	Chemicals in production
	C4, Purchase cost of energy	Energy in production
	C5, Purchase cost of water and sludge	Water and sludge in production
	C6, Warehouse costs	Warehouse operating costs: rent, utilities etc.
Other costs	C7, Overhead/other costs	Additional costs of production

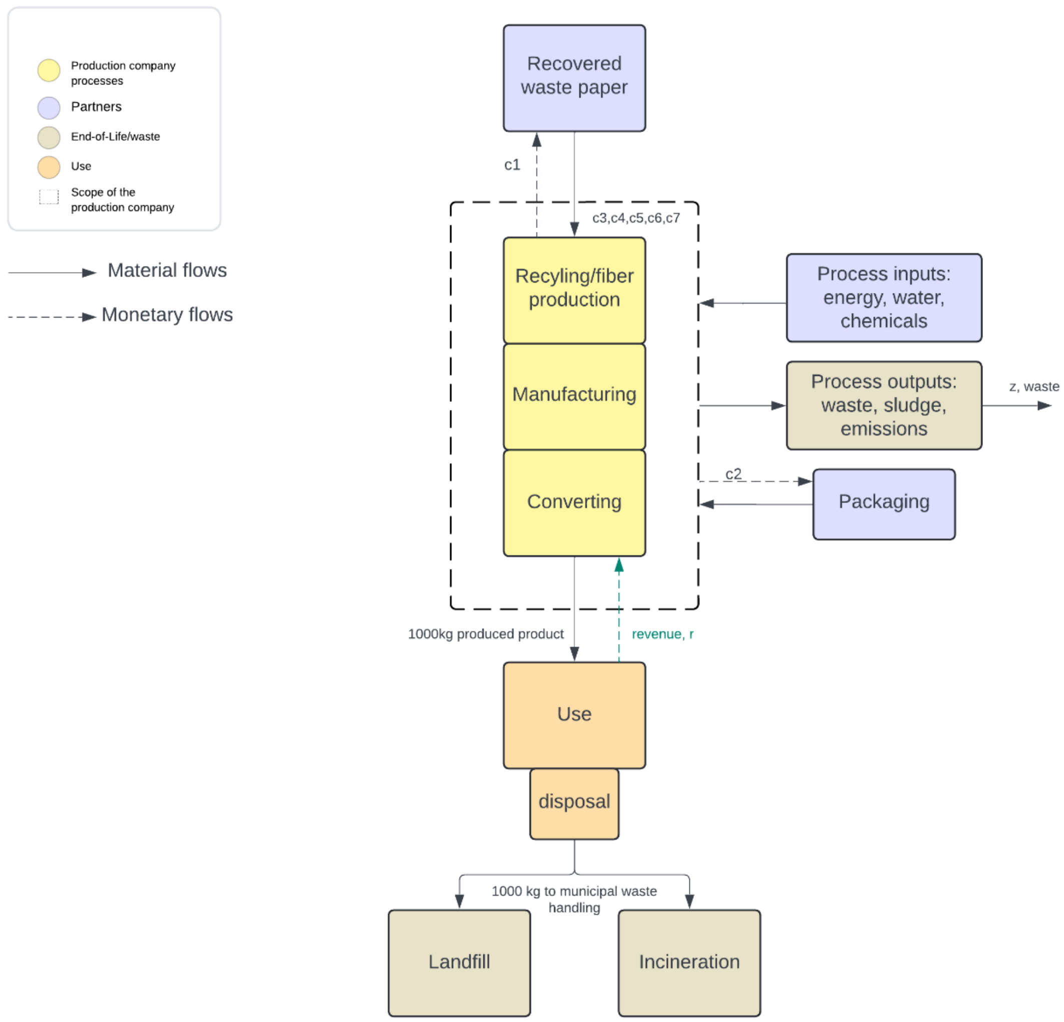

Figure 5. Flowchart Scenario 3

3.1.2.4 Scenario 4: Fresh wood based paper pulp is the sole input of paper fibre to the production

Scenario 4 represents a business model around the type *a* production. In Sweden, Scenario 4 S is completely based on a real business model. The actual type *a* production in Germany produces a slightly different product, which make for an unfair comparison to the other scenarios in Germany. Therefore, Scenario 4 G had to be a fictional scenario based on Scenario 3 G, implementing elements from the actual type *a* production. The cost structure for these scenarios is displayed in Table 3 and the flowchart of the product system and business model in Figure 6.

Table 3. Cost structure in Scenario 4

Cost and revenue structure in Scenario 4	Cost/Revenue	Associated physical flow
Revenue	R, Revenue when the product is sold	The product is transferred to a customer
Direct purchase cost	C1, Purchase cost of fresh fibre pulp	Input of fresh fibre pulp
	C2, Purchase cost of packaging materials	Packaging materials
Process costs	C3, Purchase cost of chemicals	Chemicals in production
	C4, Purchase cost of energy	Energy in production
	C5, Purchase cost of water and sludge	Water and sludge in production
	C6, Warehouse costs	Warehouse operating costs: rent, utilities etc.
Other costs	C7, Overhead/other costs	Additional costs of production

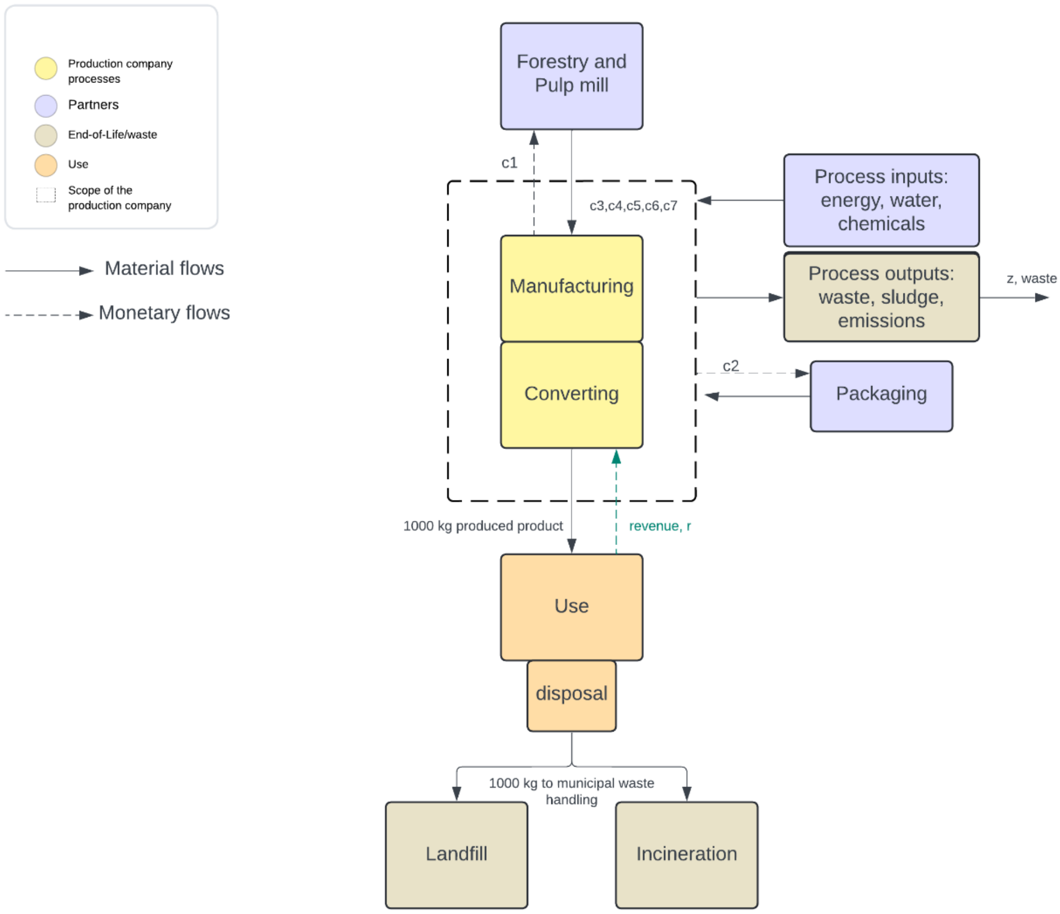

Figure 6. Flowchart Scenario 4

3.1.3 Impact categories and system boundaries

Impact categories were selected as to reflect the key differences in impact which the recycling service might contribute to. Upon collecting initial information about the company's production and the recycling service, the main difference the recycling service was deemed to make was with regards to the throughput of fresh wood based paper pulp and the emissions from fresh wood based paper pulp production, the company's own (recycling and manufacturing) processes and transports. Information on what type of environmental impacts these differences could affect was gathered both from LCA experts at the company in question and from Umweltbundesamt (2022).

Consequently, the impact categories Global warming potential (GWP) and forest area were selected. Climate change was deemed a necessary impact category to include and it is affected by the differences accounted for earlier. The potential contribution of paper recycling to save forest area called for including this as an impact category. As described in Umweltbundesamt (2022), the demand for primary wood can be converted to occupied forest area, which has (negative) implications for biodiversity and carbon dioxide storage. Other impact categories that could potentially have been included are i.e. eutrophication and acidification, but brief inspection of the impact scores provided by LCA experts at the company suggested that these categories would not be affected to a high degree.

The system boundaries are cradle-to-grave to account for all phases in the product's life cycle and reflect the effect the recycling service can have on the business models' environmental impact. The temporal boundary is determined by the loop time of recycling service. However, this is not significant for the analysis because of the steady-state assumption in the LCA, and the single-use nature of the product. The geographical system boundaries are global with regards to environmental impacts considered, as the potential local aspects of climate change and forest area impact are disregarded. As the scenarios are set in Sweden and Germany, the geographical boundaries of the product and business systems under evaluation are restricted to these countries though.

3.1.4 Data sources and data quality

Scenarios 1 and 2 are highly fictional, whereas scenarios 3 and 4 reflect the actual production to a much higher degree. This has implications for the quality of data used in this assessment. The company is the sole source of data regarding physical flows, monetary flows and impact data, which is more certain and accurate in Scenario 3 and 4. The data for Scenarios 1 and 2 had to be estimated with help from experts at the company, and is subject to large uncertainties. Details regarding these aspects are found in Section 3.3 Inventory analysis.

3.1.5 The relationship between transactions and production

The coupling between the number of transactions t and the amount of produced products q is simple as all scenarios are sales business models. One transaction means that one *transaction unit* of products q_t (given in mass) is sold. These transaction units q_t differ slightly between the exact types of products that are produced at the two markets. The relationship can between the amount of transactions and the physical flows can hence be expressed through the following equation:

$$q = t \cdot q_t. \qquad (4)$$

3.2 Goal and scope: Coupling phase

This section presents the functional unit of the study and the coupling of monetary and physical material flows in the business model scenarios.

3.2.1 Functional unit

The functional unit was set to a profit level of 100 000 Euros, generated over one year. However, the character of the monetary data employed in this study (see Section 3.3.3) and the fact that no absolute BM-LCA results are presented render this particular choice rather insignificant. The monetary flows in all business model scenarios are quantified in relation to the amount of produced and sold products. The relative differences in BM-LCA results among the business model scenarios are thus independent of the desired profit level and time horizon, as there are no fixed costs (independent of the amount of products), and no costs occur at discrete points in time. The rationale behind this particular choice was that 100 000 Euros over one year might be a reasonable target for the company's business models. Yet, the time-continuous cost data employed would risk make the results imprecise if a shorter time horizon had been chosen. In reality, the company's costs are hardly continuous, and such an approximation is likely worse the shorter the time horizon.

3.2.2 Coupling of monetary and physical flows

The modelling of costs employed in this study (all costs are relative to the amount of production, see Section 3.3.3) provides for an easy connection between monetary flows and the amount of production. Three main categories of costs make up the cost structure: Direct purchasing costs, process costs, and other costs. For each business model scenario, the following equation was set up where the profit is the difference between all revenues and costs:

$$\pi = R - C \,. \quad (5)$$

With the cost and revenue structure accounted for in Table 1 in Section 3.1.2.1, the former equation reads

$$\pi = R - \sum_{i=1}^{8} C_i \quad (6)$$

for Scenario 1 and 2. Table 2 and 3 in Section 3.1.2.3-4 present the cost and revenue structure of Scenario 3 and 4. For these scenarios the former equation instead reads

$$\pi = R - \sum_{i=1}^{7} C_i . \quad (7)$$

Tables 1, 2 and 3 in Section 3.1.2.1-4 also qualitatively express the connection between the costs and physical flows.

Next, the costs and revenues in Equation 6 and 7 are expressed in terms of the amount of transactions t , through a set of coupling factors. The coupling factors f_i express the contribution to cost C_i per sales transaction t and f_{rev} denotes the revenue per sales transaction. For explanations of how the coupling factors were determined, see Section 3.3.3. With these coupling factors, a connection between the profit level π and the amount of sales transactions t is established. Equation 8 and 9 express these relationships for Scenario 1 and 2 and Scenario 3 and 4 respectively:

$$\pi = \left(f_{rev} - \sum_{i=1}^{8} f_i\right) \cdot t, \quad (8)$$

$$\pi = \left(f_{rev} - \sum_{i=1}^{7} f_i\right) \cdot t. \quad (9)$$

From Equation 8 and 9, the amount of transactions required to sustain the given profit level $\pi$is derived as follows for Scenario 1 and 2

$$t = \pi \div \left(f_{rev} - \sum_{i=1}^{8} f_i\right), \qquad (10)$$

and for Scenario 3 and 4:

$$t = \pi \div \left(f_{rev} - \sum_{i=1}^{7} f_i\right). \qquad (11)$$

Lastly, for each business model scenario, the amount of production corresponding to t transactions is derived with the equation presented in Section 3.1.5:

$$q = t \cdot q_t. \qquad (12)$$

This step concludes the coupling of monetary and physical flows in the business model scenarios. The amount of products q serves as the reference flow for the inventory analysis and impact assessment. That is, the physical flows in the product systems (i.a. those described in tables 1, 2 and 3 in Section 3.1.2.1-4) are quantified with respect to the amount of products q.

3.3 Inventory analysis

While the quantified data on physical and monetary flows in the business model scenarios and their environmental impacts cannot be presented in this study due to confidentiality, this section offers some qualitative descriptions of said data and how it was obtained.

3.3.1 Data on GWP impact and energy consumption

GWP impact data for the "base cases" Scenario 3 G and Scenario 3 S, and for Scenario 4 S, was provided by LCA experts at the company. Additional information (on i.e. the recycling process in Scenario 3) and estimates which made it possible to estimate the corresponding impact data for the rest of the scenarios were also provided. The LCA data was divided into five main categories: Upstream production, inbound transports, core processes (recycling and production), downstream transports and waste management.

Detailed data on the energy consumption and its GWP impact was provided for the recycling and production processes, which enabled sensitivity analysis with respect to the electricity mix. The energy consumption generally differs among the scenarios, and the recycling process in Scenario 1, 2 and 3 renders these cases an additional energy consuming process compared to Scenario 4. In Scenario 1 and 2, there is an extra transport process compared to the other scenarios. This transportation distance and its GWP impact were estimated by the company.

Different amounts of production waste are also generated in the scenarios, which directly affects the GWP impact scores, and indirectly also the forest area impact scores. The amount of waste firstly depends on the share of used products that are disposed of as general waste at end-of-life, which increases from zero to 100% from Scenario 1 to Scenario 4. This waste is assumed to be disposed of in the production country and its waste management system. Secondly, waste is generated in the recycling and production processes. Recycling of the single-use product renders less waste than recycling externally purchased recovered paper. The amount of waste generated in these processes determines how much recovered paper and fresh wood based paper pulp is required as inputs.

3.3.2 Forest area data

As per the methodological choice (accounted for in Section 3.1.2.1) of considering 1/7 of the input of recovered waste paper to the recycling process in Scenario 1, 2 and 3 to be fresh wood based paper, the “demand” for fresh wood based paper fibres was quantified for all scenarios. This demand corresponds to a demand for forestry. This study employs the methodology described in Umweltbundesamt (2022) (published by the German Environmental Agency), assuming a linear relationship between the amount of production of fresh paper pulp and the extent of forestry, presented as the forest area required during one year of forestry. An estimate that one tonne of tissue paper corresponds to 4000 m^2 • year of forestry is presented in Umweltbundesamt (2022). This means that the annual growth on this area produces enough fresh wood fibre to produce 1 tonne of tissue paper. However, it is highlighted in Umweltbundesamt (2022) that this quantitative metric is reductive as it excludes qualitative properties of forestry, that are highly relevant to its environmental implications. For the sake of this study, the exact value of the conversion factor is irrelevant as no absolute values for the forest area impact scores are presented. This study merely determines the relative differences in scenarios’ demand for forestry, which said approach caters well for, regardless of the conversion factor, assuming that the qualitative aspects of the forestry are the same for each scenario.

3.3.3 Data on monetary flows

The company provided data on monetary flows in the form of coupling factors f . These express the monetary flows in relation to one transaction unit of the tissue product. Throughout the rest of the report, the terms ‘costs’ and ‘revenues’ will often implicitly refer to said factors, that is the *costs and revenues per transaction*. For each of the eight business model scenarios, one coupling factor was supplied for each cost and revenue listed in the corresponding table of the cost and revenue structure in Section 3.1.2.1-4.

Due to the modelling of the monetary flows, which has been accounted for, the monetary flows in the business model scenarios are directly proportional to the amount of production. In reality, the business models likely include costs that are not directly proportional to the magnitude of production (fixed or semi-fixed costs), which a more refined modelling would accommodate. Furthermore, the coupling factors should theoretically be possible to decompose into different factors. Yet, on the form that they were provided, already quantified, it is difficult to carry out this decomposition quantitatively. The coupling factors’ dependency on underlying parameters is treated qualitatively in this section.

The revenue in all business model scenarios in Germany is the same as they provide the same product. The same goes for the Swedish scenarios – but the revenue differs from the one in Germany, which may in part be because it is a different product, but other factors likely play in as well. Quantifications of these revenues and the costs (real and estimated) were provided by the company.

The cost division of Scenario 1, 2 and 4 in Germany are estimated based on the real costs of in Scenario 3 G. These were rather rough estimates as only the *direct purchase cost* category (the cost of the inputs to the core processes) was varied among the scenarios. The company deemed the other cost categories too uncertain to be able to vary. The direct purchase cost is higher in Scenario 4 G than in Scenario 3 G as fresh wood based pulp is more expensive than recovered paper. In Scenario 2 G, this cost is higher than in the base case. This is because the single-use products replace the other paper-based input to the recycling process which produces 20% of the pulp in this scenario, and the cost of bringing back the single-use products to the production site after use is higher than the cost of the other paper-based input. In Scenario 1 G, said recycling process which can practically only provide 20% of the pulp is assumed to produce 100% of the pulp. This makes the direct purchase cost lower in total in Scenario 1 G than in Scenario 3 G, since this recycling process has a lower running cost than the other recycling process (the cost of running the process is included in the direct purchase cost).

For the Swedish scenarios, real costs were provided for Scenario 3 and 4. Similarly to the German cases, the costs in Scenario 1 and 2 were estimated based on Scenario 3 by simply altering the direct purchase cost. The cost of running the recycling process was not estimated to change as the recycling service was scaled up. Therefore, the total cost of Scenario 1 S is higher than in Scenario 2 S, which in turn is higher than in the base case, as the collection of used products is more expensive than purchasing recovered paper. On the other hand, the total cost in Scenario 4 S is higher than in all the other Swedish cases, mainly because the fresh wood based pulp is much more expensive than either of the inputs to the recycling process. However, the energy cost is lower in Scenario 4 S than in the other scenarios, as it does not include the recycling process.

Taking both costs and revenues into account, the profit margin was observed to differ considerably between the two markets. The margin on the German market is significantly lower than on the Swedish market.

3.3.4 Data on energy prices and electricity mix

Data on energy prices of grid electricity, biomass, biogas and natural gas was retrieved from statistical sources and governmental agencies and are represented in Table 4.

Table 4. Energy prices of different production energy types

Energy type	**Price Sweden**	**Source Sweden**	**Price Germany**	**Source Germany**
Grid electricity	7 euro cents/kWh	Swedish Energy Agency, 2018	12 euro cents/kWh	Swedish Energy Agency, 2018
Natural gas			2.5 euro cents/kWh	Statista, 2023
Biogas	1.15 SEK/kWh			Biodriv Öst, 2024
Biomass fuels	248 SEK/MWh			Swedish Energy Agency, n.d.

Inventory data on greenhouse gas (GHG) emissions from different electricity mixes in different countries were obtained using the EF v3.1 method through the database Ecoinvent v3.10, using the OpenLCA software. Specifically, the utilized data sets in Ecoinvent were: electricity, low voltage, residual mix | electricity, low voltage | Cutoff, U for Germany, Sweden, France and UK. The values are presented in Table 5.

Table 5. GWP of different country specific electricity mixes expressed in kg CO2 [eq] per kWh (Ecoinvent v3.10)

Country	**kg CO2-Eq per kWh**
Germany	0.84236
Sweden	0.064974

France	0.200198
UK	0.452917

3.4 Impact assessment results

The environmental impact scores of the business model scenarios were derived with respect to the reference flow, i.e. the number of sold transaction units in each case. The result is derived as environmental impact per profit unit. The impact on climate change is presented as kg CO2-eq per functional unit. Forest area is presented as m^2 used forest per functional unit.

The results from the impact assessment of GWP, displayed in Figure 7, show that the emissions per profit level is considerably higher on the German market compared to the Swedish market. Notably, Scenario 4 on the German market is not profitable. Therefore, its impact cannot be assessed with the BM-LCA method, why it is left out of the results. Moreover, production from only recovered fibre, Scenario 3, on both the Swedish and the German market has lower emissions per profit unit than the case with a 20% recycling loop, Scenario 2, as the cost of recovered fibre is lower than the cost of collecting the used products and transporting them back to the production site. Nevertheless, the fictional case of a 100% recycling loop, Scenario 1, has better environmental performance because of estimated lower costs related to the production processes. Additionally, the differences between scenarios 1, 2 and 3 are more prominent on the German market than on the Swedish market.

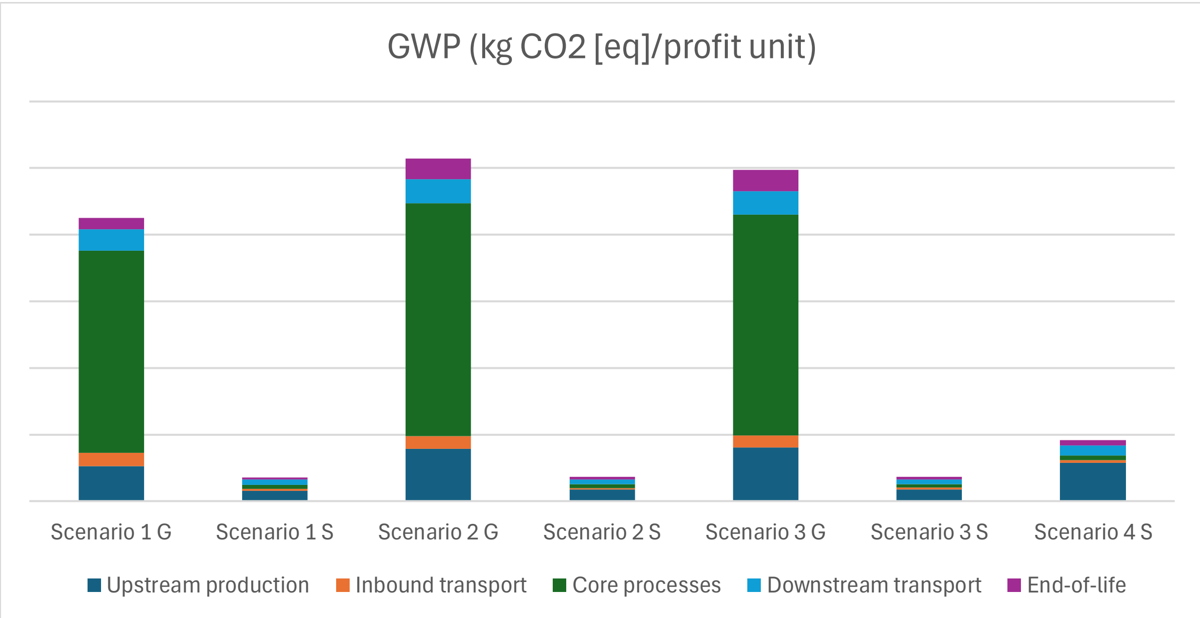

Figure 7. Impact assessment results Global Warming Potential for Germany and Sweden

In the German case, emissions from the core processes recycling, manufacturing and conversion compose the main hotspot for the climate change impact category, followed by upstream production. The emissions from transportation mostly consist of downstream transports and are very similar among the four scenarios. The end-of-life impact account for a relatively small share of the impact, and this decreases as the recycling service is scaled up. In the Swedish case, viewed in Figure 8, upstream production account for the largest share of the emissions, and core processes have a small share of the impacts per profit unit. Downstream transport instead has a larger relative share of the emissions. The most significant difference is seen in Scenario 4, where emissions from transport, end-of-life and mainly upstream production is much higher.

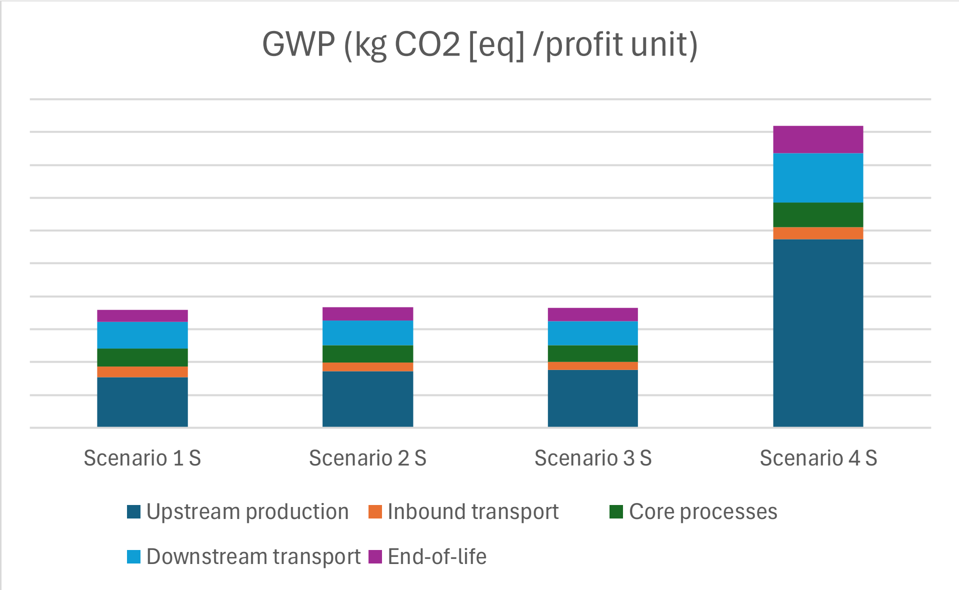

Figure 8. Impact assessment results Global Warming Potential for Sweden

The forest area impact scores of the scenarios are displayed in Figure 9, which shows a decreasing impact as the recycling service's contribution of pulp to the production increases. The emissions from the fresh wood based paper pulp scenario, Scenario 4, stand out as they are considerably higher than in the other cases. Furthermore, Scenario 1 has close to no impact on forest area.

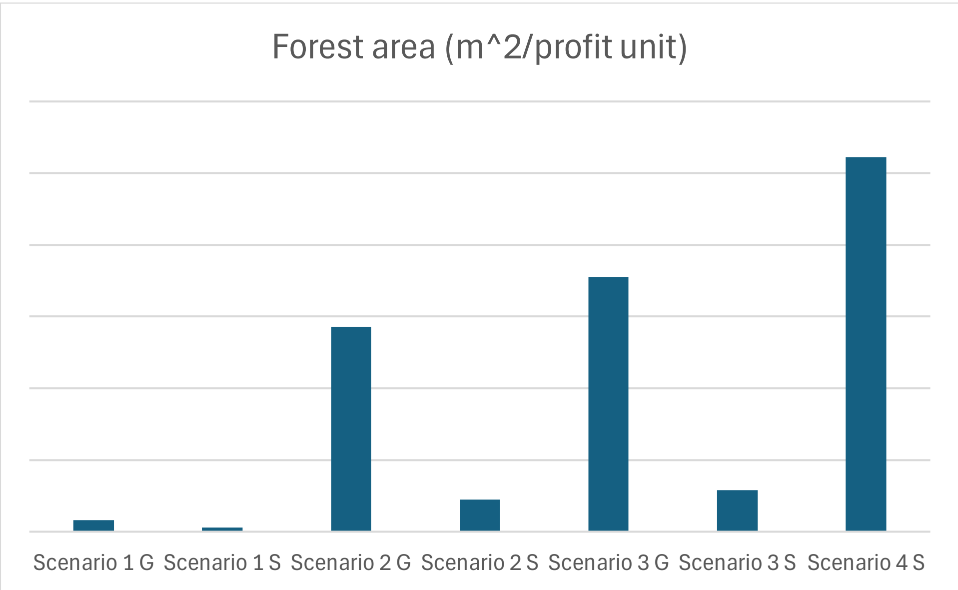

Figure 9. Impact assessment results Forest area for Germany and Sweden

4 Sensitivity Analysis

In this section, the dependence of the business model scenarios' GWP impact scores on various parameters is explored. The forest area impact scores only depend on the amount of input of fresh wood based pulp upstream to the production, which according to our modelling is exclusively determined by the scale of the recycling service. Therefore, the sensitivity analysis for the forest area impact category was considered trivial and was excluded.

The business models scenarios themselves, on the Swedish and German market, make up for a market analysis. Further market analysis was carried out by implementing the energy mixes and waste management systems of other countries, and analysing the effects on the GWP impact scores.

Sensitivity analysis is conducted by assuming linearity of energy prices, transportation distance in the recycling loop, the revenue margin and the recycling loop's contribution to the production. The latter parameter is varied between 0% and 20% (Scenario 2 and 3), as the way in which Scenario 1 G was constructed complicates higher percentages in the analysis. Scenario 4 G is excluded from all of the sensitivity analysis except of the revenue margin, as it is not profitable.

4.1 Energy price

The sensitivity analysis of varying the energy price is conducted on the accumulated energy price for the production processes. The effect is calculated stepwise between –50% and +50%.

The sensitivity analysis shows a large dependency on the energy price on the German market, and a small dependency on the Swedish market, presented in Table 6 On the German market, the GWP change is larger in percent than the corresponding change in energy price. This characteristic is very prominent when increasing the price. The cause of the behaviour is the large quantity of products needed to sustain the profit level in the German case compared to the Swedish case, rather than a larger share of the energy costs. In fact, the energy cost share of the total costs on the German market is only slightly higher. Between scenarios, the difference is marginal, except in Scenario 4, showing that the energy costs have a larger impact in the production from fresh wood based fibre.

Table 6. Results sensitivity analysis in % change on GWP

Energy price change %	Scenario 1 G: Change GWP %	Scenario 1 S: Change GWP %	Scenario 2 G: Change GWP %	Scenario 2 S: Change GWP %	Scenario 3 G: Change GWP %	Scenario 3 S: Change GWP %	Scenario 4 S: Change GWP %
-50%	-46%	-11%	-49%	-11%	-48%	-10%	-16%
-20%	-25%	-5%	-28%	-4%	-27%	-4%	-7%
-5%	-8%	-1%	-9%	-1%	-8%	-1%	-2%
5%	9%	1%	11%	1%	10%	1%	2%
20%	50%	5%	63%	5%	58%	5%	9%
50%	511%	14%	2530%	13%	1097%	13%	25%

4.2 Electricity mix

To capture the effect on environmental impact of different energy mixes, two additional electricity mixes, different from Sweden and Germany are applied it to each scenario. The first, France because of its high dependency on nuclear power, and the UK because of its mix of high fraction fossil fuels and renewables. The change in GHG emissions were applied on the four cases in the German production system the Swedish production system respectively.

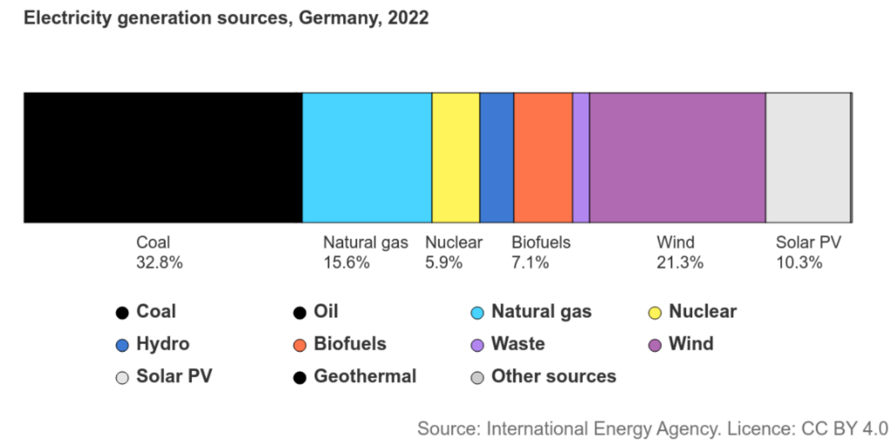

Figure 10. Electricity mix Germany 2022

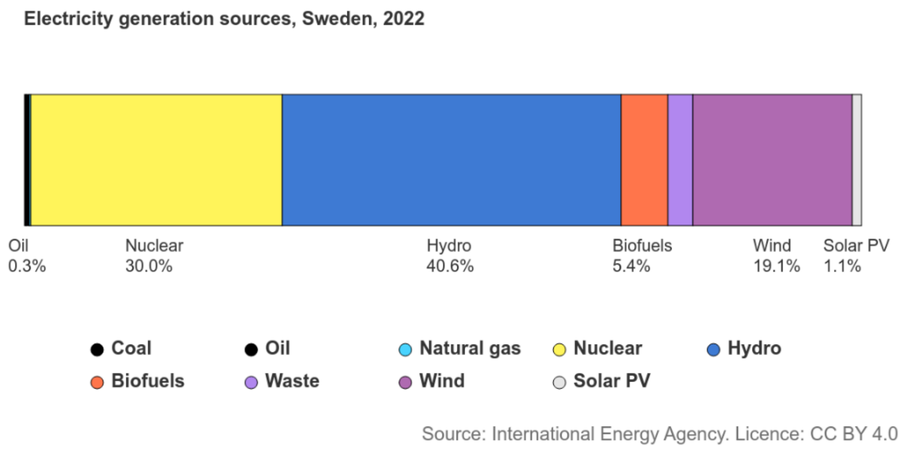

Figure 11. Electricity mix Sweden 2022

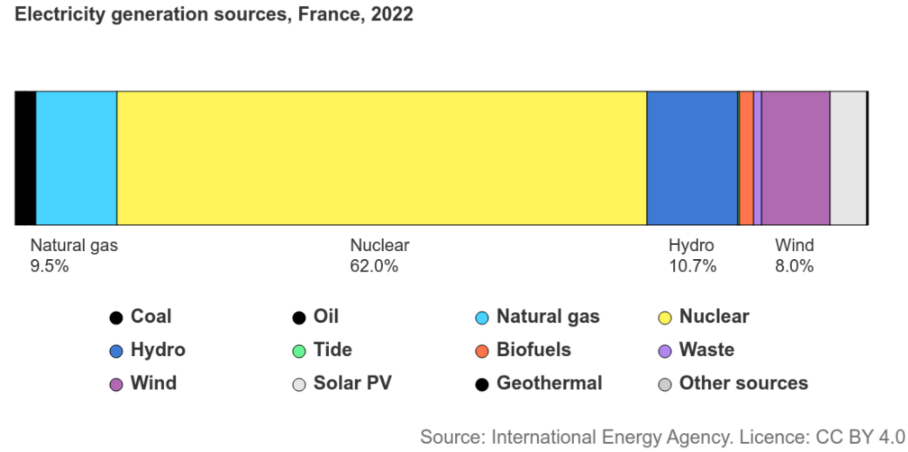

Figure 12. Energy mix France 2022

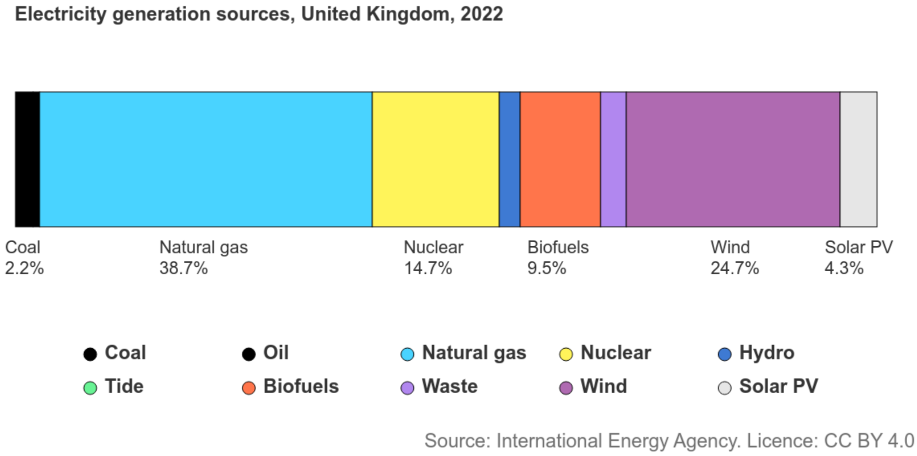

Figure 13. Energy mix UK 2022

From the results, seen in Table 7, a significant effect of the electricity mix on the emissions of business models can be concluded. Applying other electricity mixes on the Swedish production system decreases performance drastically. By using the UK mix that has a large share of natural gas, the emissions per profit increases by almost 50%. However, less in Scenario 4, due to less electricity used in the processing because no recycling process is needed. On the German production system, the UK mix has lower impact on performance because the energy mixes are more similar, with a high share fossil fuels and renewables. In this case, the French mix increases performance more because of the high share of nuclear power. The French electricity mix is more like the Swedish mix in the aspect of GHG emissions, affecting the Swedish production system less than the UK mix.

Table 7. Results sensitivity analysis of different electricity mixes on GWP, change in %

Electricity mix	Scenario 1 G: Change GWP %	Scenario 1 S: Change GWP %	Scenario 2 G: Change GWP %	Scenario 2 S: Change GWP %	Scenario 3 G: Change GWP %	Scenario 3 S: Change GWP %	Scenario 4 S: Change GWP %
France	-28%	16%	-26%	15%	-26%	15%	8%
UK	-17%	48%	-16%	44%	-16%	43%	24%

4.3 End-of-life

The fraction of the municipal solid waste that goes to landfill and incineration differs between countries, shown in Table 8. Both countries in this case study, Germany and Sweden, has a very small amount of waste going to landfill. Therefore, two more cases of countries, France and UK, with higher landfill shares, were applied in each case, except in Scenario 4 because of no discarded product, of the German market and the Swedish market, instead of the real distribution. Further, the impact of landfill gas that is collected through flaring and recovery has a high impact on GHG emissions, it is also captured in the two cases. The application of different waste management emissions is limited to the discard of the product without packaging because of limited data access to the composition of packaging.

Table 8. ISO standard data on country specific waste management

Country	**Share landfill (%)**	**LFG collection rate (flaring + recovery) (%)**	**Share incineration with energy recovery (%)**	**Incineration disposal (%)**
Germany	4%	14%	92%	4%
Sweden	1%	21%	99%	0%
France	42%	25%	58%	0%
UK	19%	37%	77%	4%

The market comparison in Table 9 shows a high dependency on waste management. A higher share landfill disposal, and lower land fill gas collection rate, has a direct impact on the environmental performance of the linear cases. Primarily on the Swedish system because the base case share of waste that's disposed to landfill is close to none. Notably, in case 2, because of the circular loop, the effect is slightly lower than in the linear cases.

Table 9. Results sensitivity analysis of different country specific waste management treatment, change in % of GWP

Country	Scenario 2 G: Change GWP %	Scenario 2 S: Change GWP %	Scenario 3 G: Change GWP %	Scenario 3 S: Change GWP %	Scenario 4 S: Change GWP %
France	33%	95%	41%	115%	93%
UK	8%	31%	10%	38%	31%

4.4 Transportation distance

Differences in the transportation distance of transported circular paper will be examined through a sensitivity analysis on Case 1 and 2 in both Sweden and Germany, of –20% and +20% transportation distance change.

The result from the sensitivity analysis displayed in Table 10, concluded that transportation distance of the circular loop has a negligible effect on the environmental performance of the studied business models across markets. A larger fraction of circulated product result in a higher environmental impact when the transportation distance varies, regardless, it is only a small fraction of the percentual increase in distance.

Table 10. Results sensitivity analysis of recycling loop transportation distance in % change on GWP

Loop transportation distance change %	Scenario 1 G: Change GWP %	Scenario 1 S: Change GWP %	Scenario 2 G: Change GWP %	Scenario 2 S: Change GWP %
-20%	-0.8%	-1.8%	-0.2%	-0.3%
+20%	0.8%	1.8%	0.2%	0.3%

4.5 Circular flow

The amount of used tissue products that the recycling service supplies to the recycling and production processes will depend on i.a. customer behaviour. Furthermore, the infrastructure of the recycling process in the German production system practically limits this inflow to maximally make up 20% of the recycled paper fibres. The recycling service's provision of paper fibres to the recycling process is varied through a stepwise sensitivity analysis from 0% to 20% tissue product take-back to recycling and production, i.e., a stepwise sensitivity analysis between Scenario 1 and 2. The share of the tissue products that is disposed to municipal waste at end-of-life varies correspondingly from 100% to 80%.

The results presented in Table 11, show that the environmental impact per profit unit increases with more extensive recovery of used products. This is primarily due to higher costs for take-back of used products than costs for purchasing recovered waste paper externally, resulting in more products need to be sold to sustain the profit level. However, the dependency of GWP impact on the circular flow fraction is not very strong on either the German or the Swedish market. The effect on the German market is higher because the relative cost increase is greater there than in Sweden.

Table 11. Results sensitivity analysis on different recycling fraction %, results in % of GWP

% Circular loop	Sweden	Germany
5%	0.2%	1.0%
10%	0.5%	1.9%
15%	0.7%	2.9%

4.6 Revenue margin

Since the revenue margin is different on the German and the Swedish markets, where the German margin is considerably lower because of higher sold quantity and lower purchasing power on the market. A sensitivity analysis is thus conducted by increasing the revenue margin on the German market stepwise up to the same margin as the Swedish margin.

As derived in the impact assessment, the comparison of GWP per profit level of the base cases in the study, displays a large difference in climate impact, as viewed in Table 12. Where the German system has over 1000% more impact per profit. Largely due to the different revenue margins in Sweden and Germany, therefore more products must be produced and sold to sustain the same profit level.

The sensitivity analysis display how after a first increase of the revenue marginal on the German case, Scenario 4 of fresh wood based fibre production on the German market becomes profitable and can be compared to the other cases. Compared to scenario 4 on the Swedish market, the German case has a larger fraction of emissions in the core production process and inbound transport, and a lower share of emissions in the upstream production. The reason being that the Swedish case in reality has a less costly manufacturing process when producing the product. In the German case, the production is assumed to have the same manufacturing costs due to data limitation, as when producing from recovered paper, and a slightly higher share of emissions in this process. Additionally, the cost of Swedish fresh fibre is significantly higher than on the German market.

Table 12. Results sensitivity analysis of increasing revenue margin on German market, results in % change of GWP

Increasing revenue margin German market	Scenario 1: GWP difference %	Scenario 2: GWP difference %	Scenario 3: GWP difference %	Scenario 4: GWP difference %
Base case	1084.4%	1297.7%	1260.2%	n.d
Step 1	394.7%	436.8%	438.1%	655.9%
Step 2	212.7%	232.2%	235.4%	141.1%
Step 3	128.5%	140.5%	143.6%	43.4%
Equal margins	80.1%	88.5%	91.3%	2.1%

The overall trend when increasing the revenue margin on the German system is that fewer products must be produced and sold, decreasing the environmental impact per profit. In turn, this makes all cases on the German market closer to the impact on the Swedish market. Regardless, when applying the same margin, displayed in Figure 14, there is still a distinct difference in performance in all scenarios except in scenario 4. In scenarios 1, 2, and 3, producing from recovered paper or recycled products, the German system has over 80% more environmental impact. However, in scenario 4, the performance is similar with only a 2% difference, primarily due to the high purchase costs of fresh wood based fibre in Sweden.

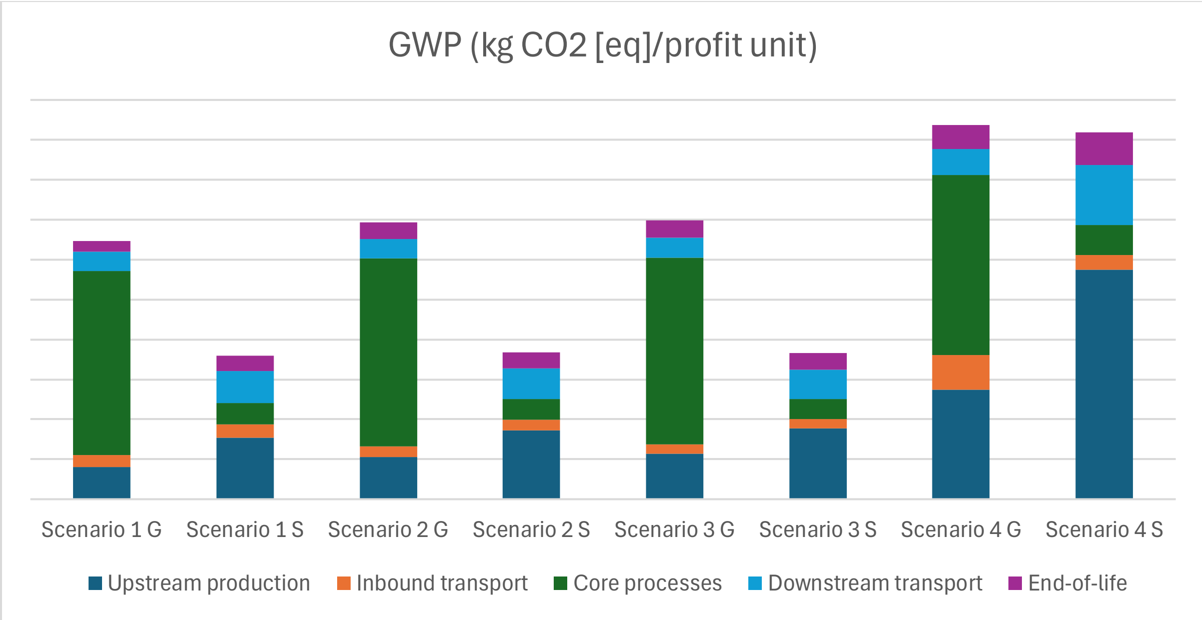

Figure 14. Impact assessment results on GWP for equal revenue margins in Germany and Sweden

5 Analysis

In this section, the findings from the impact assessment and sensitivity analysis are synthesised to answer the first four research questions of the study.

5.1 The decoupling potential of the recycling service

In this section, a discussion of the results connected to the first and second research question is presented.

1. Can the recycling service contribute to decouple the company's business models around the product?
2. What are the environmental hotspots of the recycling service and the company's business models?

Overall, the recycling service shows potential to decouple the company's business models around the product on both markets. The fictive case with 100% closed loop recycling has the lowest GWP impact scores for both countries, however, this difference is rather marginal between this case and the other scenarios which incorporate recycling. The main effect of the recycling service is on the forest area impact score, where it drastically reduces the impact. As earlier described, low impact on forest area makes for lower impact on biodiversity and allows for greater carbon storage in forests, which contributes to mitigate climate change. However, with the current physical and monetary flows and infrastructure constraints of the recycling and production processes in Germany, the recycling service does not contribute to decoupling compared to the linear case of production from recovered fibre, when considering only GWP impact, which increases marginally.

Moreover, the environmental hotspots are different on the German and Swedish market. On the German market, emissions are mainly connected to the production processes of the tissue product. On the Swedish market, the larger fraction of the environmental impact are made up by upstream production. Additionally, downstream transportation has a larger impact on the Swedish market compared to the German market.

5.2 Circular business models and market specific parameters

The third and fourth research questions are discussed in this section.

3. What economic and technical parameters most significantly affect the environmental performance of the recycling service and the business models?
4. How does the environmental performance of the recycling service and the business models vary across different markets, and which parameters are determinant?

The findings of the study express the high uncertainty connected to business models on different markets, both on existing and new markets. Uncertain market parameters have a large impact on the environmental performance and profitability of circular business models. The study display the complexity of how both the difference in cost structure and emissions effect the performance on different markets.

The costs tied to the production system and procurement of materials varies largely between markets. The study shows how delicate the environmental performance of circular models is for changes in cost variations. The purchase price of energy depends not only on electricity price, but on oil price, biomass price, and natural gas price. Different composition of energy on different markets makes knowledge about the composition of energy and volatility of energy prices important to making strategic business decisions. Moreover, since the study indicate that more circular business models are less exposed to fluctuations in energy price, increasing the circularity can increase the resilience of environmental performance to unexpected geopolitical events and economic downturns that affects prices.

Furthermore, the study finds that revenue margins have a substantial impact on environmental performance of business models. There are several motivations behind why companies vary revenue margins between markets. Firstly, a static approach to pricing would imply decreasing margins because of higher production or procurement costs. On a mature market with high competition, companies can't afford to increase prices because customers have the option to choose another vendor.

Nevertheless, pricing vary between regions due to differences in customer purchasing power, and in the case of similar production costs, the margin can be increased or decreased if customers are willingly to pay a higher or lower price for the same product. Moreover, the quantity of sold products will affect the margins, and if the company are able to produce and sell more products on a market, the margins can be set lower because of larger absolute revenue. Furthermore, companies' product portfolios can be complex and consist of many different products, where some are expected to contribute with other values than economic values, such as a diversified value offering, resulting in different margin levels on different products.

All these factors affect the environmental performance of circular models, the study express that a higher percentage of circular loop will be less impacted by these changes, however, marginally. Creating a motivation for companies to consider margins across the product portfolio, on different markets, in order of making informed decisions on the overall environmental performance of their business models. In the specific case of Germany and Sweden, framed in this study, the Swedish market is expected to have a higher margin due to less quantity produced, and higher overall customer purchasing power which results in a higher environmental performance of the business model on this market compared to the German market.

Furthermore, the sensitivity analysis of the circular loop percent is valuable due to the importance of the current state of the circular business model, customer behaviour and users' attitude towards recycling. The study displays a negative correlation between an increase of the loop up till the physical constraint in the production in Germany of 20%. This could explain the status of the current extent of the circular model that exists today. Today, the implementation of circularity focus on other values than purely economical, such as branding and company reputation. Regardless, the result of this study shows that a theoretical high implementation could perform radically better than the current business models in terms of environmental impact per profit unit. However, on the German market this would need substantial capital investments not addressed in this study. The Swedish market could be more realistic in this regard.

Moreover, improvements of the current profitability of an increased circular loop could be made through communicating the soft environmental values captured by a recycled product and developing the value proposition of the product, for example by offering transportation back to the production plant as an additional service. Nevertheless, this would be constrained by the customers attitude towards the communicated added value of this service. Furthermore, a more extensive circular loop depends on the user's attitude towards recycling the products in separate bins, this could vary across markets due to cultural differences in attitudes towards recycling.

Furthermore, the importance of end-of-life, electricity mix and transportation distance is captured in the study. The transportation distance of the circular loop plays a marginal part for the environmental performance of business models, which could serve as motivation for companies for their expansion strategy on existing markets. Because an increase in transportation only marginally increases emissions per profit level, companies can without concern for worse environmental performance increase their current customer basis and the distance of the circular takeback of the products around the plant, making the circular business scalable for larger geographical territories on the same market.

The magnitude of the end-of-life impact on the business models, capture how a circular loop decreases the dependency of market specific waste management systems on the environmental impact per profit level of the business models studied. Because a circular loop directly decreases the amount of product that is disposed as municipal waste, decreasing the risk associated with increased emissions when introducing the business model on a new market.

The electricity mix also directly affects the environmental performance of the business models in the study. However, as opposed to the effect of different waste management systems, the circular business models and the linear system from recovered paper are more vulnerable than the conventional linear production from fresh wood based fibre to differences in electricity mix. Therefore, companies should be aware of the underlying electricity mix when introducing a circular business model on a new markets since it substantially influences the environmental impact per profit level.

6 Discussion

The first section of this chapter addresses the method employed in this study, and its suitability and limitations for answering the first four research questions. This discussion serves to answer the fifth research question of the study. The second section discusses the findings of the study in a broader sense, and how they relate to the research field around BM-LCA. Moreover, the latter section holds suggestions on areas of further studies.

6.1 Merits and limitations of BM-LCA in this study

The fifth and last research question reads:

5. How (well) does BM-LCA and sensitivity analysis serve to answer the four former research questions?

To discuss this question, one must consider the suitability of the method and its level of certainty for each of the former four research questions. Firstly, BM-LCA is constructed to assess the level of decoupling of business models. However, the first question was not to assess a business model, but a recycling service, and the effect it might have on business models' level of decoupling. To answer this question, fictive business model scenarios were constructed. Construction of such scenarios make for many modelling choices which likely influence the results of the BM-LCA. Furthermore, the data in such scenarios are naturally uncertain. In the case of this study, the data for the fictive scenarios were estimated by experts at the company in question, through extrapolation of data from the real business models and product systems. These estimates were rather rough, and conservative in the sense that the fictive scenarios were assigned the same numbers as real business models in case of great uncertainty, rather than guessing what difference might be.

All in all, constructing scenarios and assigning them data on physical and monetary flows is likely a large source of uncertainty in this study. This likely also holds for construction of scenarios to apply BM-LCA generally, to some extent, depending on how "certain" the modelling and the data for scenarios are. Scenarios aside, there are still sources of uncertainty regarding the "real" cases which our considered in this study which are likely relevant for other BM-LCA studies too. As for conventional LCA, methodological choices regarding the product system and the quality of the data on the physical flows influence the results of BM-LCA too. In BM-LCA, the coupling between physical and monetary flows amplifies the uncertainty. As actual business actions likely are too complex and irregular to perfectly couple monetary and product flows in a feasible way, the coupling step requires simplifications.

Another methodological issue which affects the findings of both LCA and BM-LCA studies are that of impact categories. It is crucial to know which to include to capture the most relevant the impacts. Apart from the climate change, which arguably is the most standard impact category, forest area, which is much less common, was selected in this study. If forest area was left out, the study would not have found that the recycling service does not make much difference in comparison to the other business model scenarios of the type *b* production. Thus, the choice of impact categories was highly significant in this case. Yet, with these two impact categories only, there is risk that considerable impacts of other types are left out. However, by inspecting impact data of the company's production in the categories acidification and eutrophication, which suggested the scenarios would not differ much with respect to these categories, effort was made to handle this risk.

All said sources of uncertainty also influence the findings related to research question 2, 3 and 4. Concerning the second research question, BM-LCA is well suited to analyse the hotspots of product systems, a property which it inherits from LCA. Sensitivity analysis is suitable for analysing the third research question, but it has two main limitations in this case. Firstly, the level of granularity was low and the uncertainty high, primarily for the economic data, but also to some extent for the data on physical flows and technical parameters. This makes it difficult to identify exactly which parameters are most significant. Secondly, uncertainty also arises as a limited set of parameters is selected for performing sensitivity analysis. Furthermore, the market analysis related to the fourth research question is very limited. Only the variation of two technical parameters in the product systems across two countries is explored. However, an exhaustive market analysis is not feasible, and even a limited market analysis can provide some insights on how the environmental performance of the scenarios might vary.

In this study, all uncertainty accounted for is addressed (yet, not fixed) by conducting sensitivity analysis, which provides for a more nuanced view of whether the recycling service can contribute to decouple the company's business models. This is a suggested approach to handle uncertainties in BM-LCA (Böckin et al., 2022), and could be applied in other studies, with or without the extra uncertainties which scenario construction entails.

6.2 The position of the study in the research field

The study adds to the small set of BM-LCA case studies and contributes to demonstrate how the methodology can be applied. It affirms some of the findings from the previous studies and continues to explore new potential avenues in the research field. Firstly, as in the studies from Goffetti et al. (2022), Sandqvist & Westberg (2022) and Holzhausen & Troedsson (2023), a conventional business model is compared to more circular alternatives. This study finds that the circular business models (scenarios) have potential to lead to decoupling relative to their linear counterparts, which is analogous to the conclusions of these previous studies.

Böckin et al. (2022) developed BM-LCA because of the need for a method to assess the environmental performance of business models and for innovating business models to make them more decoupled. Goffetti et al. (2022), Sandqvist & Westberg (2022) and Holzhausen & Troedsson (2023) maintain that the method is indeed useful for these purposes. These merits of the method are demonstrated in this study too, as it allowed to compare the business model scenarios with respect to environmental performance and analyse how this depends on various parameters. Specifically, one of the findings of the study are that the recycling service could decouple the company's business models around the tissue product, thus exemplifying the method's capabilities for providing guidance towards decoupling.

Goffetti et al. (2022) analysed the potential for decoupling at business model level by means of sensitivity analysis. While the sensitivity analysis in this study scratched on the surface of such an analysis (by varying the dimension of the recycling service and the transportation distance it entails), it primarily served to analyse how the business model scenarios' environmental performance may vary across different markets (by varying end-of-life management systems, electricity mix, energy price and revenue margin). Altering market dependent parameters in a BM-LCA in this manner appears to be a useful means for such an analysis. The possibility for this type of analysis derives from the quantitative nature of BM-LCA, which was highlighted by Böckin et al. (2022) as one of its key merits. By conducting a market analysis of business models' environmental performance through sensitivity analysis (as proposed by Böckin et al. 2022), the study contributes to explore the capabilities of BM-LCA. Furthermore, it enunciates the matter of market dependency of business models' environmental performance. The BM-LCA results show that this dependency can be significant and some influential factors are discussed. This could be an equally important contribution, as literature search suggested this area is largely unexplored. Further studies could continue to look into this matter.

Sandqvist & Westberg (2022) employed fictive business model scenarios in their BM-LCA study of sales and subscription business models around automobiles. As the recycling service is very small-scale as of today, scenario modelling had to be undertaken in this study too, to analyse its decoupling potential. The crossroad between BM-LCA and forecasting to analyse potential future business models is an interesting field that the study scratches the surface of. As accounted for in the former Section 6.1, the forecasting employed in this study is not particularly sophisticated and it entails a good measure of uncertainty. Altering one element in a business model likely has second-hand effects on other elements too, which is worthwhile considering for constructing scenarios that are relevant to assess. This holds both for scenario modelling with the aim of forecasting as well as capturing other properties, e.g. market differences. An area of further studies could be to elaborate on how BM-LCA and scenario modelling should be combined to obtain relevant and more reliable results.

Lastly, the study has also touched upon the limitations of BM-LCA as a methodology. Further research could delve deeper into the theoretical questions around the method. The matter of what BM-LCA results can tell in general about decoupling at business model level, and how the method could be used to address larger questions, i.e. macro-scale decoupling, are two such examples.

7 Conclusion

To conclude, this study investigates a closed-loop recycling service for a single-use tissue product, with regards to its potential to decouple the company's business models around the product. Four business model scenarios are constructed, in which the material input to the production varies between recycled product, recovered paper and fresh wood based paper pulp, and each of them are set on both the Swedish and German markets. While the difference in GWP impact between the scenarios are marginal, the recycling service shows large potential to decouple the profitability of the company's business models from the amount of land used for forestry. This caters for the conclusions that the recycling service appears to contribute to decoupling environmental impact overall. Nevertheless, with the current recycling process infrastructure in the production on the German market, the recycling service increases the GWP impact score slightly when it is scaled up from 0% to 20%, as the used single-use products replace a cheaper input to the process. The high level of uncertainty related to constructing fictive business model scenarios and assigning them data on environmental impact and monetary flows presents one of the weaknesses of this study.

Furthermore, the study concludes that the environmental hotspots vary between markets where product systems and cost structure are different. The results settle that the Swedish production system has the largest environmental impact fraction in upstream production, and the German production system instead has the largest fraction in production processes. Additionally, the sensitivity analysis shows a large dependency of the business model scenarios' environmental performance on market parameters. The study demonstrate that the decoupling potential depend to a large extent on revenue marginal, energy prices, energy mix and waste management. Furthermore, the strengths and weaknesses of circular business models in regard to these market parameters were identified in the study.

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