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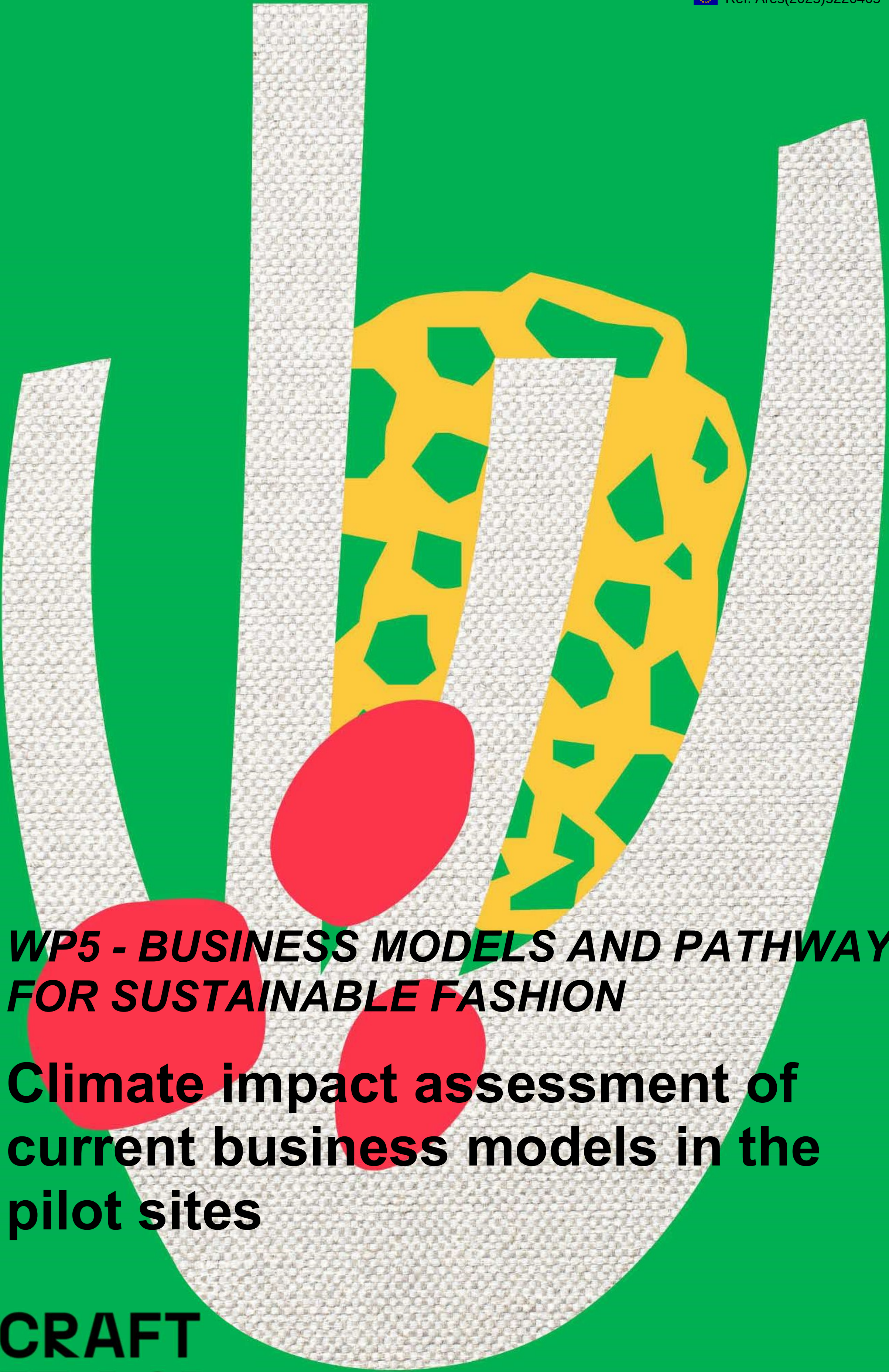

WP5 - BUSINESS MODELS AND PATHWAYS FOR SUSTAINABLE FASHION

Climate impact assessment of current business models in the pilot sites

CRAFT IT 4 SD

Craft Revitalization Action
for Future-proofing the Transition
to Innovative Technologies
for Sustainable Development

GENERAL DATA

PROJECT NAME	Craft Revitalization Action for Futureproofing the Transition to Innovative Technologies for Sustainable Development
PROJECT ACRONYM	CRAFT-IT4SD
PROJECT NUMBER	101132596
CALL	Horizon-Cl2-2023-Heritage-01
TOPIC	Horizon-Cl2-2023-Heritage-01-02
TYPE OF ACTION	HORIZON Research and Innovation Actions
GRANTING AUTHORITY	European Research Executive Agency
PROJECT DURATION	36 Months

DOCUMENT CONTROL SHEET

WORK PACKAGE NUMBER	WP5
WORK PACKAGE TITLE	Business models and pathways for sustainable fashion
DELIVERABLE NUMBER	D5.2
DELIVERABLE TITLE	Climate impact assessment of current business models in the pilot sites
NUMBER OF PAGES	130
TYPE	Report
DISSEMINATION LEVEL	PU – Public
DUE DATE (MONTH)	M18
LEAD BENEFICIARY	VTT
AUTHORS	OAMK, TUIASI, MODACC, VIA

VERSIONING AND CONTRIBUTION HISTORY

Version	Date	Author/Editor	Collaborators	Description
_V01	9 June 2025	Annu Markkula, Silvia Forin, Eveliina Hylkilä, Essi Paronen, Hanna Pihkola, Hannamaija Tuovila		Initial draft
_V02	26 June 2025	Annu Markkula, Silvia Forin, Eveliina Hylkilä, Essi Paronen, Hanna Pihkola, Hannamaija Tuovila	Fred Saarinen, Juliana Penagos	Peer-reviewed version
_V03	30 June 2025	Annu Markkula, Silvia Forin, Eveliina	Adriënne Heijnen	Quality Manager's

		Hylkilä, Essi Paronen, Hanna Pihkola, Hannamaija Tuovila		reviewed version
_V1.0	30 June 2025	Annu Markkula, Silvia Forin, Eveliina Hylkilä, Essi Paronen, Hanna Pihkola, Hannamaija Tuovila	Adriënne Heijnen	Final version for submission

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List of abbreviations and acronyms

Abbreviation/acronym	Description
BCI	Better Cotton Initiative
CCSI	Cultural and Creative Sectors and Industries
CSRD	Corporate Sustainability Reporting Directive
CO_2e	Carbon dioxide equivalent, unit for Global Warming Potential
D	Deliverable in a Work Package
EEA	European Environment Agency
EF	Environmental Footprint
ESPR	Ecodesign for Sustainable Products Regulation
EU	European Union
GFA	Global Fashion Agenda
GHG	Greenhouse Gas
GLO	Global Level Data, ecoinvent database region code used for global level data
GWP	Global Warming Potential
ILCD	International Reference Life Cycle Data System
LCA	Life Cycle Assessment
LULUC	Land Use and Land Use Change
OEF	Organisational Environmental Footprint
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
POM	Plastics Manufacturers Polyoxymethylene
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RER	Europe, ecoinvent database region code used for data from European geographical areas
RoW	Rest-of-World, ecoinvent database region code used for varying geographical areas defined case by case
SME	Small and Medium-sized Enterprise
WP	Work Package

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EXECUTIVE SUMMARY

The CRAFT-IT4SD project aims to leverage the European cultural and creative sectors to advance the green transition. As part of the project, sustainable business models in fashion and clothing are studied with a specific focus on their potential to achieve climate impact reductions to promote the green transition.

The present deliverable (D), D5.2, “Climate impact assessment”, is the second deliverable of the CRAFT-IT4SD Working Package (WP) 5, “Business models and pathways to sustainable fashion.” D5.2 presents the results of TASK 5.2, “Climate impact assessment”. Building on the work carried out in WP5 TASK 5.1, “Current status,” TASK 5.2 continues the efforts of TASK 5.1 by assessing the potential climate impacts of business models of selected case companies in the four CRAFT-IT4SD pilot sites located in Denmark, Finland, Romania, and Spain.

Like many other sectors, fashion strives to achieve net-zero emissions by 2050, in line with keeping global warming below 1.5 degrees. Sustainable, circular business models have been proposed as one solution to tackle this challenge. While in recent years, an extensive body of literature has emerged on sustainable business models, not much of this literature has addressed the sustainability impacts of these models in quantitative terms. Behind this are several reasons, such as the stage of business model development that impacts data availability, challenges to obtain reliable data across value chains, and resources and technical skills needed to analyse and interpret quantitative environmental impact data. However, given the urgent need to reduce climate impact, it is crucial to move beyond descriptive business models and quantify the climate impact reduction potential of sustainable models. This understanding is vital for improving, developing, and financing business models, providing better information for decision-making, and supporting the climate transition, considering recent and upcoming regulations. Within the fashion and textile sector, business models are closely interlinked with products and consumer behaviour, which all need to be considered in the assessment.

The present deliverable presents the findings of the climate impact assessments conducted for four micro and small-sized companies that operate in the CRAFT-IT4SD pilot sites. The participating companies apply sufficiency-based business models that represent the highest strategies in the waste hierarchy as defined in the EU Waste Framework Directive. These models were selected as the emphasis of WP5 as they also target consumption reductions, alongside technological innovations and efficiency improvements to enhance sustainability. While small companies cannot alone change the broader textile ecosystem, their business models, products, and practices can offer valuable insights for other companies and consumers in reducing climate impacts originating from the textile sector.

The assessed business models included the following: Textile re-use and re-design (Case Company 1); Clothing rental (Case Company 2); Tailor-made clothing (Case Company 3); and Clothing pre-order (Case Company 4). For Case

Companies 1, 3 and 4, the climate impacts assessment was conducted based on the main principles of Life Cycle Assessment (LCA) and carbon footprint as specified in ISO 14040/44 and 14067. The climate impact assessment was conducted using the Environmental Footprint (EF) 3.1 impact assessment method, focusing on the climate change impact category. To the extent possible, the assessed business models and products were also benchmarked against a potential conventional business model or product to better understand the climate impact reduction potential. These comparisons are fictive and based on assumptions, as the studied companies did not have such benchmarks readily available. For Case Company 2 (Clothing rental), potential climate impacts of alternative use scenarios were considered based on a combination of primary data and literature, without actual life cycle modelling. In addition to these four case studies, the climate impact reduction potential of take-back business models was studied based on a literature review.

The case study findings illustrate some common climate hotspots and thus provide support for the sector to better understand climate impact reduction-relevant actions. They also highlight the importance of understanding the background assumptions that are made in impact assessments and the specific context of each case study.

The first case, textile reuse (Case Company 1), illustrates the climate impacts of a sufficiency-based business model in the fashion sector, consisting of the use of post-production textile waste, also referred to as deadstock. The potential climate impacts of the company's textile reuse and re-design business model were analysed by calculating the (cradle-to-gate) carbon footprint of an exemplary product, a bum bag, mainly composed of deadstock materials (textiles and zipper) as well as primary components (webbing strap, triglide and side release buckle). In the study, the reused materials were assumed to be burden-free, i.e., their climate impact was not accounted for, while their transportation from the factory to the company was considered. The results highlight the climate benefits of secondary textile use, which leads in this case to a carbon footprint reduction of 67% with respect to an equivalent product made of primary components only. Moreover, the production of the remaining primary materials as well as the ironing process taking place at the company could be identified as main contributors to climate change and can be addressed in future mitigation actions.

The second case, clothing rental (Case Company 2), focuses on potential climate impacts of rental clothing. A few scenarios were built for different life cycle choices and consumer habits, to find out potential hotspots in the rental clothing's life cycle. The rental clothing items studied included a formal dress made of silk and a casual cardigan made from wool and polyamide. Potential climate impacts of the rental item's life cycle were studied by calculating alternative use scenarios (from raw material extraction to use, end-of-life excluded), based on a combination of literature and company-specific data related to the use phase. The results show that the climate impacts per wear can be significantly lower for rental garments which are worn up to their potential, compared to retail garments used fewer times. On the other hand, the life cycle impact of rental garments might increase compared to retail clothing if transports increase due to frequent rentals. However, this impact can be minimised by combining the trips with other errands, using public transport, biking or walking. For the studied garments, the biggest climate impacts were created during the manufacturing phase, and there is potential to decrease climate impacts, if rental services would partly replace retail purchases, and if the rental clothes are used up to their maximum potential. Evidence from the case study highlights that customers committed to the rental service have changed their purchase behaviour, buying less clothes from retail shops.

The third case, tailor-made clothing (Case Company 3), focuses on tailor-made clothing (also referred to as the made-to-measure business model) to provide long-lasting garments made for the individual request of a customer. The study examined the climate impacts of manufacturing a tailor-made blouse (cradle-to-showroom, excluding use and end of life), made from 100% cotton fabric, with polyester buttons and cotton thread. The results highlight that the fabric production process, contributing to 80% of the total carbon footprint, is mostly caused by cotton weaving. When the blouse is a tailor-made product, it is expected to fit the customer better compared to a normal blouse, and be of high quality, with the potential to stay in use longer than an average blouse, extending the use phase of the product. Empiric evidence from the case study (small sample of customers) indicated that after 4 years, their product was still in active use. Thus, there could be potential to double the lifetime of the garment, avoiding the purchase of another blouse per consumer, and saving required primary resources. In our example, the manufacturing of one blouse creates 5-6 kg of carbon dioxide equivalents (CO_2e). Avoiding this purchase could result in a 4% decrease in an average consumer’s clothes-related carbon footprint per year.

The fourth case, clothing pre-order (Case Company 4), addresses the overproduction of textile products, which is due to inaccurate demand forecasting and leads to excess products that are sold off or disposed of. The case company applying the pre-order model uses an online pre-order service, through which only ordered items are delivered. The pre-order business model was analysed by calculating the carbon footprint of a pair of jeans, from raw material extraction to delivery to up to three consecutive clients in case the product is returned. The results show that the pre-order system leads to a reduction of climate impacts by approximately 20%, because overproduction is avoided. Within the jeans’ life cycle (with the exclusion of use and end-of-life), fabric production processes play a predominant role, contributing to almost 60% of the total carbon footprint, while transportation to three consecutive clients’ accounts for about 10%.

In addition to the company case studies, the climate impact of the take-back business model was evaluated in a literature review via analysing articles on second-hand sales business models in the absence of articles directly evaluating the take-back business models. Based on the review, second-hand sales scenarios do not always have a smaller climate impact than business-as-usual scenarios where the garment is used by one user. This indicates that various aspects, especially the use phase, replacement of new clothing and burden allocation, should be considered in each case to understand whether the take-back business model can provide climate benefits.

Except for the take-back business models, all other sufficiency-based business models studied for this deliverable showed potential for greenhouse gas (GHG) reductions at the product level, with 20-67% lower greenhouse gas emissions compared to estimated benchmark products. The take-back model would need to be studied further in empirical contexts to better understand when the model can lead to climate benefits.

Irrespective of the business model, extending the life cycle of fashion products is crucial for reducing climate impacts. Most of the impacts in the fashion sector arise from the clothes manufacturing and primary production phases, highlighting the potential to avoid greenhouse gas emissions by keeping garments in use longer and avoiding excess production and waste. In addition to resource savings, improvements in production practices, such as switching to low-carbon energy sources, improving energy efficiency, using lower-impact materials and reducing waste generation in every life cycle phase, can further reduce climate impacts. However, to be effective, the sufficiency-based business models should be able to reduce consumption, which might be challenging from a value creation perspective.

Together with the results of TASK 5.1, published in D5.1, D5.2 provides the foundation for building sustainable climate transition enabling business models in the final task of WP5, TASK 5.3, “Business modelling”. Furthermore, the D5.2 results provide valuable insights for diverse upcoming pilot site activities in WP3, “New technologies, infrastructures, platforms, and data value for the CCSI”, WP4, “Pilot coordination, implementation and monitoring” and WP6, “Skills and learning communities across fashion and related CCSI”.

KEYWORDS: Carbon Footprint; Climate Impacts; Greenhouse Gas Emissions; Fashion Industry; Life Cycle Assessment; Sustainable Business Models; Sustainable Climate Transition; Sufficiency-based Business Models

1. INTRODUCTION

This chapter outlines the starting point of the work carried out in CRAFT-IT4SD WP5 TASK 5.2, “Climate impact assessment”. It describes briefly the potential of selected business models in reducing climate impacts and the recent regulatory initiatives to reduce fashion’s climate impacts. Furthermore, the chapter delineates the report's objectives, its structure, and its relationships with other CRAFT-IT4SD work packages.

1.1. European fashion sector and climate impacts

Since the European Green Deal was introduced in 2019, the Cultural and Creative Sector and Industries (CCSI) have gained increasing recognition for their vital role in supporting Europe's goal to become the first climate-neutral continent by 2050 (Vuijlsteke, 2024).

Regarding the climate impacts of the CCSI, one of the key sectors is the fashion industry. Like many other sectors, fashion strives to achieve net-zero emissions by 2050, in line with keeping global warming below 1.5 degrees (UNFCC, 2021). Depending on the source, the sector is claimed to create 2-10% of global greenhouse gas (GHG) emissions (Apparel Impact Institute, 2022; Bauer et al., 2023). According to the European Environmental Agency (EEA, 2025), in 2022, the supply chain of textile products purchased by EU households generated an estimated 159 million tonnes of carbon dioxide equivalent (CO_2e) emissions – approximately 355 kg per person. Approximately 50% of this amount could be attributed to clothing, while 30% was related to other household textiles, and 20% to footwear. As a whole, this ranks textiles as the sixth most impactful household consumption category in terms of climate impact, following housing, food, and mobility, and on par with sectors like restaurants, hotels, recreation, and culture.

Yet, according to the Circularity Gap Report for Textiles 2024 (Circle Economy, 2024) the global textile industry is only 0.3% circular. Based on the same source, the average European uses 26 kilograms of textiles and produces 12 kilograms of textile waste every year. The report also indicates that 61.4% of used garments are disposed of in landfills or incinerated, 8% are reused or exported, and 6.3% of waste textiles are recycled. According to the United Nations Environment Programme (UNEP) (UNEP, 2018), every second, a garbage truck's worth of textiles is either landfilled or burned. If current trends continue, the fashion industry will consume a quarter of the world's carbon budget by 2050, leaving the sector far behind its emission targets.

The global rise of the fast fashion business model over recent decades has been a major driver of the fashion industry's substantial negative impacts on the climate and environment. Its rapid expansion has intensified resource use, accelerated production cycles, and contributed significantly to greenhouse gas emissions and environmental degradation. The fast fashion model has been criticised for its high usage of raw materials, water and land resources and GHG emissions (EEA, 2019; Niinimäki et al., 2020; Thorisdottir et al., 2024). Other factors contributing to the sector's adverse environmental impacts, which are also closely tied to the expansion of fast fashion, include the sector's global industrial growth, non-transparent value chains, linear business models, mass production operations, and reduced garment prices (Köhler et al., 2021; Šajn, 2019).

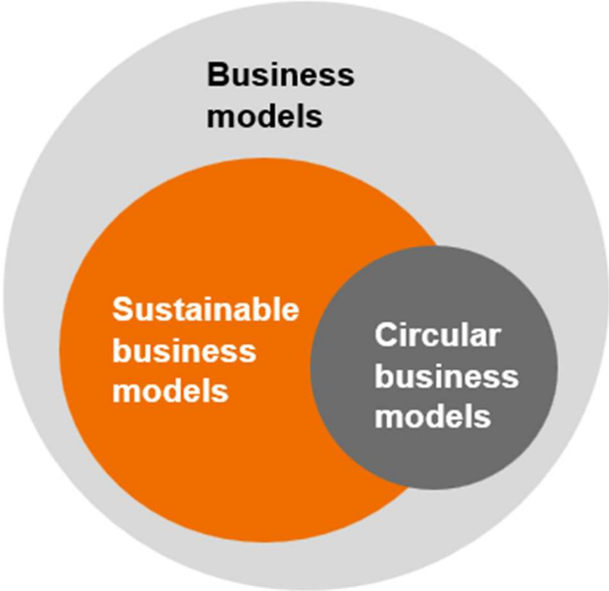
Although these environmental challenges in the sector have been longstanding (Thorisdottir & Johannsdottir, 2019), recent years have witnessed heightened efforts at the European Union (EU) institutions and/or Member States of the EU

to tackle these issues. These efforts aim to support industrial competitiveness by promoting more sustainable business practices that respect planetary boundaries. This commitment is reflected in the 2022 EU Strategy for Sustainable and Circular Textiles, which emphasises the need to rethink value creation (European Commission, 2022b) and align practices with the EU's circular economy targets, ensuring resources remain in use as long as possible to achieve a sustainable economy (European Commission, 2019).

In this context, sustainable business models have emerged as one potential way to mitigate the adverse impacts of current business practices (Markkula et al., 2024). Although there are many definitions of sustainable business models, these models typically consider a wider range of stakeholders, adopt a system-level perspective, and incorporate economic, environmental, and social aspects of sustainability (Bocken & Short, 2021; Evans et al., 2017). For example, as defined by Geissdoerfer et. al. (2018), sustainable business models can be understood as 'business models that incorporate pro-active multi-stakeholder management, the creation of monetary and nonmonetary value for a broad range of stakeholders, and hold a long-term perspective'.[1]

As noted by Bocken et al. (2022), as well as in the first deliverable of the CRAFT-IT4SD WP5, D5.1 "Mapping and descriptions of current business models in selected pilot sites" (Markkula et al., 2025), sustainable business models can take various forms. For example, a business model that aims to be more sustainable may focus on reducing production impacts by improving efficiency, reusing materials, or reducing consumer demand (Bocken et al., 2022). However, while the word "circular" is often equated with "sustainable," circular business models are not automatically sustainable. That is to say that some circular business models are more sustainable than others, and some can even resemble traditional business models, as shown in Figure 1.

[1] The term 'sustainable business model' is a well-established concept in scientific business management literature. While there are several definitions of this term, it is essential to recognise that the sustainability of a 'sustainable business model' is, within that literature, predominantly assessed in qualitative terms and does not reflect how sustainable the model actually is.



Adapted from Geissdoerfer et al (2018), as presented in the CRAFT-IT4SD report D5.1 (Markkula et al., 2025)

Figure 1. Relationships between business models, sustainable business models and circular business models

Sustainable and circular business models can thus cover various businesses and phases along the product value chain, ranging from production to distribution or including both (Abbate et al., 2024). To reduce the climate impacts of the sector, one solution would therefore be to consider where, along the value chain, major climate impacts occur. In terms of climate impacts, according to a report by McKinsey and Global Fashion Agenda (GFA) (McKinsey and GFA), over 70% of the climate impact of the apparel and footwear value chain is generated in the upstream supply chain activities such as raw material production, preparation, processing and apparel assembly. According to the same source, the remaining 30% originates from downstream activities, which include various distribution-side-related activities such as retail, use, and end-of-use.

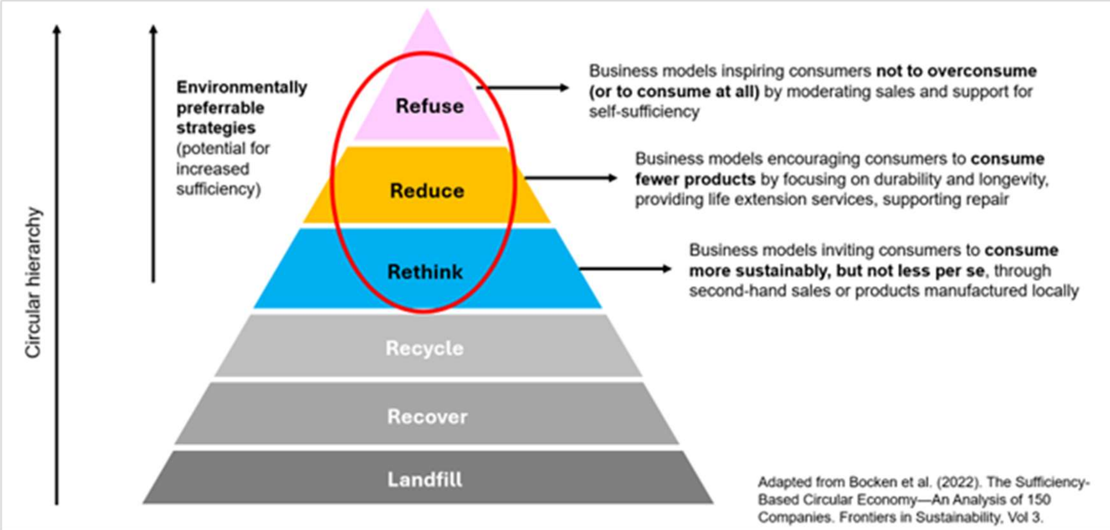
Similar figures are reported in other reports. According to the European Environment Agency (EEA) (EEA, 2025), only 30% of the greenhouse gas emissions linked to European textile consumption occur within Europe. The remaining 70% take place outside Europe, as nearly all stages of textile production are carried out in countries with lower production costs. The same source reports that between 2010 and 2022, a trend of decoupling of emissions from consumption can be seen as per capita greenhouse gas emissions from textile consumption decreased by 22%, even as overall consumption rose by 15%. This is mainly attributed to a reduction in the greenhouse gas intensity of textile products.

Recent research, however, suggests that while climate impact reductions in the supply chain, e.g. by improving energy efficiency and renewable energy, help reduce climate impacts, they are likely insufficient to lower the overall climate footprint of the fashion sector (Peters et al., 2021). Choosing fibres that have a lower climate impact during their production, such as choosing cotton over synthetic fibres, can often reduce climate impacts (EEA, 2025).[2] There is also variation between different types of similar-sounding raw materials. For example, according to Shah et al. (2018), when compared with conventional cotton, organic and Better Cotton Initiative (BCI) cotton show considerable advantages for several environmental impact categories, including climate.

However, shifting to more sustainable fibres alone is not likely to solve the climate challenge. For instance, a study conducted in the United Kingdom found that meeting climate targets necessitates recycling, cleaner production, and significantly reducing new consumption, which current fashion business models may struggle to support (Millward-Hopkins et al., 2023). Therefore, it looks that efficiency improvements and technological innovations must be combined with major shifts in consumption patterns to meet global climate impact reduction targets, requiring the development of sufficiency-based approaches that address the challenges of both overproduction and overconsumption (IPCC, 2022). This perspective is echoed by the EEA (EEA, 2025), which suggests that transitioning to circular business models—focusing on eco-design, reuse, repair, and recycling—can reduce the textile industry's reliance on fossil fuels and help mitigate its climate impact.

Against this backdrop, the focus of CRAFT-IT4SD WP5 was directed to examine sufficiency-based business models (Bocken et al., 2022) and their potential to advance the climate transition. These models are a subset of sustainable business models (Bocken et al., 2022). They aim to enhance sustainability by minimising material and energy usage for goods and services and encouraging consumers to reduce consumption (Bocken & Short, 2016) as illustrated in Figure 2.

[2] As highlighted by the European Environment Agency (EEA, 2025), greenhouse gas emissions from fibre production vary significantly by material. According to the same source, cotton-based textiles typically have the lowest climate impact. In contrast, synthetic fibres tend to generate higher emissions due to their fossil fuel origins and the substantial energy required during production. It should, however, be noted that these are general estimates. Furthermore, in addition to climate impacts, other environmental impact categories should also be considered to assess the environmental sustainability of a particular fibre, produced in a particular location.



Sufficiency-based business models as presented in D5.1 (Markkula et al., 2025)

Figure 2. Sufficiency-based business models

As highlighted by Bocken and Konietzko (2022), applying the strategies of refuse, reduce and rethink, sufficiency-based business models address the highest waste priority levels in the EU Waste Framework Directive (European Commission, 2018). These models address both the business and consumer perspectives. Businesses should emphasise durable design, extending product life (e.g., second-hand markets), frugal innovation, conscious sales (i.e., opposing 'fast fashion'), and moderating consumption (Bocken et al., 2014). Consumers should shift towards responsible products (Dyllick & Hockerts, 2002; Young & Tilley, 2006).

In the first task of WP5, TASK 5.1, “Current state”, these models were studied to understand how common the models are within the European fashion sector and what kind of examples of these models can be found in the four CRAFT-IT4SD pilot site locations in Denmark, Finland, Romania and Spain. TASK 5.1 also studied the opportunities and challenges of these models, as well as future aspirations related to these models. Furthermore, based on the work carried out in TASK 5.1, relevant topic areas for the TASK 5.2 climate impact assessment were identified. The work carried out in TASK 5.1 informed and supported the selection of the different sufficiency-based business model cases for which the climate impacts were then calculated in TASK 5.2. The results of TASK 5.1 have been reported in more detail in the first deliverable of WP5, D5.1, “Mapping and descriptions of current business models in selected pilot sites” (Markkula et al., 2025). The relevant topic areas for climate impact assessment were presented in D5.1 and are re-addressed in Chapter 0 of the present report.

The following sufficiency-based business models were chosen to be examined for their climate impact reduction potential in TASK 5.2: textile reuse and re-design (Case Company 1); clothing rental (Case Company 2); tailor-made clothing (Case Company 3); and clothing pre-order (Case Company 4). In addition to the business model case studies, the climate impacts of take-back business models were studied based on a literature review.

All the participating case companies were either micro or small companies, which, in terms of size, represent typical entities in the European fashion sector. In Europe, micro companies (197 000) make up 89%, small companies (17 730) account for 9%, medium-sized companies (3 940) represent 2%, and large companies (591) constitute 0.3% (EURATEX, 2024).[3] They are connected to global value chains and operate in a market environment that includes large global companies with a strong presence in Europe.

There is a clear need for a study like this for several reasons. First, while in recent years, an extensive literature has emerged on sustainable business models (Bocken & Short, 2021; Evans et al., 2017) including fashion (Bocken & Short, 2021; Coscieme et al., 2022; Mukendi et al., 2020; Thorisdottir et al., 2024), not much of this literature has considered the environmental sustainability impacts of business models in quantitative terms (Abbate et al., 2024; Böckin et al., 2022; Das et al., 2021).

One of the reasons behind this is that business models can be evaluated at different stages along the business model innovation process (Gilsing, 2022). The evaluation stage has a clear impact on the accuracy and availability of data that can be utilised. As Gilsing et al. (2022) note, in general, the evaluation of business models in the early stages tends to be primarily qualitative, while the later stages of business model innovation are typically supported by quantitative methods. Those methods can include, for example, environmental and economic impact assessments.

Overall, assessing quantitatively the environmental impacts of business models is not a widespread practice. This is often due to the lack of resources, expertise, and reliable or comparable environmental data (Das et al., 2021; Das et al., 2023) that can be challenging topics to address, especially for micro companies and small and medium-sized companies (SMEs) (Løkke & Madsen, 2023). For example, SMEs, which represent the majority of companies in the sector in Europe, generally struggle to find adequate resources.

Furthermore, in practice, it is also highly challenging to address all the various sustainability impacts that might take place after the implementation of the new business model. Models such as circular, service-based, or sharing models that are initially perceived as environmentally more sustainable can lead to various rebound effects, which can diminish or even negate their intended positive impacts, resulting in unintended adverse effects (Johnson & Mont, 2025; Zamani et al., 2017). Sometimes, this is related to data and resource availability (Das et al., 2023; Millward-Hopkins et al., 2023; Sandin et al., 2023).

Measuring actual environmental impacts would, therefore, be crucial to recognise how new models can quantitatively reduce adverse impacts compared to

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[3] While micro companies and SMEs form 99% of the companies in the sector, there is significant variation in the number of persons employed by these companies. The European Apparel and Textile Organisation (EURATEX) (2024) classifies companies by the number of employed persons as follows: micro companies (0 to 9 employees), small companies (10 to 49 employees), medium companies (50 to 249 employees), and large companies (250 or more employees). Based on the same source, the total number of companies in the sector is 197 000 companies (175 330 micro companies, 17 730 small companies, 3 940 medium companies, and 591 large companies), employing 1 300 000 persons in total.

traditional ones. Even imperfect assessments often provide learnings that can be useful for avoiding burden shifting from life cycle phase to another. For example, while circular business models are generally considered more sustainable than linear ones, several studies have also concluded that not all circular models lead to significant climate benefits; some may have worse or unknown climate impacts (Dahlbo et al., 2017; Fonseca et al., 2023; Geissdoerfer et al., 2018; Peters et al., 2021; Sandin & Peters, 2018). Such understanding would also be needed to comply with regulations like the Corporate Sustainability Reporting Directive (CSRD) (European Commission, 2022a), the Green Claims Directive (European Commission, 2023) and the Ecodesign for Sustainable Products Regulation (ESPR) (European Commission, 2024b), as these regulations have direct and indirect implications for all companies, depending on their size.[4]

Life cycle assessment (LCA) is a methodology that is commonly used to quantify potential environmental impacts of a product, a service or an organisation. Several LCA-based approaches can be applied to assess the environmental performance of a business model or a product. As discussed by Böckin et al. (2022), these approaches can take either a product or a business model as their object of analysis. As various factors can influence the accuracy of the assessment, the selection of the appropriate LCA approach needs to be decided on a case-by-case basis, also taking into account the information needs of the stakeholders involved, and transparently reporting the assumptions made. Chapter 2 outlines the general LCA approach used in TASK 5.2 to assess the climate impacts of sufficiency-based business models and related products, with detailed case study descriptions and their specific methodological specifications provided in Chapter 3 and the related Appendices.

1.2. Objectives of the report

While the overall objective of the CRAFT-IT4SD project is to harness the potential of European CCSI to drive the green transition, the present deliverable, D5.2, “Climate impact assessment”, focuses on assessing the climate impacts of selected fashion business models in the four CRAFT-IT4SD project pilot sites across Europe. In addition, the report lays out ideas for future-oriented scenarios to support sustainable climate transition-supporting business model development.

Together with the results of D5.1, “Mapping and descriptions of current business models in selected pilot sites” (Markkula et al., 2025), the results of D5.2 provide the basis for building new sustainable climate transition-enabling business models in the final task of WP5, TASK 5.3 “Business modelling”, with results to be published in D5.3.

[4] While, for example, the CSRD and ESPR target primarily large companies, all companies in the supply chains of the large companies may need to provide sustainability-related information to their larger partners to comply with the CSRD and ESPR requirements. The proposed Green Claims Directive would apply to all companies making environmental claims about their products or services in the EU, with exemptions or simplifications for smaller companies.

1.3. Structure of the report

The report is structured as follows. The next chapter, Chapter 2, focuses on the methodology applied in CRAFT-IT4SD WP5 TASK 5.2 to assess the climate impacts of selected business models.

Chapter 3 summarises case studies on the climate impacts of four sufficiency-based business models used by small companies in Denmark, Finland, Romania, and Spain. These models include textile reuse, clothing rental, tailor-made clothing, and clothing pre-order. The chapter also reviews the climate impacts of take-back business models based on existing literature.

Chapter 4 explores ideas and building blocks for future climate scenarios to develop sustainable business models, building on the climate impact assessments and literature review findings from Chapter 3.

Chapter 5 outlines how the key topic areas identified in D5.1, relevant for the climate impact assessment and future-oriented climate scenario building in TASK 5.2, have been addressed in this deliverable.

The final chapter, Chapter 6, provides the concluding remarks of this report. It outlines the continuation of WP5's work and explains how the results of WP5 TASK 5.2 will support other CRAFT-IT4SD work packages.

1.4. Connections to other CRAFT-IT4SD tasks and work packages

The literature reviews conducted in TASK 5.2 on the climate impacts of the selected sufficiency-based business models extend the previous literature review carried out on sustainable fashion business models and climate impacts for WP2, “Scientific and methodological foundation: Challenges and opportunities for the CCSI in the sustainable transition,” as reported in D2.1., “Method Playbook – Initial” (Clausen et al., 2024). They also extend the sustainable business model literature review of D5.1 “Mapping and descriptions of current business models in selected pilot sites” (Markkula et al., 2025), by presenting LCA-based approaches to assess the climate impacts of business models in quantitative terms.

Alongside the results of TASK 5.1 published in D5.1, D5.2 lays the groundwork for developing sustainable climate transition-enabling business models in WP5's final task, TASK 5.3, “Business Modelling”. Additionally, the insights from D5.2 are valuable for various upcoming pilot site activities in WP3, “New Technologies, Infrastructures, Platforms, and Data Value for the CCSI”, WP4, “Pilot Coordination, Implementation, and Monitoring”, and WP6, “Skills and Learning Communities Across Fashion and Related CCSI”.

2. METHODOLOGY

This chapter outlines the main aspects of the methodology applied in the work carried out for this deliverable. Additionally, the chapter discusses how the results obtained in the case studies conducted for this deliverable can be communicated to a wider public.

2.1. LCA methodology

The potential climate impacts of the studied sufficiency-based business models are evaluated using Life Cycle Assessment (LCA) methodology, focusing on climate impacts only. LCA is a standardised methodology (International Organization for Standardization, 2006a, 2006b) to assess the environmental impact of a product, service, or organisation. In LCA, the environmental impact is studied considering the whole life cycle of a product or service, starting from raw material extraction and ending with final disposal. Besides evaluating the potential environmental impact, with LCA methodology, it is possible to detect possible environmental burden shifting between life cycle stages and impact categories. The modelling of a product's life cycle involves interlinked unit processes connected by material or energy flows. Each process has inputs and outputs that link it to preceding and subsequent processes.

According to the ISO 14040 standard (International Organization for Standardization, 2006a), LCA consists of four phases: goal and scope definition, life cycle inventory, life cycle impact assessment, and interpretation of results, as illustrated in Figure 3. The LCA process is typically iterative; hence, the decisions made in each phase typically need to be revised during the study.

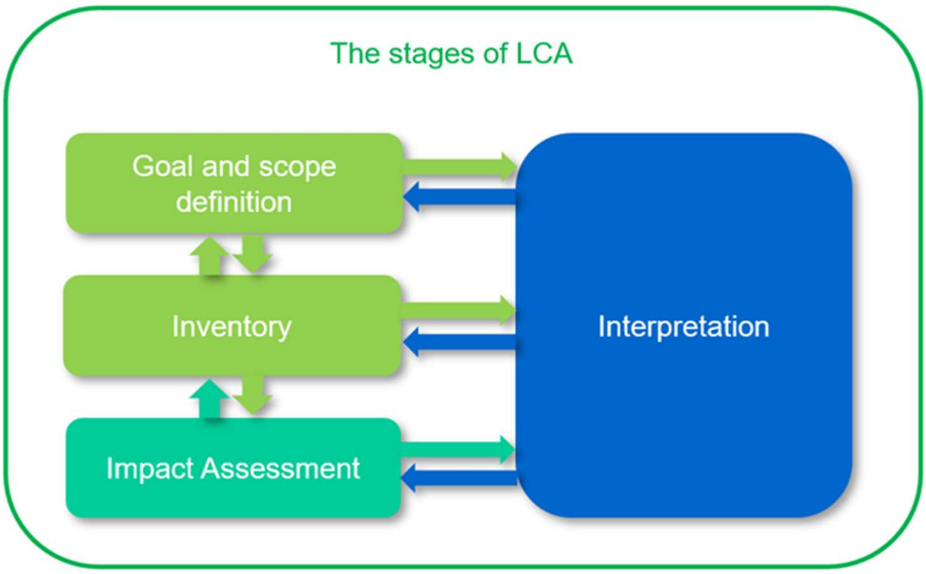

Figure 3. The four stages of life cycle assessment according to ISO 14040

The goal and scope stage describes the study's objective, purpose, and target audience. It establishes the system boundaries and contains the assumptions and potential scenarios required for the calculations. At this stage, the functional unit is also defined. The functional unit represents the need that the product or service fulfils. Common examples of functional units include the number of products (e.g., one pair of jeans) or amounts of use (e.g. 100 wears of a pair of jeans).

Life Cycle Inventory (LCI) includes data collection and balance calculations for all unit processes within the life cycle. The results of the LCI are presented as inputs and outputs of the entire system. Figure 4 illustrates the main input and output flows included in the data collection. The data sources for inputs and outputs can be categorised as primary and secondary. Primary data is obtained directly from the product manufacturer and/or its subcontractors, while secondary data is sourced from databases or literature. Data sources used in the case studies are presented in their separate chapters.

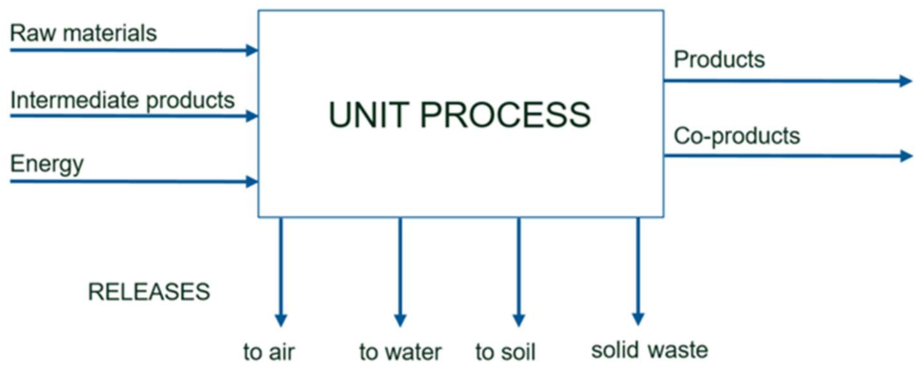

Figure 4. Collected data in the life cycle inventory stage

The life cycle impact assessment stage converts the LCI results into environmental impacts. There are various impact assessment methods, each with different optional characterisation, normalisation, and weighting factors. Carbon footprints included in this deliverable use the EF 3.1 climate change impact assessment method.

Interpretation of the results relies on the three preceding stages of the assessment. Interpretation is an ongoing process that evaluates the consistency of the previous stages. Ultimately, the interpretation stage identifies significant issues, draws conclusions, outlines limitations, and provides recommendations.

Carbon footprint is an LCA study focused on one environmental impact category. The goal of a carbon footprint study for a product is to evaluate its potential impact on global warming. This involves calculating all relevant GHG emissions and removals throughout the product's life cycle. The resulting carbon footprint is expressed in kg CO_2e, which serves as a unit for comparing the radiative forcing of a GHG to that of carbon dioxide (International Organization for Standardization, 2018). For each GHG, a characterisation factor is applied. The characterisation factors used in this study for the most common GHGs are listed in Table 1. Climate change impact is calculated using the global warming potential (GWP) indicator over a 100-year time horizon (GWP100), expressed in CO_2e.

Table 1. Characterisation factors of the most common greenhouse gases used in the EF 3.1 impact assessment method for the climate change impact category

Greenhouse gas*	Characterisation factor in EF 3.1
Carbon dioxide, fossil	1
Carbon dioxide, from soil or biomass stock	1
Dinitrogen monoxide	273
Methane, fossil	29.80
Methane, non-fossil	27
Nitrogen fluoride	1.74

*The list does not include all the greenhouse gases.

All LCA studies are case-specific. Hence, in each LCA study, the examined system is defined separately, and some life cycle stages and processes might be excluded. In this deliverable, the whole life cycle was not assessed in all the case studies. When life cycle stages or processes were excluded, the reasoning for these decisions is presented in the Appendices in the section *Scope of the study* of the relevant case study. Additionally, the data used in the case studies was evaluated in each case study section according to the data quality criteria by the International Reference Life Cycle Data System (ILCD) Handbook (European Commission, 2010).

Furthermore, the case-specific nature of the results should also be considered when communicating the results. The communication of LCA results is presented in more detail in Chapter 2.3.

2.2. Selection of case companies

During the first pilot iteration phase of the CRAFT-IT4SD project, with the help of consortium members, several micro companies and SMEs testing sufficiency-based business strategies and business models were identified in the CRAFT-IT4SD pilot sites as potential participants for the climate impact assessment of TASK 5.2.

After discussions among the pilot site leads and the WP5 TASK 5.1 and TASK 5.2 teams, selected companies were approached by email explaining that the CRAFT-IT4SD project researchers would like to carry out a climate impact assessment for their business model to better understand the climate impacts of sustainable business models. The selection was based on the company's geographical location and business model. The aim was to have one participating company from each of the four CRAFT-IT4SD pilot sites, with all companies representing different sufficiency-based business models.

Four micro companies and SMEs, representing each of the four CRAFT-IT4SD pilot sites and different sufficiency-based business models, were invited to participate in the assessment. The participating companies were informed that the final report of the climate impact assessment would be public. In alignment with the ethical and data management guidelines of the CRAFT-IT4SD project as outlined in D4.1 "Playbook 01 - CCSI for sustainability 01 - updated", D1.3 "Data management, ethics and GDPR plan (initial)" and D8.1 "POPD - H - OEI - Requirement No. 1", the participating companies were told they could still decide what information to disclose in the public report regarding their climate impact assessment case.

Once the preliminary climate impact assessment results were finalised, the companies were offered the opportunity to participate in a Teams meeting where the results were presented. The companies also received the preliminary assessment results in Word format and the meeting presentation materials. They were asked to review the Word document, inform the researchers of any potential errors in the data and also to inform the researchers of any information they did not wish to disclose in the public report, and confirm whether their company name could be publicly disclosed in the final report.

2.3. Communication of LCA results

If the LCA results are intended for communication to the general public, it is important to consider the requirements of existing and upcoming legislation on environmental claims.

In the last years, given the rise of environmental consciousness, which influences consumer behaviour and purchasing decisions, the environmental characteristics of products have increasingly affected marketing communications strategies. This led in many cases to false or misleading claims about the environmental performance of products. In the context of environmental claims, it is important to differentiate by claim type, to be as clear and specific as possible, and to have solid evidence for backing up any environmental claims made. Or to avoid making environmental claims, if sufficient evidence is missing.

According to the amendments already accepted to the Directive on empowering consumers for the green transition through better protection against unfair practices and better information (the "Consumer Protection Directive") (European Commission, 2024a), environmental claims and generic environmental claims are defined as follows:

> *"Environmental claim means any message or representation which is not mandatory under Union or national law, in any form, including text, pictorial, graphic or symbolic representation, such as labels, brand names, company names or product names, in the context of a commercial communication, and which states or implies that a product, product category, brand or trader has a positive or zero impact on the environment or is less damaging to the environment than other products, product categories, brands or traders, or has improved its impact over time".*

The first type of environmental claims includes generic environmental claims in a business-to-customer communication for which the company is not able to demonstrate recognised excellent environmental performance relevant to the claim, such as "eco-friendly," "green," or "biobased"; making an environmental claim about the entire product or the entire business when it concerns only a certain aspect of the product or a specific activity, and claiming, based on the offsetting of greenhouse gas emissions, that a product has a neutral, reduced, or positive impact on the environment in terms of greenhouse gas emissions, e.g., "carbon positive," "net zero," or "climate compensated". Such communication has been banned since 2024 by the Directive on empowering consumers for the green transition through better protection against unfair practices and better information (European Commission, 2024a).

The second type of environmental claims is related to product presentation and visuals. Suggesting a product's or company's environmental benefits via product presentation and images (e.g. trees, rainforests, water, animals), colours (e.g. blue or green), symbols and labels is considered misleading, according to the EU Unfair Commercial Practices Directive (European Commission, 2005) and the related Guidance on Interpretation (European Commission, 2021).

The third and final category of environmental claims pertains to explicit and verifiable product characteristics. To enhance transparency and guide consumers towards a comprehensive understanding of environmental sustainability, the EU legislators are actively working on the Green Claims Directive (European Commission, 2023) (status: April 11, 2025). The initial proposal mandates that claims be grounded in widely recognised scientific evidence and standards, employ a life-cycle approach to prevent burden shifting, adopt a multi-impact perspective, and undergo verification by a certified third-party expert. Additional stipulations pertain to comparative assessments, which must be based on standards that ensure consistency in assumptions and criteria, encompass the same life cycle stages to ensure a fair evaluation, utilise the same impact indicators for consistent assessment of environmental claims across different products, and employ equivalent data, whether primary or secondary, to guarantee the reliability of findings. It should be noted that the current Directive proposal excludes from its application microenterprises, i.e. companies with fewer than 10 employees and an annual turnover that does not exceed 2 million euros.

The studies presented in this report were conducted for research and development purposes, and their aim is to provide ideas and guidance for reducing the climate impacts of the studied business models and products. It is recommended that companies that aim to communicate their results obtained in this project to consumers follow closely current developments in legislation.

Furthermore, it is important to note that the case studies conducted here are single-indicator assessments (only the climate change impact category out of the 16 environmental impact categories included in the Environmental Footprint (EF) 3.1. method is accounted for). All assessed products and business models have other environmental impacts too, and the carbon footprint results alone cannot be used as evidence for environmental sustainability. Additionally, the case studies do not encompass the whole product life cycle, since the study focused on the life cycle phases that were relevant for the specific business model or product in question. Moreover, the benchmark cases used as a reference to quantify the climate effects of the business models do not fulfil the requirements of a comparative assessment to be communicated to consumers according to the Green Claims Directive proposal (European Commission, 2023), as the data sources were not of equal quality, due to a lack of direct benchmarks.

3. CLIMATE IMPACT ASSESSMENT RESULTS

This chapter presents the summaries of the case studies conducted for the four sufficiency-based business models that have been adopted by four micro and small-sized companies representing the four CRAFT-IT4SD pilot sites in Denmark, Finland, Romania and Spain. The assessed case studies include the following: textile reuse, clothing rental, tailor-made clothing and clothing pre-order. Table 2 summarises the participating case companies.

Table 2. Summary of the participating case companies

Company name	**Company code**	**Business model**	**Location**	**Size[5]**
REDU	Case Company 1	Textile reuse	Moldavia, Romania	Micro company
Mallaamo	Case Company 2	Clothing rental	Ostrobothnia, Finland	Micro company
Week of Wonder	Case Company 3	Tailor-made clothing	Central Region of Denmark	Micro company
TWOTHIRDS	Case Company 4	Clothing pre-order	Catalonia, Spain	Small company

Potential climate impacts for each business model case were assessed at the product level. Each sufficiency-based business model case is assessed against a potential benchmark to better understand the climate impact reduction potential of the sufficiency-based model. In addition, the climate impacts of take-back business models are discussed based on a literature review.

[5] The company size classification, presented in more detail Footnote 3, is based on the classification presented in EURATEX (2024).

3.1. Case 1: Textile reuse

3.1.1. Introduction

Case Company 1, REDU (later “the company”), is a Romanian micro company that focuses on sustainable fashion by collecting textile waste from factories and transforming it into new products. The company is located in the CRAFT-IT4SD pilot site in North-East Romania, in the Moldavia region. The company creates items such as clothes, streetwear, and accessories like bags from post-production textile waste. This material is referred to in the case study as deadstock. As defined by Hejlova et al. (2025), deadstock refers to unsold inventory that remains unused and is often left over from previous seasons or cancelled orders, and it can include both fabric and finished garments that were never sold.

The company aims to minimise textile waste by using as much of the collected deadstock fabric as possible, often combining small pieces to create larger ones. They also operate a zero-waste store and collaborate with other shops to sell their products.

The company’s products are made from a variety of materials, including cotton, polyester, and jersey fabric. They try to stay consistent with their product offerings, but the availability of materials can vary, and the closure of factories in their region has also influenced their material availability. Material traceability is also a challenge.

The company’s business ecosystem includes partnerships with factories, fabric stores, and individuals who donate materials. They are also looking to collaborate with recyclers to handle the waste they generate. The company aims to improve the sustainability of its business by increasing transparency and traceability of fabrics and complying with new regulations.

The company’s case study, presented in the following, focused on how the use of pre-consumer deadstock fabrics can affect a product’s carbon footprint. The results are not expected to be generally applicable, since the primary data used was case-specific and related to a limited production environment. Rather, the knowledge gained from this study is suitable for expanding the corpus of case studies on the reuse of pre-consumer deadstock fabrics in textile production with a focus on climate impacts.

The aim of the study was to calculate potential climate-related impact of a bum bag produced in the company’s workshop in Iași, Romania, using pre-consumer deadstock fabrics made available by local textile factories (cotton and polyester) as main components. Further components (the webbing strap, the side release buckle and the triglide) are primary and ordered by the company from China. Along with the production and transportation of primary materials, processes taking place at the company’s premises (textile washing and ironing, bum bag sewing) were accounted for based on the water and electricity consumption of the devices. To assess potential GHG emission savings due to use of deadstock fabrics, an equivalent product (same mass and materials) composed solely of primary fabrics and components was selected and modelled with generic data.

3.1.2. Main findings

The estimated total carbon footprint of the bum bag amounted to 0.51 kg CO_2e. Figure 5 shows that the primary components used (webbing strap, triglide, side release buckle) are responsible for about 72% of total climate impacts. Among the processes carried out at the company, the pre-treatment of the fabrics (ironing) had a high climate change impact (0.12 kg CO_2e, 23% of total), while the contribution of the washing and sewing processes was negligible due to the lower electricity consumption. Transportation processes were accountable for 10% of the cradle-to-gate emissions, more than half thereof related to the transportation of primary materials from China to Romania.

Juxtaposing the results to a primary benchmark product (a bum bag with the same mass and components produced using only primary materials), the latter shows a three times higher carbon footprint. To better understand the results, it should be noted that deadstock materials are assumed in this study to be burden-free, i.e. the climate impacts related to their production are virtually entirely allocated to their "first life" (in which they remained unused) and left unconsidered in this study. Under these assumptions, the sole use of deadstock components can contribute to a climate impact reduction of up to 90% if compared to a scenario in which only primary materials are used.

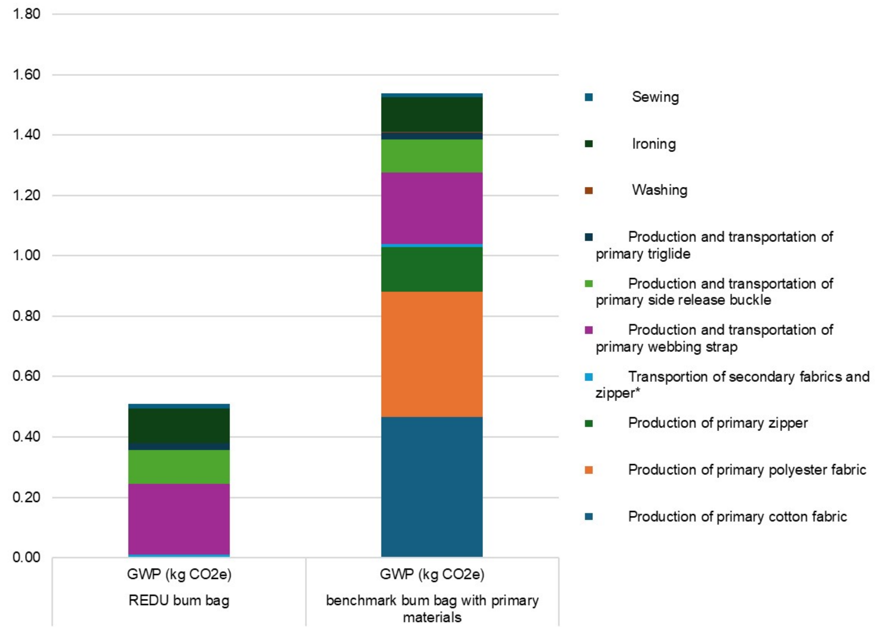

Figure 5. The carbon footprint of the analysed bum bag and the benchmark juxtaposed

The main findings of the study are summarised in Table 3.

Table 3. Summary of the main findings in the textile reuse business model case study

Main findings	**Business model: Textile reuse**
The most burdensome life cycle stages	Production of primary components and ironing (pre-treatment of deadstock material)
Potential trade-offs	In future, the availability of deadstock fabrics could decrease if more companies move towards zero-waste production, and/or if reuse becomes more common.
Impact reduction potential	Re-using unsold products or other unused garments (like cutting waste) improves resource efficiency and saves required primary resources and generated GHG emissions. Using only deadstock material can contribute to reducing emissions by up to 90% in comparison to a similar product made of only primary materials. The potential climate benefit related to deadstock use depends on the assumed share of the deadstock in the product, and the assumed benchmark and related GHG impacts. Required pre-treatment of the deadstock material, e.g. ironing generates some impacts. Switching to low carbon energy and/or using energy-efficient machinery during the pre-processing and manufacturing steps may further reduce the carbon footprint of the products based on re-used fabrics.

3.1.3. Conclusions

The use of deadstock materials has the potential to reduce a textile product's carbon footprint dramatically. In the scenario displayed in this study, in which deadstock materials are considered burden-free and sourced locally, a carbon footprint reduction by up to 90% with respect to the use of primary components with intercontinental logistics can be assumed. Moreover, the use of secondary materials allows avoiding the waste treatment of (in this case, unused) fabrics, thus leading to an overall reduction of the corporate carbon footprint of the companies that make the fabrics available for reuse.

Besides the sourcing of bum bag components, also improvements in the production phase, which are under the influence of the case company, can be taken into account. These regard the electricity consumption related to the ironing step, which is linked to the ironing duration and the power of the device. The case company can, in this situation, reassess the production procedure and explore alternative machinery. At the same time, it is highly recommendable to keep using electricity from renewable sources, since this has four times lower climate impacts than the nationwide electricity consumption mix, which is mainly composed of fossil sources.

The bum bag product-level study was complemented by the calculation of the climate impacts of a fictive benchmark product consisting of virgin materials only. It is important to note that such benchmarking results are not intended (and shall not be communicated) as a comparative study, since the benchmark product was assessed using predominantly generic secondary datasets.

3.2. Case 2: Clothing rental

3.2.1. Introduction

Case Company 2, Mallaamo (later "the company"), is a Finnish micro company running a local clothing rental service. The company is located in the CRAFT-IT4SD pilot site in Northern Finland, in the Ostrobothnia region. It was founded to address the need for sustainable fashion and to reduce the consumption of single-use clothing. The business model focuses on renting out high-quality national brands, with a significant portion of their inventory being garments designed or made in the national context.

The company has a service point in the city of Oulu where it offers a variety of clothing items, from everyday wear to evening gowns, catering to both regular members and one-time renters for special occasions. The service allows members to exchange their rented clothes weekly, and there is also an option for annual memberships.

The company emphasises sustainability by encouraging the use of durable national brands and providing repair services to extend the life of the garments. The company has decided to avoid using an online store to minimise the environmental impact of shipping.

The case study, presented in this deliverable, analysed how garment renting affects potential climate impacts in two different cases. The study was carried out with a combination of case-specific data and a literature review. The case study analysed how garment renting may affect potential climate impacts related to clothes during their use phase. Potential impacts related to renting a silk dress and a wool cardigan were evaluated, focusing on different use scenarios. These garments were selected since they were among the most popular and durable garments in the store.

Since the main interest was in the use phase (clothing rental-related activities by the consumer), this case study did not include actual carbon footprint modelling. The results are not expected to be generally applicable, since the data used was case and location-specific, and the study was based on certain assumptions and limitations. Rather, the knowledge gained from this study can be used to provide more understanding of the potential of clothing rental service business models' climate impacts and how to reduce them in future. Potential impacts of rental clothes in comparison to retail clothes purchased by one consumer were considered based on alternative use scenarios, constructed based on secondary data.

3.2.2. Main findings

The largest share of environmental impacts for both dresses and cardigans comes from manufacturing, as shown in Figure 6 and Figure 7. Rental transportation impacts are also significant if the garment is picked up and returned solely for that purpose. Combining errands or bypassing the rental store was estimated to reduce transportation emissions to zero. Washing impacts were minimal, with delicate wash and dry-cleaning having little effect on the estimated greenhouse gas emissions.

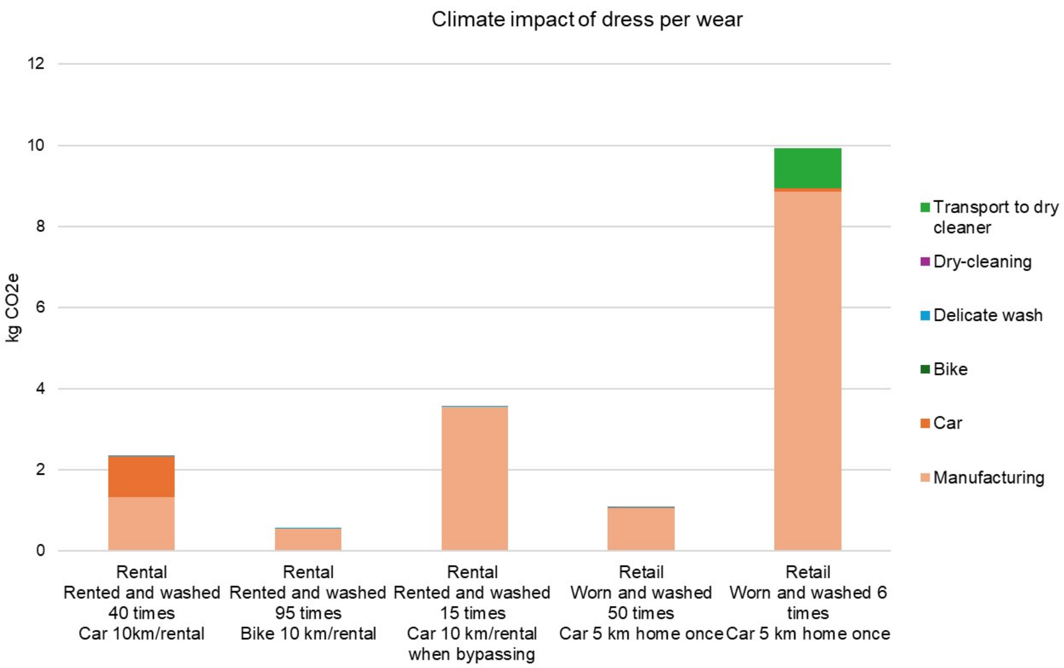

Figure 6. Climate impact of the rental scenarios, silk dress' impact calculated per wear

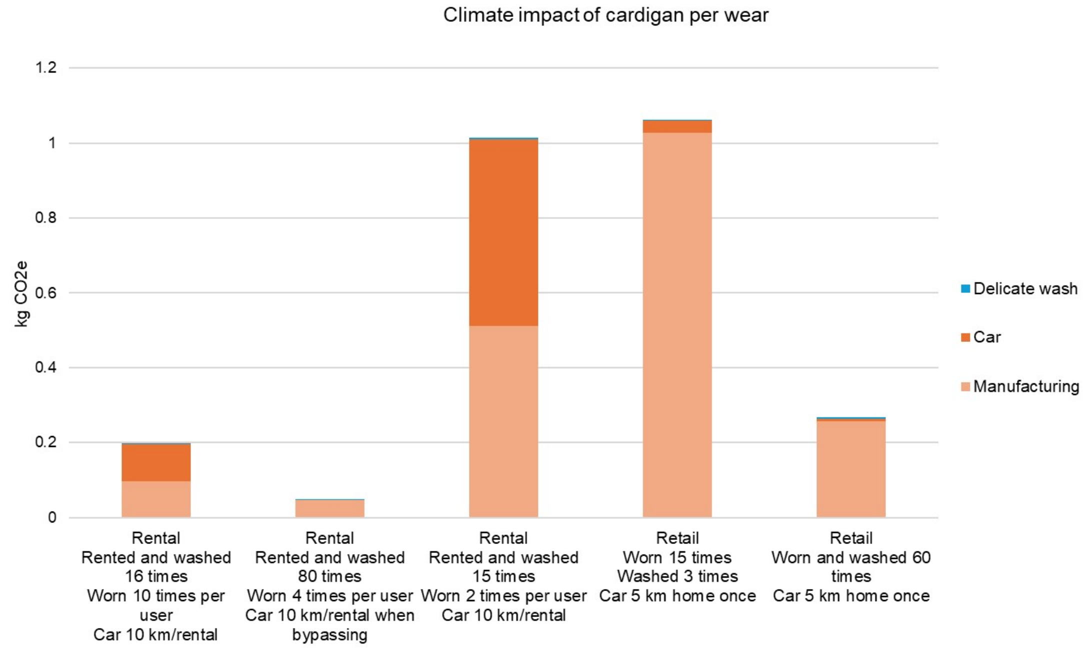

Figure 7. Climate impact of the rental scenarios, cardigan's impact calculated per wear

The estimated climate impact for the studied life cycle phases (manufacturing + use) of the silk dress in rental scenarios varied between 53 - 93 kg CO_2e per dress. For the dress assumed to be purchased from retail, the estimated climate impact varied from 54 to 60 kg CO_2e per dress. The impacts per wear varied in rental dress scenarios from 0,6 to 3,5 kg CO_2e/wear, and in retail scenarios, from 1.1 to 9.9 kg CO_2e/wear.

The estimated climate impact of the studied cardigan life cycle (manufacturing + use) varied between 16 - 31 kg CO_2e/cardigan in the rental scenarios, and between 15.9 – 16.1 kg CO_2e/cardigan when assuming purchase from retail. The estimated climate impacts per wear were for rental cardigan were between 0.05 – 1.02 kg CO_2e/wear, and for retail cardigan, 0.3- 1.1 kg CO_2e/wear. For both the dress and the cardigan, the total life cycle impacts per garment can be higher in the rental scenarios due to increased washing and transport due to a higher number of uses, but the estimated impacts per wear were lower in the rental scenarios.

Rental options can sometimes be, however, less favourable due to increased transportation and continuous dry-cleaning. In this Finnish case study, transportation and washing emissions were minor, with manufacturing causing the biggest climate impact. If manufacturing emissions of garments are lower, the number of times the garment needs to be worn is lower for the emissions per wear to be similar. For example, a silk dress that causes 50 kg of CO_2e during the manufacturing phase needs to be worn more often, compared to a cardigan with a carbon footprint of 17 kg CO_2e, to have the same emissions per wear.

Generally, well-liked rental garments with many users have rather low GHG emissions per wear. Garments should be durable and popular to ensure frequent rentals. If rental services are added to traditional purchasing habits, their ability to decrease overall consumption is lower. On the other hand, if the use of rental clothing avoids even one purchase per year, it can already affect the total climate impact and resource consumption per consumer. Especially, if rental garments are those with a higher carbon footprint from the manufacturing stage. If rental garments are not frequently used or lack durability, their assumed climate impact per wear increases.

The main findings of the study are summarised in Table 4.

Table 4. Summary of the main findings in the clothing rental business model case study

Main findings	Business model: Clothing rental
The most burdensome life cycle stages	Manufacturing of the garment and passenger car transportation, when rental pick-ups are carried separately from other trips.
Potential trade-offs	The use scenarios for retail clothes might differ, and the life cycle could be extended with second-hand sales, for example. Potential trade-offs and/or rebound effects may occur if rental comes on top of conventional purchases, it does not reduce current levels of consumption. Moreover, if rental clothes are not in frequent use or are not durable enough, their assumed impact per wear increases.
Impact reduction potential	Significant potential if more people chose rental over retail, once or twice per year. Renting can reduce the purchase of new garments and increase the number of times rental garments are used over their life cycle compared to other acquisition methods. More evidence from frequent customers reducing their consumption and purchasing fewer new clothes due to use of rental services would be needed to substantiate these impacts.

3.2.3. Conclusions

Rental services have significant potential to decrease climate impacts related to clothes consumption, if it reduces the nr. of purchased clothes, and if the rental clothes are popular and durable. Estimated greenhouse gas emissions per wear were lower for rental garments worn up to their potential, especially if the transportation related to pick-up and return is optimised with other errands.

3.3. Case 3: Tailor-made clothing

3.3.1. Introduction

Case Company 3, Week of Wonder (later "the company"), is a Danish micro company that focuses on sustainable fashion and operates on a made-to-measure business model. The company is located in the CRAFT-IT4SD pilot site in the Central Region of Denmark. The company's approach to fashion is centred around slow fashion and mindful consumption, aiming to create high-quality, long-lasting garments that fit perfectly and meet the individual needs of each customer. This model is rooted in classic menswear and involves creating garments based on precise customer measurements, ensuring minimal overproduction and eliminating excess inventory.

The company offers a range of customisable clothing items, including blazers, trousers, and shirts for women. Customers can book appointments to visit the design studio, where they can choose fabrics and customise their garments to fit their unique measurements. The production process is carried out in collaboration with selected production partners in Europe, who share the same sustainability values.

The made-to-measure model used by the company is based on an IT program that allows for specific measurements to be connected to each design. This system enables the alteration of standard designs to fit the unique measurements of each customer. The materials used are carefully selected, utilising both leftover fabrics and carefully selected primary fabrics, to ensure that the value chain is known and as sustainable as possible. The company operates locally as it requires physical face-to-face appointments for fittings.

The aim was to study the potential climate impact of one blouse manufactured with a tailor-made (also referred to as a made-to-measure) business model. A specific benchmark was not calculated for the blouse, but the carbon footprint of the tailor-made blouse was compared to carbon footprints for different shirt types found in the literature. Additionally, the longevity of a tailor-made garment was discussed as a factor contributing positively to the extension of the life cycle and use intensity of the product.

3.3.2. Main findings

The potential climate impact of a tailor-made blouse sold by the company (cradle-to-showroom) was estimated to amount to approximately 5.1- 6.2 kg CO_2e. The fabric manufacturing, and especially cotton weaving, was the biggest hotspot in the tailor-made clothing's life cycle. The carbon footprint of the tailor-made blouse is presented in Figure 8.

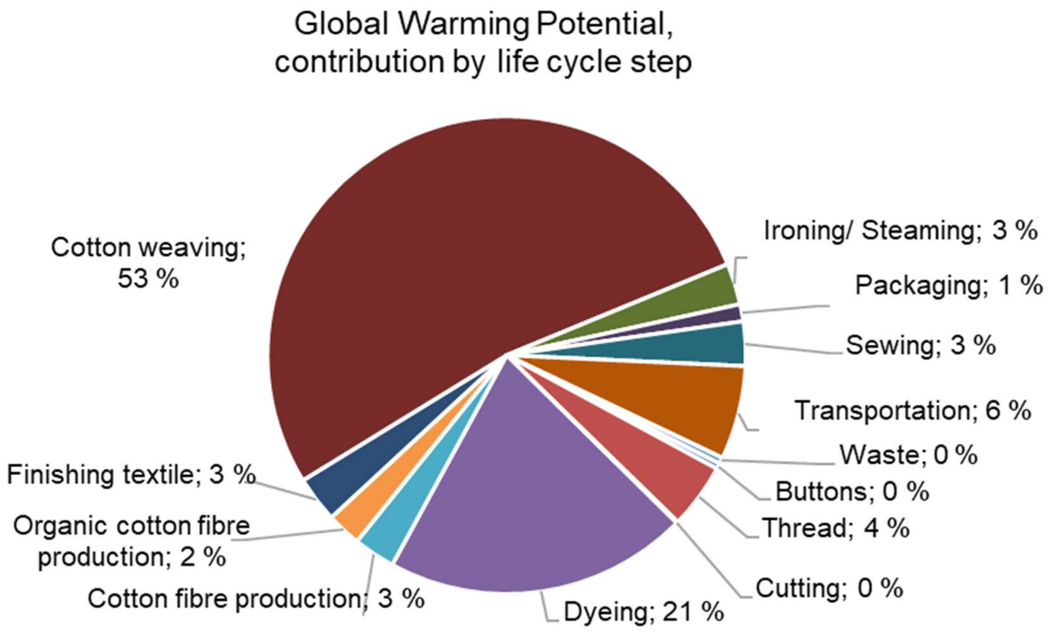

Figure 8. Carbon footprint of the tailor-made case study, contribution of different life cycle stages

When the garment, e.g. blouse, is made to measure, there is a high chance and expectations that the well-fitting form is worn more often compared to non-made-to-measure clothing. Therefore, it could be assumed that a customer purchasing a tailor-made blouse doesn't have to buy so many other blouses to fulfil the same need. It can also be assumed that a fitting, tailor-made blouse will stay in use longer, assuming that the quality is good and the garment is maintained well with an appropriate washing method, etc.

Based on a customer survey conducted by the company and previous literature, the tailor-made blouses are assumed to be used at least as much as average blouses. Based on the collected customer feedback, the blouses might stay in use even twice as long as average blouses. Thus, they have the potential to extend the product life cycle, be used more often than conventional blouses and save their customers from buying new shirts.

The main findings of the study are summarised in Table 5.

Table 5. Summary of the main findings in the tailor-made clothing business model case study

Main findings	**Business model: Tailor-made clothing**
The most burdensome life cycle stages	Manufacturing, especially cotton weaving.
Potential trade-offs	Potential trade-offs and/or rebound effects may occur if a tailor-made garment is not used more frequently or for a longer period than a mass-produced conventional garment, purchasing it may not lead to climate benefits.
Impact reduction potential	Tailoring for special needs has the potential to decrease excessive production of unfitting garments, as tailored clothes might have longer life cycle compared to mass-produced clothes.

Additionally, although not calculated in this case study, producing garments using readily available materials and tailoring them to individual measurements can help eliminate the back-and-forth exchange of materials, production, and collection samples typical of conventional business models before the final product reaches the end-user. These aspects, although not considered in the calculations, suggest that tailor-made clothing has the potential to reduce emissions and textile waste by minimising the need to send production samples.

3.3.3. Conclusions

The fabric manufacturing, and especially cotton weaving, was studied to be the biggest factor in the tailor-made clothing's life cycle. The accuracy of the results could be improved by using primary data for the raw material sourcing and fabric manufacturing phases, instead of global average data, whereas the cutting and sewing and finishing phases were assessed based on primary data collected from the producer. Based on the collected user experiences, a tailor-made blouse made with high-quality fabric has the potential to stay in use for longer than an average blouse.

3.4. Case 4: Clothing pre-order

3.4.1. Introduction

Case Company 4, TWOTHIRDS (later "the company"), is a Spanish small-medium-sized company[6] that has built its business on a pre-order service. The company is located in the CRAFT-IT4SD pilot site in Northeastern Spain in Catalonia. With its business model, the company primarily aims to tackle the overstock problem in the fashion industry. As defined by Hejlova et al. (2025), overstock refers to surplus inventory that exceeds current demand, which

[6] EURATEX (2024) defines small companies as consisting of 10 to 49 employees and medium companies as consisting of 50 to 249 employees.

typically results from overproduction or inaccurate demand forecasting, leading to excess products that need to be sold off, often at discounted prices.

The company initially sold their products in a brick-and-mortar store but later began running an online pre-order service to reduce waste and overproduction. The company focuses on sustainability, using local suppliers, sometimes turning deadstock materials into limited-edition collections. As explained in Chapter 3.1, deadstock refers to unsold inventory that remains unused and is often left over from previous seasons or cancelled orders, and it can include both fabric and finished garments that were never sold (Hejlova et al., 2025).

The company offers both women's and men’s wear, including items such as t-shirts, blouses, shirts, sweaters, dresses, jackets and pants. They produce all their clothing in close locations in Europe, and source many of their fabrics and yarns from Europe. The company’s customers are in several European countries.

The company has been working on improving product quality, eco-design, durability, longevity, and recyclability of its products. This has included working on obtaining sustainability certifications and providing more detailed certifications and sustainability data for their product. They have also been considering implementing a take-back system and repair platform.

The aim of the study was to investigate the potential climate impact of a pre-ordered pair of jeans (including packaging) delivered directly to the customer’s home without retail involvement.

The jeans assessed in this case study were made of organic cotton. Fabric production (weaving and dyeing) and jeans finishing took place in Portugal, while additional components (a zipper and a brass button) were imported from outside of Europe. The product was distributed worldwide in different countries, and in accordance with the company’s no-waste policy, it was assumed that returned items would be sent to up to three successive clients.

To assess the potential effects of the pre-order business model on climate, the difference in greenhouse gas emissions between a pre-order model that avoids over-production and a conventional business model was considered. The benchmark model was based on data published by Duhoux et al. (2024), according to which 21 out of 100 produced textile products remain unsold because they do not meet a real demand. In addition, differently than in the case of the company, the benchmark product was delivered to one client only and then destroyed. In this way, for each delivered pair of jeans, in the benchmark case, more items need to be produced than with a pre-order business model.

It should be noted that the model accounted for the waste originating during the production process, but did not include the use and end-of-life phase of the jeans. The use phase, mainly consisting of washing and drying, was expected to have a high impact on the overall carbon footprint of jeans, but did not depend on the business model and was therefore not considered here. On the other hand, for most clothes the biggest climate impact originates from the manufacturing phase, as also indicated in the case study presented in Chapter 3.1.

3.4.2. Main findings

The potential climate impact of a pair of jeans sold by the company (cradle-to-client's doorstep) was estimated to amount to approximately 5.4 kg CO_2e. Within the production process, 81% of the emissions were related to raw materials extraction, production processes and production-related waste. Avoiding overproduction through a pre-order model led to an estimated carbon footprint reduction of 20%. These results are shown in Figure 9.

The delivery of returned items (up to twice, for a total of max. 3 deliveries per pair of jeans) contributed to only 2% of the total carbon footprint of a pair of jeans. Avoiding waste did therefore not drive consistent additional emissions.

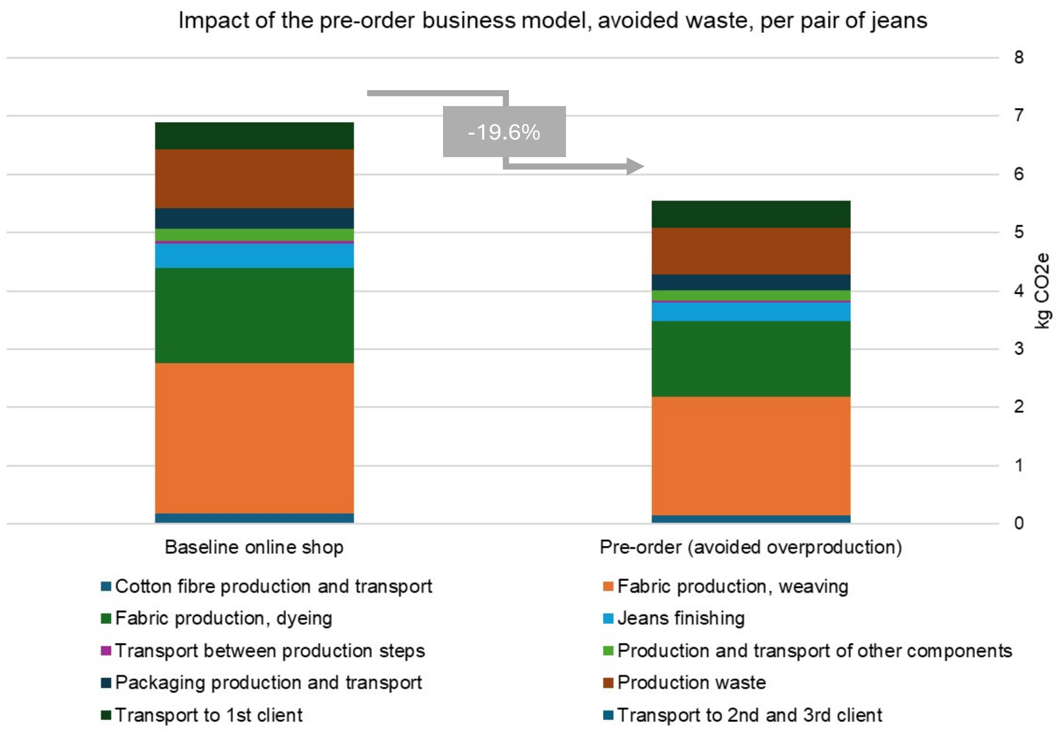

Figure 9. Estimated climate impact of the pre-order business model

The main findings of the study are summarised in Table 6.

Table 6. Summary of the main findings in the clothing pre-order business model case study

Main findings	Business model: Clothing pre-order
The most burdensome life cycle stages	Fabric production (weaving, dyeing) and treatment of production waste.
Potential trade-offs	The potential trade-offs and/or rebounds of the company's no-waste policy through transportation to the second and third clients were tested, but the contribution of delivery to the total climate impact proved insignificant.
Impact reduction potential	Climate impacts can be reduced by approximately 20% due to avoided overproduction through pre-order.

3.4.3. Conclusions

The main contributors to the estimated cradle-to-client's doorstep carbon footprint of a pair of jeans were the production steps. Detailed data from the involved companies can provide a more accurate estimate of their magnitude and useful information to derive mitigation strategies.

Overproduction, which according to macroeconomic estimates amounts to 21% in the textile industry, can be addressed by establishing a pre-order system and reselling returned items. The additional transport emissions emerging from reselling amount to less than 10% of the climate impacts avoided through the pre-order model and do not constitute a significant trade-off. At the same time, it should be noted that transport emissions are strongly dependent on the driving distance. From a climate perspective, the development of a national or continental market is preferable to an expansion overseas.

3.5. Literature review: Take-back

3.5.1. Introduction

A literature review was performed for a business model in which a garment is resold by the brand that manufactured the garment or commissioned the manufacturing of the garment to its supply chain partners. This business model is hereafter referred to as the take-back business model. This take-back business model was selected among other take-back business models because it enables the take-back service offering company to have the most control over the supply chain activities and related data.

The literature review aimed to answer three research questions:

1. What is the potential climate impact of the take-back business model compared to the business-as-usual model?
2. What are the potential climate hotspots of the take-back business model?

3. What are the uncertainties and data gaps which should be considered when evaluating the potential climate impacts of the take-back business model?

3.5.2. Main findings

The reviewed literature included 11 scientific articles. None of the included articles examined the take-back model, where consumers return garments to the same brand. Therefore, this literature review does not directly answer the research questions. However, the articles do study garment reuse and resale through second-hand scenarios, offering initial insights into the potential climate impact of the take-back business model.

The main observation of the literature review is that second-hand sales scenarios do not always have a smaller climate impact than business-as-usual scenarios where the garment is used by one user. Namely, the range of potential climate impact of the take-back business model compared to the benchmark varied from being 98% higher to being 98% smaller, when the sensitivity of the assumptions is included. The results depended heavily on the applied LCA modelling assumptions.

Also, the most burdensome life cycle stages of the studied business model vary depending on the LCA modelling assumptions. For example, the raw material acquisition and garment production covered ca. 90% of the climate impact of jeans in the study of (Levänen et al., 2021) about different textile ownership scenarios. Another example is the study by Mora-Sojo et al. (2023) where user mobility was almost completely responsible for the climate impact of physical retail and e-commerce, second-hand processes. In the studied articles, the uncertainties were related to modelling parameters, LCA scope and behavioural changes which are needed for adopting circular practices. The findings indicate that various aspects, especially the use phase, replacement of new clothing and burden allocation, should be carefully considered in the climate impact assessment of take-back business models.

The main findings of the study are summarised in Table 7.

Table 7. Summary of the main findings in the take-back business model literature review

Main findings	Business model: Take-back (studied by reviewing second-hand business models)
The most burdensome life cycle stages	Depends heavily on the LCA modelling assumptions: the range of climate impact of the take-back business model compared to the benchmark varied from being 98 % higher to being 98% smaller. The following stages were identified as hotspots in the reviewed literature: raw material acquisition and production, use stage, consumer mobility and production of unreplaced products.
Potential trade-offs	Varied between the reviewed studies. Potential trade-offs and/or rebound effects may occur if the take-back service does not substitute for manufacturing (and purchasing) new garments, or comes on top of existing production and consumption.
Impact reduction potential	However, generally, the potential climate benefits of the take-back business model could likely be realised if customers use second-hand items more frequently than the average second-hand user and if second-hand garments from preferred brands significantly replace the purchase of new ones.

3.5.3. Conclusions

It is recommended to use real user data for the use stage modelling decisions regarding the actual use of the garment, and whether the take-back service substitutes for producing and purchasing new garments. In this type of survey, the potential climate benefits of the take-back business model could be realised if customers use second-hand items more frequently than the average second-hand user and if second-hand garments from preferred brands significantly replace the purchase of new garments.

4. FUTURE-ORIENTED CLIMATE SCENARIOS FOR BUILDING SUSTAINABLE BUSINESS MODELS

This chapter presents future-oriented climate scenarios for building sustainable business models. The chapter builds on the climate impact assessment case studies and literature review findings that were presented in Chapter 3.

As outlined in Chapter 1.1, the European fashion industry is primarily composed of micro and small enterprises. According to EURATEX (2024), micro companies – defined as companies with 0 to 9 employees – number around 197 000 and account for 89% of the sector. Based on the same source, small companies, employing 10 to 49 people, make up approximately 9% (17 730 companies). Medium-sized companies (3 940) represent 2%, while large enterprises (591) constitute just 0.3% of the total (EURATEX, 2024).

While micro and small enterprises may not have the leverage to transform large-scale industrial practices, they play a vital role in the European textile industry. These businesses not only provide employment but also have the potential to influence consumption patterns and promote Europe's creative culture and heritage. According to the European Environment Agency (EEA, 2025), only 30% of the greenhouse gas emissions associated with European textile consumption occur within Europe, with the remaining 70% generated abroad, primarily in countries where production is outsourced. However, if European micro and small enterprises champion sufficiency-based consumption models, they could act as examples and help reduce the demand for new textile production, thereby lowering overall climate impacts. For instance, extending the lifespan of garments and minimising textile waste through reuse and repair could significantly cut greenhouse gas emissions.

The following section discusses the assessed business models and products in terms of their potential to support the climate transition, framed through future-oriented climate scenarios. The assessed business models included the following: textile reuse and re-design (Case Company 1); clothing rental (Case Company 2); tailor-made clothing (Case Company 3); and clothing pre-order (Case Company 4). In addition to the business model case studies, the climate impacts of take-back business models were examined through a literature review, which informed the development of climate scenario considerations for the take-back model.

4.1. Textile reuse

This chapter explores climate scenarios associated with the textile reuse and redesign business model. It examines the model's potential to contribute to climate transition goals by extending material lifespans, reducing demand for new production, and minimising waste.

The climate impact reduction potential of the use of deadstock materials looks promising. It can reduce the climate impacts originating from overproduction and the destruction of unsold textiles. At the same time, it should be noted that this business model is based on the existence of overproduction in the textile sector, i.e. on an inefficient production practice. Therefore, reuse models can be seen as powerful tools to make the best out of the existing inefficiencies and as a transition instrument for the mid-term future on the way to a reduction of mass textile production to durability-oriented consumption schemes.

However, it is also important to consider the potential trade-offs and rebound effects of these models that can arise if these kinds of models are scaled up. As long as deadstock textiles are received as donations and not paid for by companies, their use does not set incentives for overproduction.

Moreover, the reuse model considers the EU waste hierarchy and leverages the reuse possibility, which is the highest step of the waste hierarchy model that can be addressed by a value chain stakeholder in the company's position. This process transforms waste materials into valuable products, generating positive employment opportunities and beneficial supply chain effects. These outcomes, in turn, support the zero-burden assumption made for this case study.

Further, besides the climate impact reduction brought about by deadstock reuse in comparison to the sole use of virgin materials, a reuse business model positively affects also sustainability aspects relevant to textile production, such as water consumption, fertilizers and pesticides use for cotton production, water pollution and the safety of workers and affected communities at the first stages of the product value chain, because it is likely to reduce textile production in general. On the other hand, reduced textile production may, in turn, result in a decrease in textile production employment along the same value chain stages, unless those are substituted with green job alternatives.

Last but not least, this kind of business model does not require access to large-scale investment and seems fit for small actors like innovative micro companies. By utilising and creating value from and with materials others don't need, small actors can often combine the ability to restore various traditional handicraft skills at the local level, enhance local community and belongingness, and consumer awareness and participating, extending also beyond the local area of the business when additional distribution and communication channels are used.

4.2. Clothing rental

This chapter explores climate scenarios associated with the clothing rental business model. It examines the model's potential to contribute to climate transition goals by reducing the need to buy and own clothing items.

Manufacturing was found to have the biggest impact on the garment's life cycle impacts, and when the impacts were studied per instance of use. There is some risk to trade-offs, if high-emission transportations are used in the rental pick-up and return, but by optimising the drives with other errands decreased this problem. Washing, at least in the Finnish context, did not cause a noticeable climate impact in the results, neither for total life cycle nor per wear. This was partly due to the assumed washing temperature (30 degrees) for both silk and wool.

According to the rental company's perspective, many customers with rental memberships have stopped buying clothes for their own, except for some everyday basic clothing. Based on a survey from Swedish rental case, customers responded to rentals replacing ownership by 70%, meaning that 70% won't purchase a dress when they rent. Sustainability may not be the main driver for customers, but the rental services have great potential to decrease environmental impacts when the manufacturing of new garments can be reduced. When designed well, economical and accessible rental services have great potential to decrease the environmental impacts of the textile sector, especially for selected groups of consumers. Such changes in consumption habits could lead to resource savings in textiles. Considering that in 2020, the average textile consumption-related carbon footprint per European inhabitant was 270 kg CO_2 per year, of which 50% (135 kg CO_2) was related to clothes (EEA, 2022), a 50% reduction in clothing-related GHG emissions per inhabitant could be achieved if consumers switched to renting instead of purchasing in specific clothing categories, such as those studied in this report. While it is likely that not all manufacturing of new garments can be replaced with rental services, rental has great potential to replace at least some part of new garment purchases.

4.3. Tailor-made clothing

This chapter explores climate scenarios related to the tailor-made (also referred to as made-to-measure) business model. It examines the model's potential to support climate transition goals by reducing the need for purchasing multiple ill-fitting, low-quality garments that are more likely to be discarded sooner than a tailor-made product. Instead, the model promotes investment in well-fitting, timeless, high-quality clothing. Additionally, the model can help eliminate the back-and-forth exchange of production and collection samples before the final product reaches the end-user, further reducing emissions and textile waste.

The business model of a tailor-made clothing (a made-to-measure blouse) could be compared, for example, to a mass-produced blouse manufactured based on traditional size charts. In the case of mass production, some of the burden comes from manufacturing an excessive amount of garments that are not bought or used by customers. The traditional fashion industry encourages excessive and seasonal buying, and maintains overconsumption, while tailor-made clothing business models are quite contradictory to traditional fashion and don't support buying too much.

The overproduction can be avoided when each garment is made for a specific customer. When a customer feels the need for some type of clothing and purchases it through a tailor-made clothing company, where clothing is fitted for the customer, that is often a planned appointment and not an impulse purchase. Instead, this consumption decision embodies conscious, responsible, and mindful practices. These are forms of sufficiency-based consumption that promote reducing and rethinking consumption habits.

If garments made to personalised measurements were to replace normal retail clothing, it could be assumed that the lifespan could increase. At best, the total amount of garments produced and purchased could be reduced due to lifetime expansion. GHG emissions generated from unsold textiles vary between 660

000-12 540 000 tonnes CO_2e, depending on the assumed carbon footprint generated per kg of textile, and 4-9% of all manufactured, unsold textiles are destroyed (Duhoux, 2024). If mainstreaming tailor-made, made-to-order type of business models could decrease the number of unsold textiles by 5%, potential GHG savings could be significant (up to 650,000 tonnes CO_2e).

4.4. Clothing pre-order

This chapter explores climate scenarios associated with the clothing pre-order business model. It examines the model's potential to contribute to climate transition goals by reducing excess production and minimising waste.

The business model based on pre-order and waste avoidance shares similarities with the reuse business model case study, presented in Chapter 3.1, which focuses on the reuse of deadstock textiles due to overproduction. When compared to the reuse model, the pre-order model can be considered more advantageous from a circularity perspective, as it leads to waste and over-production avoidance from the very beginning. From this perspective, this approach is viable for the long term, not just for a transition phase, and does not incentivise production waste.

An additional element that highlights the promising nature of this model is the fact that it is enabled by e-commerce, including order and direct delivery, which is increasingly popular. However, it should be noted that the climate or other environmental impacts of digital solutions are not estimated in this study, although energy consumption through servers and clients using the purchase takes place. On the other hand, many traditional retailers also run web stores, and therefore, the impacts of e-commerce solutions are likely to be quite similar to both the pre-order business model and the traditional retail model with a web store. Some studies also indicate that in some instances, e-commerce might be more carbon efficient than buying at the shop (Beziat & François, 2024).

4.5. Take-back

The take-back model was studied based on a literature review. The literature reviews covered both take-back and second-hand business models as explained in Chapter 3.5.

The main observation of the literature review was that take-back models and second-hand sales scenarios do not always have a smaller climate impact than business-as-usual scenarios where the garment is used by one user. Namely, The climate impact of the take-back business model, when compared to the benchmark, ranged from 98% higher to 98% lower. Key stages identified as hotspots in the reviewed literature include raw material acquisition and production, the use stage, consumer mobility, and the production of unreplaced products. These hotspots indicate that, under certain circumstances, the take-back models can have the potential to reduce climate impacts.

To better understand the potential climate benefits of take-back and second-hand models, the following aspects would need to be assessed on a case-by-case basis to determine the climate benefits of the take-back or second-hand model:

1) usage rate of the second-hand garments and 2) whether the purchase of the second-hand garment substitutes purchasing new garments. The potential climate benefits of the take-back business model could be realised if customers use second-hand items more frequently than the average second-hand user and if second-hand garments significantly replace the purchase of new garments.

5. TOPIC AREAS HIGHLIGHTED IN D5.1 AS INPUTS FOR CLIMATE IMPACT ASSESSMENT IN D5.2

In the first deliverable of WP5, D5.1 “Mapping and descriptions of current business models in selected pilot sites”, five key topic areas were identified as relevant for climate impact assessment and future-oriented climate scenario building in TASK 5.2. Table 8 summarises how these topic areas have been addressed in the present deliverable.

Table 8. Topic areas from D5.1 informing climate impact assessment in D5.2

Topic area	Description	Coverage in D5.2
1(5): Selection of comparative cases	The type of business model that would be replaced by the new sufficiency-based business model and the relevant model for comparing potential climate benefits need to be analysed carefully.	The studied sufficiency-based business models were chosen to provide examples of sufficiency-based fashion businesses in the four CRAFT-IT4SD pilot sites. Particular attention was given to selecting comparative cases for each of the assessed business models. This involved carefully identifying the type of production and consumption that each model could replace. Since the companies representing sufficiency-based fashion business approaches were already implementing sufficiency-based strategies, it was not possible to assess the impacts of a scenario where a company is only considering whether to start implementing a sufficiency-based business model or integrating a sufficiency-based approach into their current, conventional business models. Therefore, the comparative cases were all fictive. Detailed justifications for these selections are provided in the Appendices on a case-by-case basis.

Topic area	Description	Coverage in D5.2
2(5): Potential for consumption reduction	It is important to analyse whether the sufficiency-based model reduces consumption, specifically the consumption of virgin materials.	Particular attention was placed on the potential of the assessed business model to reduce consumption and the use of virgin materials. The first case, textile re-use, focused on deadstock material use and did not address changes in consumer buying frequency or amounts. However, using deadstock material reduces emissions compared to a similar product made entirely of primary materials, thereby reducing the consumption of virgin materials. The second case, clothing rental, can reduce consumption when the model reduces the acquisition of new garments and increases the number of times garments are used over their life cycle. The third case, tailor-made clothing, can reduce the purchases of new garments if the tailor-made garment is used longer than a mass-produced conventional garment, and its acquisition reduces the need to buy several similar garments over the same time. The fourth case, pre-order, focused on the role of the pre-order system in reducing overproduction, indicating that pre-order reduces the need to produce excess new items. The final model, take-back, was addressed based on a literature review. The model can contribute to consumption reduction when it substitutes for buying new garments, and if customers use the second-hand items more frequently than the average second-hand user. The potential of these different business modes is discussed in more detail on a case-by-case basis in Chapter 3.

Topic area	Description	Coverage in D5.2
3(5): Impacts of new digital solutions	The climate impacts of new digital solutions need to be considered if they are used in sufficiency-based business models.	None of the assessed business models incorporated new digital solutions that significantly differ from those already used in conventional fashion business models. Where relevant, the case studies highlight that if new digital technologies are to be integrated into these models, their climate impacts should be carefully assessed to avoid unintended adverse effects.
4(5): Balancing operational logistics	Order sizes, rental logistics, take-back model logistics, and online resale logistics all influence climate impacts, profitability, and customer satisfaction. Therefore, achieving a balance between these factors is essential.	The alternatives in operational logistics were addressed in the individual case studies as appropriate. In all the assessed models, the main impacts resulted from the production phase, with upstream (production-related) transportation playing a minor role. The impact of downstream (distribution-related) transportation was also assessed as minor, except in situations where a customer uses a personal car to pick up only one garment without combining other errands within the same trip, as, for example, might happen with clothing rental. The decisions made by companies regarding acceptable production order sizes can, therefore, primarily be based on economic factors and customer waiting preferences. The potential alternatives in operational logistics from climate impact, profitability and customer satisfaction perspectives are addressed on a case-by-case basis, as appropriate, in Chapter 3 and the Appendices.

Topic area	Description	Coverage in D5.2
5(5): Broader sustainability impacts	While CRAFT-IT4D TASK 5.2 focuses on understanding climate impacts, it is also important to address other sustainability impact categories, rebound effects, and trade-offs in some manner. This can be done, for example, in qualitative terms. This approach would ensure that target audiences understand the possibilities of both positive and negative impacts, not just concerning climate, helping to consider and possibly avoid unintended adverse consequences.	The broader sustainability impacts are addressed qualitatively on a case-by-case basis, as appropriate, in Chapters 3, 4 and 6, and the full-length case study reports that can be found in the Appendices. Their coverage in this report is limited as the main focus of the present report is on climate impacts. The broader sustainability impacts have been previously covered, for example, in the EEA report 'Textiles in Europe's circular economy' (EEA, 2019).

The five topic areas and related findings outlined above will inform the final task of WP5, TASK 5.3 “Business Modelling,” which focuses on developing new sustainable business models that support the climate transition in the fashion sector. When building new business models, TASK 5.3 will also revisit the broader sustainability impacts of sufficiency-based business models. Moreover, social and cultural sustainability considerations will be addressed across all other CRAFT-IT4SD work packages, with their insights further contributing to the business model building work carried out in TASK 5.3.

6. CONCLUSIONS

The present deliverable, D5.2, is the second deliverable of CRAFT-IT4SD WP5, “Business models and pathways for sustainable fashion”. It has focused on assessing the potential climate impacts of four sufficiency-based business models that have been adopted by four micro and small-sized companies representing the four CRAFT-IT4SD pilot sites in Denmark, Finland, Romania and Spain. These models were textile reuse, clothing rental, tailor-made clothing and clothing pre-order. In addition, the report has covered the potential climate impacts of take-back business models based on a literature review. While the case companies participating in the research carried out for this deliverable all presented micro and small companies, the findings of this deliverable are also applicable to larger companies.

Sufficiency-based business models, a subset of sustainable business models, represent the highest strategies in the waste hierarchy as defined by the EU Waste Framework Directive (European Commission, 2018), aiming to avoid or reduce unnecessary consumption. As highlighted in the first deliverable of WP5, D5.1 “Mapping and descriptions of current business models in selected pilot sites” (Markkula et al., 2025), while sufficiency-based business models present an alternative for redesigning business practices to achieve global climate targets, a more quantitative assessment of their potential to reduce environmental impact is necessary for a clearer understanding of their effectiveness.

The case study findings reveal several common climate hotspots and emphasise the importance of understanding the underlying assumptions in impact assessments, as well as the specific context of each case study. Overall, the case studies conducted for this deliverable suggest that sufficiency-based business models have the potential to reduce climate impacts.

The first business model case, textile reuse, illustrated the climate benefits of secondary textile use. In the studied case, the use of deadstock textile materials for a bumbag led to a carbon footprint reduction of 67% with respect to an equivalent product made of primary components only.

The results of the second business model case, clothing rental, showed that the climate impacts of a rental silk dress and a wool-polyamide cardigan, when rented out to their maximum rental potential, were lower per wear in use scenarios when compared to garments bought for personal use and used fewer times. However, the climate benefits of rental may be compromised if users rely on car transportation and do not combine their car trips with other errands.

The third business model case, tailor-made clothing, focused on a model providing high-quality and long-lasting garments made for the individual request of a customer. The results, based on a study of a women’s cotton blouse, showed that the fabric production process contributed to 80% of the total carbon footprint. A tailor-made product was assumed to stay in use longer than an average blouse. While this was not included in the calculations, the tailor-made model is assumed to reduce climate impacts by extending the product lifetime. Empiric evidence from the case study (small sample of customers) indicated that after 4 years, their product was still in active use. Thus, there could be potential to double the lifetime of the garment, avoiding the purchase of another blouse per consumer, and saving required primary resources. The studied tailor-made model also eliminated the need to send production and sales samples back and forth, thereby reducing the need to produce these items and create textile waste.

The fourth business model case, clothing pre-order, tackled textile overproduction caused by inaccurate demand forecasting. Overproduction in the textile industry, estimated at 21% according to macroeconomic data, can be mitigated by implementing a pre-order system and reselling returned items. The case study results showed that the pre-order system, based on carbon footprint calculations for organic cotton jeans, reduced climate impacts by about 20% by avoiding overproduction. In the production of the jeans, fabric production processes accounted for nearly 60% of the total carbon footprint, while transportation to three clients contributed about 10%.

In addition to the company case studies, the climate impact of the take-back business model was evaluated in a literature review. Both the take-back model and the second-hand sales business models were addressed in the review. Based on the review, take-back and second-hand sales were found not to always have a smaller climate impact than conventional retail sales when the garments were used by one user. Therefore, when considering offering take-back and second-hand sales services to reduce business model climate impacts, companies need to assess carefully whether their new planned model can provide climate benefits. This could be the case if the take-back service significantly substitutes for buying new garments and if the take-back customers use second-hand items more frequently than the average second-hand users.

Except for take-back business models, which require further empirical research, all the sufficiency-based business models studied in this deliverable demonstrated potential GHG emission savings, based on the company cases examined. When benchmarked against their conventional fashion business alternative, the studied case products were found to have approximately 20-67% lower climate impacts. However, it should be noted that these quantitative estimates heavily depend on the selected benchmark case and assumptions used.

What kind of impact could the wider adoption of sufficiency-based business models then have in terms of climate impacts? According to a briefing by the EEA (2022) on the role of design in Europe's circular economy, in 2020, the production of textile products consumed in the EU resulted in 121 million tonnes of greenhouse gas emissions, equivalent to 270 kg of CO_2e per person. Of these emissions, 50% came from clothing, 30% from household and other textiles, and 20% from footwear. Depending on the source, it has been estimated that approximately from 70% (McKinsey and GFA) to 80% of the total climate change impact of textiles occurs during the production phase (ECOS, 2021; Östlund, 2020). An additional 3% is attributed to distribution and retail, 14% to the use phase (including washing, drying, and ironing), and 3% to the end-of-life phase (covering collection, sorting, recycling, incineration, and disposal) (ECOS, 2021; Östlund, 2020).

In all the studied company cases, the main impacts arise from the product manufacturing phase, which aligns with much of the previous literature. Due to the high share of manufacturing-related emissions, improvements in production practices and energy efficiency, switching to renewable energy where possible, and using lower-impact materials would support reducing the climate impacts. However, the sufficiency-based models also hold potential to reduce the overall levels of consumption, which an increasing body of scientific literature, representing different disciplines, suggests is necessary (Bocken et al., 2022; Bocken & Short, 2016; EEA, 2025; IPCC, 2022; Millward-Hopkins et al., 2023; Peters et al., 2021).

In many previous studies, assessing the impacts of consumption has often been excluded or limited by different assumptions. Similarly, in the case studies reported in this deliverable, assessing the impacts of consumption was estimated based on various assumptions on a case-by-case basis. While modelling consumption practices is highly challenging due to their situational and context-dependent characteristics, general conclusions on the consumption-related climate impact reduction potential of the studied sufficiency-based business models can still be drawn based on the business model case studies conducted for this deliverable.

In 2020, average textile consumption per person amounted to 6.0 kg of clothing, 6.1 kg of household textiles and 2.7 kg of shoes (EEA, 2022), leading to total consumption of 6.6 million tonnes of textile products in Europe. The same source further breaks down the numbers for clothing consumption, suggesting that, on average, the share of clothing could consist, for example, of:

- 0.8 kg of coats, trousers, skirts and dresses
- 2.0 kg of blouses, t-shirts, underpants and pyjamas
- 2.0 kg of pullovers and cardigans
- 1.3 kg of sportswear, baby clothes, handkerchiefs and scarves
- 0.3 kg of workwear
- 0.5 kg of tights, socks and stockings.

It could be estimated that by adopting sufficiency-oriented circular business models, for example, the following resource savings could be achieved per year, using as examples the evaluated case products:

- 1 silk dress rented for parties instead of purchase (0.4 kg),
- 1 long wool cardigan (with 20% polyamide) rented frequently instead of purchasing the item (0.6 kg)
- 1 cotton blouse purchased less due to the prolonged life cycle of the existing, tailor-made blouse (0.3 kg).

Altogether, such changes in consumption habits could lead to resource savings of 1.3 kg of textiles, which would be 21% less compared to the average clothes consumption (6 kg) in 2020 (considering that rental clothes would not increase total consumption). In the assessed case studies, the estimated carbon footprint caused by manufacturing these products would sum up to 71 kg CO_2e (ca. 50 kg CO_2e per silk dress, 16 kg per wool cardigan, 5 kg per cotton blouse (excluding end-of-life, which could increase the total figure approximately by 3%, leading to a total carbon footprint of 73 kg CO_2e). And at the same time, the required transport and washing of the rental clothes is estimated to cause additional emissions of ca. 1 kg CO_2 (when only direct, use phase emissions are considered). Considering that the average textile consumption-related carbon footprint per European inhabitant was 270 kg CO_2 per year, of which 50% (135 kg CO_2) is related to clothes, with these case products, a 50% reduction in generated GHG emissions per inhabitant could be achieved. While all the figures contain high uncertainty (and would vary depending on the specific products in question), this simple exercise highlights the greenhouse gas reduction potential the sufficiency-based models studied (namely rental and tailor-made) could help to achieve, at least in targeted customer segments, for which such services are available and affordable.

The studied pre-order and textile re-use case both target reducing textile waste by reducing the amount of excess production (unsold textiles) and reusing already produced materials. It has been estimated that around 20% of all the textiles put on the market are not sold at their original price, but through different sales and outlets (Duhoux, 2024). Greenhouse gas emissions generated by this number of unsold textiles could vary between 660 000-12 500 000 tonnes CO_2e, depending on the assumed carbon footprint generated per kg of textile (Duhoux, 2024). At the same time, it has been estimated that 4-9% of all manufactured, unsold textiles are destroyed (Duhoux, 2024). The GHG emissions related to the manufacturing of this number of textiles could range between 132 000 – 5 643 000 tonnes CO_2e (Duhoux, 2024). The range included in these GHG estimates is extremely high, indicating high uncertainty. However, if mainstreaming “made-to-order “type of business models could decrease the number of unsold textiles by 5%, potential GHG savings could be significant (up to 650,000 tonnes CO_2e). Similarly, reusing textiles (clothes, household textiles, fabrics) that are currently destroyed could avoid GHG emissions from waste handling and reduce the amount of primary production required. The reduction potential here could be up to 2 800 000 tonnes CO_2e, if 50% of this production could be avoided.

While much of fashion’s climate impacts are related to raw material selection and the subsequent manufacturing phases leading to the distribution of the finished product, more attention should be placed on the longevity of products. Overall, extending the life cycle of fashion products plays a crucial role in reducing the climate impacts of the fashion sector. As the main impacts along the fashion product life cycle typically arise from the manufacturing phase, there is remarkable potential to avoid emissions from textile production if more garments were kept in use to their full potential. Generally, regardless of the business model or fibre type used, extending the life cycle of fashion products plays a crucial role in reducing the climate impacts of the fashion sector.

Furthermore, future developments in the transportation sector, such as the future use of electric vehicles in goods transport, can reduce the climate impacts of those business models where transportations have a significant impact. At the same time, it should be noted that transport emissions are highly dependent on the driving distance, mode of transport and fuel used. From a climate perspective, the development of a national or continental market would be preferable to a global market presence, as this reduces transport-related emissions even further.

Finally, a prolonged use of goods would likely lead to increased climate impacts during the use phase. Despite this, the overall climate impact reductions would unlikely be compromised, due to the high share of manufacturing in the total GHG emissions related to clothing. Furthermore, in addition to reducing climate impacts, the reduced number of newly produced items would have several other positive environmental effects, such as reduced water usage, natural resource consumption, and land use.

While the case companies participating in the research for this deliverable were all micro and small companies, many of the findings apply to other companies in the sector. If technological innovations and energy improvements are insufficient to reduce the climate impacts of the fashion sector, conventional fashion business models need to be redesigned to better align with climate impact reduction targets. This means shifting from the 'sell more new items' mentality to a new value creation logic based on sufficiency-based approaches. These approaches include refusing unnecessary consumption, reusing, sharing, renting, and ultimately recycling, alongside product eco-design principles to reduce climate impacts. Considering recent and upcoming regulations, understanding the climate impacts of current business models and where these models reach their impact reduction potential is vital for improving and developing these models. It is equally essential for financing business models, future-proofing climate-transition aligned businesses, and reducing investment risks.

Whereas micro and small companies, with their limited resources, market presence, and competitive position, cannot change the broader fashion industry nor solve the climate challenge, these smaller companies have an important role in the European fashion ecosystem. These companies provide employment, enforce handicraft skills, and offer consumer sustainable alternatives, contributing to positive economic, social and cultural sustainability impacts. Furthermore, the action taken by these smaller companies towards reducing textile waste and prolonging garment and textile life cycles inevitably leads to other positive environmental sustainability impacts, such as reduced pressure on natural resources, land use changes, water use, and chemical use. In addition, they contribute positively to local employment and maintain craft and design skills and culture, for example, when textiles are reused and redesigned within the local area.

The results of this deliverable are intended to support companies and other fashion sector actors in developing their practices to support the climate transition. In the context of the CRAFT-IT4SD project, the results of D5.2 will support the execution of the final task of WP5, TASK 5.3, “Business modelling”, where new sustainable climate transition supporting business models are created. Additionally, the D5.2 results lend support to pilot site actions in WP4, “Pilot coordination, implementation and monitoring”, and disseminating knowledge on sustainable climate transition-enabling business model and related practices in WP6, “Skills and learning communities across fashion and related CCSI”.

Appendix A: Business model climate impact assessment case studies

1. Case 1: Textile reuse

Case Company 1, REDU (later "the company"), is a Romanian micro company that focuses on sustainable fashion by collecting textile waste from factories and transforming it into new products. The company is located in the CRAFT-IT4SD pilot site in North-East Romania, in the Moldavia region. The company creates items such as clothes, streetwear, and accessories like bags from post-production textile waste. This material is referred to in the case study as deadstock. As defined by Hejlova (2025), deadstock refers to unsold inventory that remains unused and is often left over from previous seasons or cancelled orders, and it can include both fabric and finished garments that were never sold.

The company aims to minimise textile waste by using as much of the collected deadstock fabric as possible, often combining small pieces to create larger ones. They also operate a zero-waste store and collaborate with other shops to sell their products.

The company's products are made from a variety of materials, including cotton, polyester, and jersey fabric. They try to stay consistent with their product offerings, but the availability of materials can vary, and the closure of factories in their region has also influenced their material availability. Material traceability is also a challenge.

The company's business ecosystem includes partnerships with factories, fabric stores, and individuals who donate materials. They are also looking to collaborate with recyclers to handle the waste they generate. The company aims to improve the sustainability of its business by increasing transparency and traceability of fabrics and complying with new regulations.

The company's case study, presented in the following chapters, focused on how the use of pre-consumer deadstock fabrics can affect a product's carbon footprint. The results are not expected to be generally applicable, since the primary data used was case-specific and related to a limited production environment. Rather, the knowledge gained from this study is suitable for expanding the corpus of case studies on the reuse of pre-consumer deadstock fabrics in textile production with a focus on climate impacts.

1.1 Aim and scope of the study

1.1.1 Aim and product system description

The study aimed to calculate the climate-related impact of a bum bag produced in the company's workshop in Iași, Romania, using pre-consumer deadstock fabrics as main components.

The bum bag is composed of cotton and polyester fabrics and a zipper originating from pre-consumer deadstock available in Romanian textile factories. Further components (the webbing strap, the side release buckle and the triglide) are primary and ordered by the company from China. Following the pre-treatment of the textiles (washing and ironing process), all components are assembled via cutting and sewing.

The bum bag product-level study was complemented by the calculation of the climate impacts of a benchmark product consisting of virgin materials only. It is important to note that such benchmarking results are not intended (and shall not be communicated) as a comparative study, since the benchmark product was assessed using predominantly generic secondary datasets.

The results are intended to inform the company's management about the potential climate impacts of their business model based on the analysed product. This knowledge can be used to steer procurement decisions and product design. If the use of the study for consumer communication is envisaged, it is recommended to make sure that the legislative requirements (e.g., national and EU-level consumer protection legislation) are considered.

1.1.2 Scope of the study

The unit of analysis for which the study results are calculated (**functional unit**) was a finalised bum bag, i.e., a small bag that can be worn around the waist by use of a strap and secured above the hips by a buckle. The **reporting flow** was defined as a piece of accessory whose mass is equivalent to 0.1964 kg.

The **system boundary** was cradle-to-gate, since the focus of the study was on the impact of components' choice (partly secondary materials), and the producer's influence on the use and end-of-life phase of the bum bag was limited.

The product modelling was carried out using the Sulca software, version 5.3.4.

The company provided data on the mass and material specification of components used in the production phase and on the machinery used and usage duration during the pre-treatment and manufacturing phases. This data was based on measurements and estimates. The technical specifications of the machinery were a source of energy and water consumption figures in the production phase. Details about assumptions, activity data provided by the company and secondary datasets used are listed in Figure 10, highlighting the processes accounted for in the study.

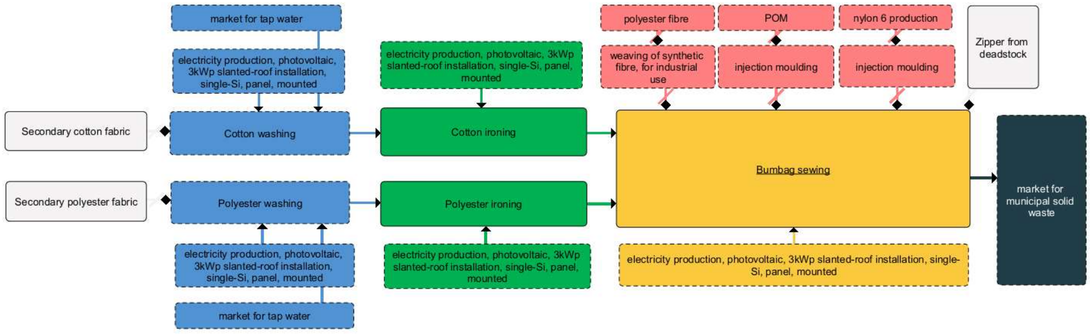

Figure 10. Cradle-to-gate system boundary of the case study

Primary data was also used for modelling transport processes when the component's origin was known. When not, the assumptions recommended in the draft PEFCR for apparel and footwear by Quantis (2021) were used.

Where primary data was not available, inventory data was retrieved from the ecoinvent LCA database, version 3.11. The study aimed at achieving good data representativeness (regional, temporal and technological) for both direct production activities taking place at the company and supply chain data, according to the ILCD data quality pedigree matrix.

A **cut-off** criterion of 1% was established, i.e., if a process was expected to contribute less than 1% to the product's mass or to less than 1% of the energy consumption linked to that product, it was excluded from the study. This led to the **exclusion** of infrastructure processes such as data machinery production for pre-treating and assembling the bum bag components, or the construction, maintenance and refurbishment of the electricity distribution network, which were not included in technology-specific electricity datasets in ecoinvent. The impact assessment method used was EF 3.1, for the GWP category.

When considering material reuse, allocation between different (in this case two) life cycles was needed, i.e., the inputs and outputs related to the primary material production (and to the final product disposal, if included in the study) needed to be assigned to one of the life cycles or sub-divided between them. In this specific case, the environmental impacts related to the production of the deadstock fabrics and the zipper used for the bum bag were allocated to the "first life" of the fabrics, and were consequently considered as burden-free when used in the bum bag (simple cut-off procedure as explained in Ekvall et al. (2020).

1.2 Life Cycle Inventory Analysis

The following **production processes** were included in the study:

- Production of the webbing strap, modelled as the production of polyester fibres, followed by the related weaving process.
- Production of the side release buckle and the triglide, modelled as the production of Plastics Manufacturers Polyoxymethylene (POM) and nylon (pellets), followed by an injection moulding process.
- Fabrics pre-treatment, which included washing and ironing. The electricity and water consumption were modelled based on the company's indication of the machine model and an estimate of the use duration. The energy production technology documented by the electricity provider (photovoltaic) was assumed in the model.
- The assembly process, involving removing excess fabric snippets and assembling all necessary components to produce the final item.
- The electricity use was estimated, and the energy source assumptions followed the same reasoning as the fabrics' pre-treatment process.

The primary and secondary data related to these processes are detailed in Table 9.

Table 9. Primary and secondary data used to model the materials use and production phase

Element	Explanation /assumptions	Value	Unit	Data source/comments
Functional Unit	1 Bumbag		kg	Data delivery REDU
Production waste		20% of fabrics		Estimate by REDU, same figure as PEFCR draft apparel and footwear (Quantis, 2021)
Primary components				
Webbing strap	polyester	0.055	kg	Mass data delivery REDU
	material: polyester fibre			Ecoinvent: polyester fibre production, finished, RoW
	process: weaving of synthetic fibre			Ecoinvent: weaving of synthetic fibre, for industrial use, GLO
Side release buckle	acetal	0.0384	kg	Mass data delivery REDU
	Material: POM (acetal)			Eco-profiles and Environmental Product Declarations of the European (POM) Plastics Europe, February 2014 The previous version of GWP impact assessment method used
	process: injection moulding			Ecoinvent: injection moulding, RoW 1 kg of this process equals 0.994 kg of injection moulded plastics

Element	Explanation /assumptions	Value	Unit	Data source/comments
Triglide	material: nylon	0.021	kg	Mass data delivery REDU
	material dataset: nylon 6			Ecoinvent: nylon 6 production, RoW
	process: injection moulding			Ecoinvent: injection moulding, RoW 1 kg of this process equals 0.994 kg of injection moulded plastics
Secondary components				
Cotton	Losses in manufacturing: garment assembly (cutting, sewing): 20%	0	kg	Data delivery REDU
Polyester	Losses in manufacturing: garment assembly (cutting, sewing): 20%	0.07	kg	Data delivery REDU
Zipper	No losses	0.002	kg	Data delivery REDU
Production process				Machinery and the electricity network infrastructure not accounted for
Washing: water				Ecoinvent: market for tap water, Europe without Switzerland
Cotton		1.098632813	kg	Calculated based on machine technical data
Polyester		0.615234375	kg	Calculated based on machine technical data
Washing, ironing and cutting: electricity				Ecoinvent: electricity production, photovoltaic, 3kWp slanted-roof installation, single-Si, panel, mounted, Romania
Cotton washing		0.015203303	kWh	Calculated based on machine technical data
Polyester washing		0.008513849	kWh	Calculated based on machine technical data
Cotton ironing		0.333333333	kWh	Calculated based on machine technical data
Polyester ironing		0.333333333	kWh	Calculated based on machine technical data
Bumbag sewing		1.5	kWh	Estimated based on common sewing machine power, no model specific technical data available.

The following **transport processes** were included in the study:

- Transport of secondary fabrics from the factory to Iași, modelled using primary activity data provided by the company (7 km distance, road transport via van).
- Transport of secondary zippers from Bucharest to Iași (423 km, road, lorry).
- Transport processes related to the production of primary components:
    - Transport from the preliminary material (polyester fibre, POM, nylon) production site to primary component production (webbing strap, side release buckle, triglide), both assumed to be located in

China. The distance was estimated to be 1,000 km (road, lorry) according to the draft PEFCR for apparel and footwear (Quantis, 2021), transport within the same continent.

- Transport of primary components from the production site (China, precise location unknown) to Iași. The distance was estimated by combining the assumptions recommended by the draft PEFCR (Quantis, 2021) (1000 km from factory to port) and the actual distances along the route:
  between the major ports of the two countries (from Shanghai to Constanţa, 17,537 km, by container ship) and between the port of Constanţa and Iași (421 km, road, lorry).

It should be noted that, if unknown, the assumed means of transport for road transport was a lorry, 16-32 metric tons, diesel. For transport within the EU, heavy-duty vehicles' compliance with the EURO 6 emissions standard was assumed, while for transport outside of the EU, compliance with the EURO 5 emissions standard was assumed.

The only **waste treatment process** occurring within the cradle-to-gate system boundary was the treatment of production waste (after the cut and assembly process), which was modelled as a country-specific technology mix for municipal waste (market dataset). The amount of production waste was estimated by the company as being about 20%. The same figure is recommended as the assumption for waste produced during garment assembly in the draft PEFCR for apparel and footwear (Quantis, 2021).

Throughout the whole study, primary activity data (e.g., mass and material of used components) and technology-specific data (e.g., technical specifications) were used for calculating the main activity variable of the different processes (e.g., electricity consumption for washing). The inputs from and outputs to the ecosphere (e.g., land use, use of mineral resources, air emissions) were retrieved from the ecoinvent 3.11 database.

1.3 Life Cycle Impact Assessment

The total carbon footprint of the bum bag amounted to 0.51 kg CO_2e. The footprint is detailed by component and production step in Figure 11.

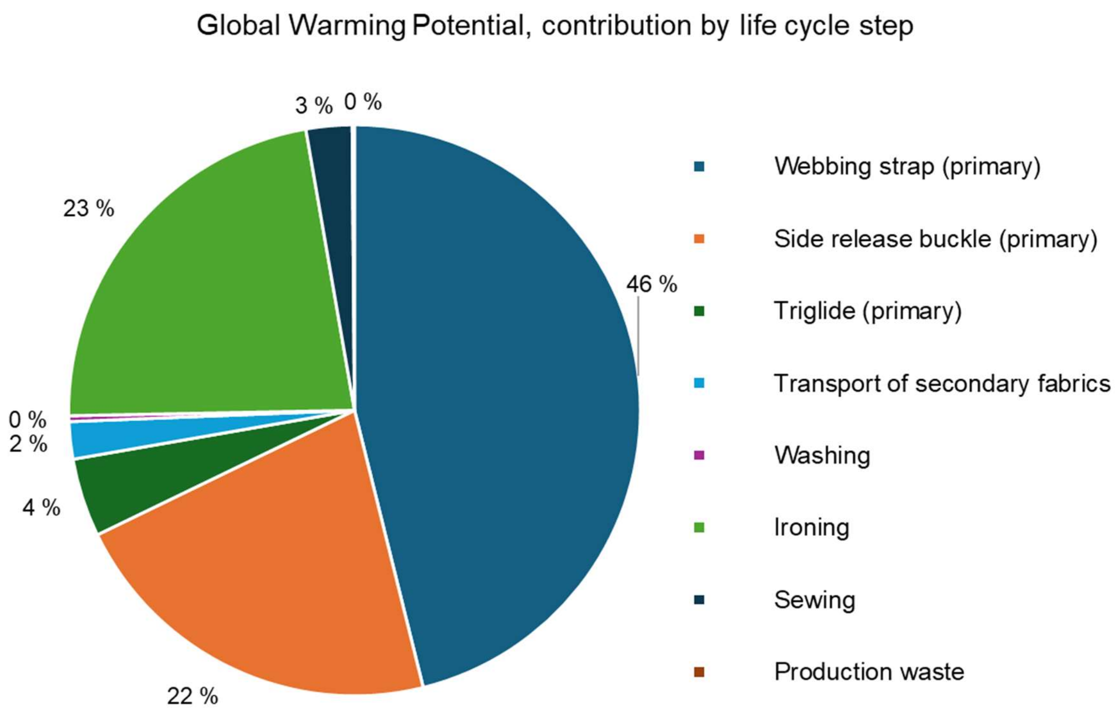

Figure 11. Carbon footprint of the bum bag (cradle-to-gate), by component and production step, according to the EF 3.1 method, impact category Climate change

Among the processes carried out at the company, the pre-treatment of the fabrics (ironing) had a high climate change impact (0.12 kg CO_2e, 23% of total), while the contribution of the washing and sewing processes was negligible due to the lower electricity consumption.

In total, the share of global warming potential linked to the direct electricity consumption at the company amounted to 25%. Its main cause was in the ironing pre-treatment process, which was responsible for a GWP of 0.11 kg CO_2e.

Transportation processes were accountable for 10% of cradle-to-gate emissions, more than half thereof related to the transportation of primary materials from China to Romania, followed by the (assumed) transportation of primary materials to the production site of primary components (polyester fibres to the webbing strap production and POM and nylon 6 to the production of side release buckle and triglide).

Concerning the emission type, 99.7% were of fossil origin, 0.2% were biogenic emissions, and 0.1% were caused by land use and land use change. The main drivers were carbon dioxide and methane air emissions, contributing by 84% and

15% to the total impact, respectively. Carbon dioxide emissions within the bum bag's life cycle mainly originated from the polyester fibre production and the injection moulding processes.

1.4 Discussion

1.4.1 Interpretation of the carbon footprint results

The study results highlight the prevalence of supply chain impacts over direct emissions, and the dominance of primary components production over secondary components transportation.

However, it is important to acknowledge that this study was limited to a cradle-to-gate assessment. While the use phase is not expected to have a significant impact, as it primarily involves washing, which is far less frequent for accessories compared to apparel, the end-of-life phase can be estimated based on the ecoinvent dataset "market for municipal solid waste, Romania" (0.849 kg CO2e/kg). By multiplying this value by the total bum bag mass (0.196 kg), an end-of-life carbon footprint of 0.166 kg CO2e can be estimated. Put another way, the end-of-life phase would be responsible for about 25% of the carbon footprint if a "cradle-to-gate + end-of-life" system boundary were considered.

Besides the choice of the system boundary, methodological decisions did not seem to affect results decisively. As far as transportation processes were concerned, conservative assumptions were followed to estimate distances within the supply chain. In line with the draft PEFCR for apparel and footwear (Quantis, 2021), the default distance for road transportation within the same continent was 1 000 km. Given the linear relationship between driven distance and climate impact (assuming the means of transport remain the same), the transportation-related figures should be considered highly uncertain and most likely overestimated. On the other hand, since transport-related emissions are about 10%, the uncertainty linked to the related assumptions is limited.

Finally, the cut-off decisions (i.e., excluding machinery and infrastructure) were tested by taking the washing machine as an example, as it is the identifiable piece of production equipment with the largest mass. According to the ecoinvent dataset "market for washing machine, global", the carbon footprint arising from the production and distribution of an average washing machine is 390 kg CO_2e. Assuming a lifetime of 10 years (according to ecoinvent dataset documentation), a 220 washing cycles per year and a capacity of 8 kg (according to the technical specifications of the washing machine series in use at the company), and considering the mass of the fabrics washed for 1 bum bag and an 80% usage rate, the washing machine impacts allocatable to one bum bag would amount to 390 kg $CO_2e/(10*220*0.196\ kg/(8\ kg*80\%)) = 0.004$ kg CO_2e, i.e. less than 1% of total emissions.

Regarding the data quality, activity data for direct production activities was primary and had a very good level of technological, temporal and geographical representativeness. A fair to good level of representativeness was also reached by the electricity data for Romania, which was technology and country-specific. On the other hand, secondary data depicting the supply chain had a very poor geographical representativeness (most processes were not region-specific), a fair technological representativeness (due to missing information about the exact production processes involved in the supply chain), and a poor to very poor temporal representativeness (data sets used for the main processes date back to 2007-2018).

All in all, the highest climate impacts were detected for the primary components, which were modelled relying on generic data (low regional and fair technological representativeness) and are therefore subject to high uncertainty. It should be noted that the company has limited influence on the environmental performance of purchased primary components. On the other hand, the company can influence the carbon footprint of their own direct activities. The use of electricity from PV sources, for example, leads to a four times lower carbon footprint compared to the average electricity mix in the same country. Therefore, possibilities for carbon footprint reduction within the company could be found by investigating the necessity and duration of the ironing pre-treatment step.

1.4.2 Benchmark product and impact of the business model

How did the company's business model affect the bum bag's environmental impact? In the following, an estimate based on literature data is provided.

As a simplification, it is assumed that the only difference between the company's bum bag and the benchmark consists in the origin of the zipper and the fabrics (cotton and polyester), which are secondary (and therefore considered burden-free) in the company's bum bag and primary in the benchmark case.

As a source for the carbon footprint of fabrics, a scientific publication displaying the cradle-to-gate emissions of both cotton and polyester fabrics produced in China was chosen (Yan et al., 2016), since data was representative of the world's largest textile producing country, the system boundary of cotton production (cradle-to-fabric) was that needed for the benchmark, and the same assumptions were applied to both fabric types. For the zipper, the indications provided by scientific literature (Zhou et al., 2023) allowed the assumption that, in line with the mentioned publications, the following figures could be used:

- the carbon footprint for dyed fabric in pure cotton, dark color, amounts to 4.47 kg CO_2e/kg
- the carbon footprint of a dyed fabric in polyester cotton, dark color, amounts to 6.04 kg CO_2e/kg
- the carbon footprint of a standard strip zipper is 0.149 kg CO_2e.

Figure 12 illustrates the results of the estimate. The carbon footprint of the benchmark product amounted to 1.54 kg CO_2e and was three times as high as the carbon footprint of the company's bum bag. The main contributors were the production of primary cotton fabric and primary polyester fabric (0.47 kg CO_2e and 0.42 kg CO_2e, respectively), which were responsible together for 57% of the benchmark's total carbon footprint.

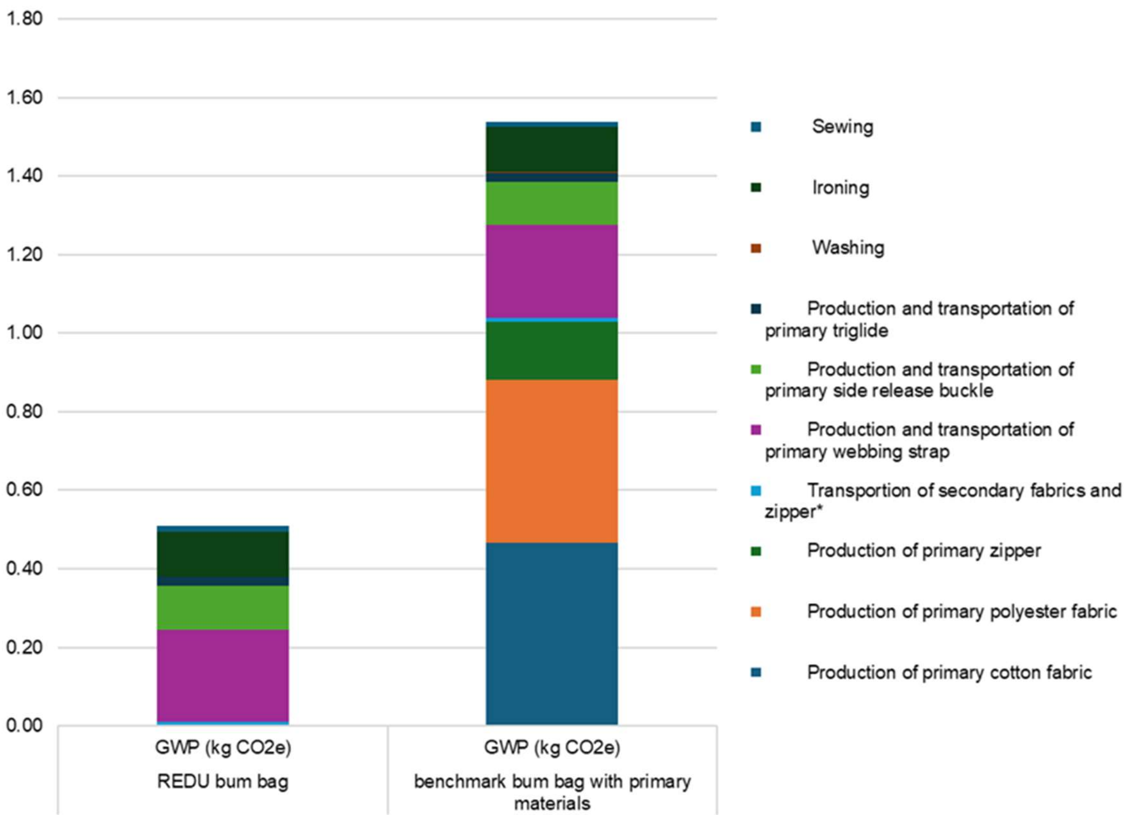

Figure 12. The carbon footprint of the analysed bum bag and the benchmark juxtaposed

It is crucial to note that the benchmarking carried out here was a mere estimate and subject to high uncertainty. The two main uncertainty sources were the carbon footprint of virgin textiles and the location of their production.

Literature sources showed high variations in the carbon footprint of textiles, which was quantified up to three times higher than assumed in the present benchmark case. For example, the carbon footprint of dyed cotton fabric was estimated to be 15.6 kg CO_2e/kg according to Li et al. (2024). With this respect, the results of the present study might underestimate the carbon footprint of the benchmark product and, consequently, the climate-related advantages of the company's bum bag.

The second main source of uncertainty concerns the transport distance for the different components. This was assumed to be the same as for primary and secondary materials, although secondary materials came from Romania, while the primary ones used for benchmarking were most likely coming from Asia. This might have led to a moderate underestimation of the benchmark case's climate impacts.

2. Case 2: Clothing rental

Case Company 2, Mallaamo (later “the company”, is a Finnish micro company running a local clothing rental service. The company is located in the CRAFT-IT4SD pilot site in Northern Finland, in the Ostrobothnia region. It was founded to address the need for sustainable fashion and to reduce the consumption of single-use clothing. The business model focuses on renting out high-quality national brands, with a significant portion of their inventory being garments designed or made in the national context.

The company has a service point in the city of Oulu where it offers a variety of clothing items, from everyday wear to evening gowns, catering to both regular members and one-time renters for special occasions. There is an option for an annual membership service, which allows members to exchange their rented clothes weekly.

The company emphasises sustainability by encouraging the use of durable national brands and providing repair services to extend the life of the garments. The company has decided to avoid using an online store to minimise the environmental impact of shipping.

The case study, presented in this deliverable, analysed how garment renting affects the climate impacts in two different cases. The study was carried out with case-specific data and a literature review. While the case study addresses climate impacts, it does not include a standardised carbon footprint calculation. The results are not expected to be generally applicable, since the data used was case and location-specific, and the study was based on certain assumptions and limitations. Rather, the knowledge gained from this study can be used to provide more understanding of the potential of clothing rental service business models’ climate impacts and how they can offer consumers a more sustainable way of consuming.

2.1 Aim and scope of the study

2.1.1 Aim and product system description

The aim of this study was to examine the climate-related impact of rental clothing that is offered to consumers. Two garments were studied, a formal dress and a casual cardigan. Both of these items were seen by the company as the most rented garments in their category. The dress represents more formal wear rented for parties, and the cardigan is rented for everyday use.

Formal dresses have a significant role in the fashion world, and their use is often limited or infrequent (Monticelli & Costamagna, 2023). Formal dresses for women are also the most analysed garment types in different LCA studies (Amasawa et al., 2023; Johnson & Plepys, 2021; Monticelli & Costamagna, 2023; Zamani et al., 2017). The studied formal dress is made of 100% silk (from an unknown origin), loose fit with medium-length sleeves.

According to the company, the cardigan is in a rental cycle almost all the time, leaving with a new customer every time it is returned to the rental company. The maximum rental time is three weeks, and the cardigan is assumed to be used many times during one rental. The studied cardigan was made for everyday wear with warm and durable knit made from 80% wool and 20% polyamide. The fit was open and long, almost reaching the knees. The studied cardigan was manufactured in Portugal, but the origin of the virgin materials was unknown. Rented garments are washed by the customer before returning to the company, and the company has a steamer for customers to use before leaving the garment.

Both garments' environmental impact during rental was estimated with a few factors on the garment's life cycle. The production of the garment and its raw materials, the number of uses, washing, transportation (+ packaging) play a key role, and the overall choices in the life cycle influence the total climate impact of the garment.

The climate impacts of the rental garment's life cycle stages were studied with a literature review and primary data from the company. Based on this data, different garment rental scenarios were built to compare different types of life cycle choices, especially in the use stage. The focus was to find the life cycle stages or decisions in the life cycle of a garment, with the biggest influence on the garment's carbon footprint, also called `hotspots`. The scenarios were compared to purchasing garments from normal retail, which often leads to the garment being worn by one owner and worn fewer times over its life cycle. With varying times of how many times the garment is worn, how it is washed, how it is transported, etc., we can see what the climate hotspots are in the rental clothing's life cycle.

The results are intended to inform the company and other users of this report about the company's business model on the climate impact of their products. Even if the study focuses on only two garments, it gives insights into the hotspots of the rental garment's lifecycle. Gained knowledge can be used to steer the procurement decisions and help guide consumers to make more sustainable consumption choices.

2.1.2 Scope of the study

The analysed products were a silk dress and an everyday-wear cardigan, both purchased by the company for rental use.

The focus of the study was to find the factors affecting the most the estimated climate impact of rental clothing, and the importance of choices made in the use stage. Only washing of garments was included, with steaming of the clean garments excluded. The disposal of garments was excluded from the study because the end of life for both rental and retail garments is assumed to be similar. Different rental and retail scenarios were carried out in Excel, looking at the potential climate impact of different choices in life cycle stages.

The following **life cycle stages**, shown in Figure 13, were included in the study and explained further:

- Fabric manufacturing
- Garment manufacturing, sewing
- Transportation
- Use stage, including e.g. washing

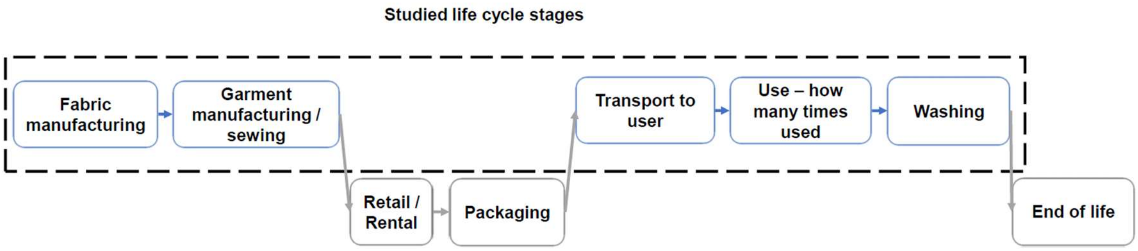

Figure 13. Studied life cycle stages in clothing rental

Fabric and garment manufacturing

The material choice in garment manufacturing can have a significant role. Especially for infrequently worn garments with no extension to the lifetime, the environmental impacts remain substantial (Piontek et al., 2020). Generally, synthetic fibres are more energy-intensive than natural fibres, with the exception of silks, which are of natural origin but of which production is very energy-consuming (Munasinghe et al., 2021). When only the production phase is considered, animal-derived fibres often have a higher environmental impact than other fibre types, and for example, silk has the greatest GHG emissions, while cotton has the lowest (Amasawa et al., 2023). Most studies address pure materials, but there is a lack of studies related to mixed fibres and blended materials (Fonseca et al., 2023; Moazzem et al., 2022), which are quite commonly used in clothing. The rental garments are in intensive use and need to have increased durability, but these garments (i.e. dresses, skirts) may also require more fabric compared to a basic piece of clothing (Amasawa et al., 2023). While synthetic fibres such as polyester and nylon increase the textile's durability and may extend the potential lifespan of the garment as materials (Circle Economy, 2024), they generally result in higher greenhouse gas emissions due to their fossil fuel origins and the significant energy required during production (EEA, 2025). Furthermore, there is a lack of knowledge in some fabric construction methods, for example, traditional methods as handloom, hand knitting and crochet, as well as value-adding techniques as textile printing and embroidery, are not much studied (Munasinghe et al., 2021).

Transportation

Transportations are involved in every step of clothing’s life cycle, when the chains are global (Munasinghe et al., 2021). The role of packaging is also noticed to be significant in the use stage of some studies (Monticelli & Costamagna, 2023). In the present case, the customers were assumed to have their own bags with them when taking rented garments home.

In many rental studies, the transportation from the rental store to home is raised as a significant factor to make rental garments, in some cases, worse than owned garments (Amicarelli et al., 2022; Johnson & Plepys, 2021; Levänen et al., 2021; Monticelli & Costamagna, 2023; Munasinghe et al., 2021; Piontek et al., 2020; Zamani et al., 2017). Additional transportation can have the potential to problem shifting, when the benefits from reduced garment production can be offset by the increased transportations between every rental (Zamani et al., 2017). Customer transportation is argued to cause the biggest carbon footprint of the use stage, especially if washing is done with a low-carbon electricity grid mix (Piontek & Müller, 2018) or if customers use transport modes with high impact (Johnson & Plepys, 2021).

Transportations are not necessarily done for rental clothes alone, and different trips can be combined. For example, Johnson and Plepys (2021) asked customers how they planned their trips, and 55% of respondents stated they combined the visit to the rental store with other errands, and 45% stated they made a point to just go to the rental store. Also, in the case of the present case study, the company reported that many customers visited the rental service point while returning home from work.

Use stage

The use stage has the most options for scenarios, since different customers have different kinds of use habits. However, how many times the garment is worn is crucial for the total carbon footprint, and extending the number of uses per product can help limit the environmental impacts of the fashion sector (Monticelli & Costamagna, 2023). A bought formal dress can sometimes be worn only once or twice, while rental dresses get more uses due to several users (Amasawa et al., 2023). The number of times an owned garment is worn might vary, for example, between 2 to 102 (Amasawa et al., 2023), and in one case was calculated to be on average 3.12 uses or wear occasions (Johnson & Plepys, 2021). A dress in a conventional wardrobe is estimated to have a lifespan of 5 years, with 23.1 wears per life (Gray, 2023). For rented clothes, the wear times can be higher, varying from 73 to 105 (Amasawa et al., 2023). However, differences in the use phase of different clothes and consumers are most likely significant. In Gray (2023) a rental dress is estimated to have 21 rental occasions, with a total of 31.5 wears. In the recently published final PEFCR (2025) for clothes and footwear, dresses, skirts and jumpsuits are estimated to have a default product duration of 70 uses, including all kinds of reuses.

Increasing the number of wears is estimated to benefit more significantly infrequently worn formal garments than, e.g. a T-shirt (Piontek et al., 2020). It is difficult to define the exact number of times a garment should be worn for it to be more environmentally friendly, whether owned or rented. For example, dresses made from emission-intensive materials need to be used many times to compensate for the burden of manufacturing, i.e. to have the same emissions per wear as a garment with less emission-intensive materials (Amasawa et al., 2023). In the study of Monticelli and Costamagna (2023), a 450 g retail dress made of 100% cotton should be used more than 7 times to have a lower impact compared to a rented dress.

Washing method also impacts the use stage, and there are many options to clean the garment after use. Generally, the colour of a garment is expected to retain at least 20 washes, and 45 domestic washes per the Durawash test method, which is used by mass-market fashion brands (Munasinghe et al., 2021). Rented garments are expected to withstand a much higher number of washes, and the material needs to be high-quality. Probably the most common cleaning is with a washing machine, with differing washing programs. The energy consumption and GHG emissions increase when washing temperatures increase (Munasinghe et al., 2021). On the other hand, formal wear requires a lower temperature and smaller load (Johnson & Plepys, 2021). For wool clothes, airing is often a sufficient option, and e.g. sweaters need washing more rarely. Wiedeman et al. (2021) used an average of 0.2 washing and drying cycles for garments, which can be used for owned garments but not for rental garments that need to be returned clean. Some formal garments need to be dry-cleaned, and in some studies, when a rented garment is dry-cleaned, it can create greater life cycle GHG emissions compared to owning a garment (Amasawa et al., 2023). Many rental studies focus on the use stage and especially washing, noticing that often-washed clothes as T-shirts, can have the biggest impact in the use stage, while rarely washed garments, like jackets, can have the biggest burden on production (Piontek & Müller, 2018; Piontek et al., 2019).

In the present case study, the garments were assumed to be washed by the customer with a delicate program in the machine or dry-cleaned at a launderette, and in the case of cardigans delicate wash program with airing out between uses.

End of life

End of life was not considered in this case study, since it was estimated that the end of life would be similar for both rented and owned garments, but the potential impacts are discussed here. Based on available studies, landfilling and incineration have been the most common end-of-life options. The share of secondary materials (mostly sourced from non-textile industries) is only 0.3% of the total raw material consumption of the textile value chain (Circle Economy, 2024). Used garments are mostly (61.4%) disposed of in a landfill or incinerated, while some (8%) are reused or exported, and 6.3% of waste textile is recycled (Circle Economy, 2024). In a case study focusing on Canada, the rental garments are assumed to be landfilled for all fabric types, while it is noticed that out of the 10 million tonnes of textiles landfilled in North America, 95% could have been recycled and/or reused (Amasawa et al., 2023).

In another study analysing the Norwegian clothing system, the garments classified as waste are incinerated (Mora-Sojo et al., 2023). The role of different fibre types in potential impacts originating from landfills has not yet been studied much (Moazzem et al., 2022). Out of the reused clothes, the better-quality clothes are sent to domestic second-hand stores for reuse, and lower-quality clothes are exported (Mora-Sojo et al., 2023). Exports are sent mostly from Europe (30%), China (16%) and USA (15%), while the importing regions are Asia (28%), Africa (19%) and Latin America (16%) (Circle Economy, 2024). Recycling of, for example, cotton can create a high level of greenhouse gas emissions, while the production of virgin cotton causes relatively low emissions (Levänen et al., 2021).

Therefore, the resources used in garments are best optimised when the functional lifetime of the textile is extended (Circle Economy, 2024).

2.2 Main assumptions and data sources

The data for the evaluated silk dress was collected from the company, describing the life cycle of a rental dress (number of uses, washes and transports, etc.) Part of the data was based on real bookkeeping by the company. The data presented in Table 10 and is based on both measurements and the company representative's experiences and estimates.

Table 10. Primary data for the rental silk dress

Element	Explanation/ assumptions	Value	Unit
Product	100% Silk dress	1	pc
Garment manufacturing	In Estonia		
Use times during one rental		2	Times/ rental
How many times rented		95	Times
Lifetime as a rental garment		5	Years
Washing	Delicate wash for silks in a washing machine		
Packaging	Customer's own bag		
Transport from the rental to the home	Walking, cycling, and passenger car		
Transport distance	Roundtrip	10	km
End-of-life	A rented garment is sold to a customer when it serves only one customer's needs		

Assumptions about the dress:

- The modelled dress is a loose fit with knee-length hem and medium-length sleeves. The amount of fabric needed for the dress was estimated to be about 4 m^2.
- The weight of the fabric for one dress was calculated to be 347.2 grams.
- The origin of the silk used in the dress manufactured in Estonia was not known, and the global averages were used as a proxy.
- The packaging of the rented garment was not included in the study; the customer was assumed to have their own bags with them.
- Transport distance from the rental company to home was expected to be 5 km (10 km as round-trip), and the same distance was used when evaluating potential climate impacts of buying clothes from retailers.
- The dress was assumed to be sold to one customer only after it had fully served its rental life cycle and could not be used for rental purposes anymore, because of the deteriorated condition of the garment.

The main assumptions for the studied cardigan made of 80% wool and 20% polyamide are presented in Table 11.

Table 11. Primary data for the rental cardigan

Element	Explanation/ assumptions	Value	Unit
Product	One cardigan	1	Pc
Cardigan	Wool	80	%
	Polyamide	20	%
Garment manufacturing	In Portugal		
Use times during one rental		10	Times/ rental
How many times rented		16	Times/ year
Lifetime as a rental garment	Assumed 5 years for rental		
Washing	Washed once before returning		
Packaging	Customer's bag		
Transport from the rental to the home	Walking, cycling, and passenger car		
Transport distance	Roundtrip	10	km
End-of-life	A rented garment is sold to the customer when it serves only one customer's needs		

Assumptions about the cardigan:

- The mixture of 80% wool and 20% polyamide was considered by using 80% of the mass of the cardigan with the wool dataset, and 20% of the weight with the polyamide dataset.
- The finished cardigan consisted only of wool and polyamide, and there were no buttons, etc. or any accessories.
- The weight of the finished cardigan was estimated to be 600 grams.
- The cardigan was expected to be in the rental cycle almost all the time, meaning in a year, for 16 customers, who each keep the cardigan for a maximum of 3 weeks.
- Cardigan was expected to be in the rental cycle for 5 years.
- The packaging of the rented garment was not included in the study, and the customer was assumed to have their bag with them.
- Transport distance from the rental company to home was expected to be 5 km, as 10 km round-trip, and the same distance was used for buying clothes from retailers.
- It was assumed that the owned cardigan was washed less than the rented one.

2.2.1 Data

The data for the scenario calculations were searched from the literature and the ecoinvent 3.11 databases. Table 12 presents the data options and

Table *13* presents the chosen data sources and potential range in applied values. It is noteworthy that by making different decisions for the used data, the results could be different. These results are therefore not applicable to other cases beyond the present case study.

Table 12. Data options for different materials or life cycle stages, found from several sources

Data options found:	Range of values Kg CO_2e/kg textile	Ecoinvent 3.11	Astudillo et al. (2014)	Moazzem et al. (2022)	Munasinghe et al. (2021)	Wiedemann et al. (2021)	Laitala et al. (2018)	Bevilacqua et al. (2011)	Motiva (2023)	Helen (2024)	Bosch (2014)
Silk	52,5 – 157	x	x								
Wool	1,7 – 43	x	x	x	x	x					
Polyamide	5,5- 8,3	x	x								
Delicate wash	0,022 – 0,32	x					x	x	x	x	x
Dry-cleaning	0,022-0,045						x				

Table 13. Chosen data sources for different life cycle stages in scenarios

Element	Explanation	Data source
Silk	Dress 100% silk	Market for textiles, silks, GLO. Ecoinvent 3.11.
Wool	Cardigan 80% wool	Estimation based on literature sources and ecoinvent 3.11 datasets
Polyamide	Cardigan 20% polyamide	Market for nylon 6-6, RER. Ecoinvent 3.11.
Car transport	Drive(s) from rental or retail store to home	VTT ELIISA model (including emissions from fuel combustion/conversion in cars, car fuel usage, fuel mixes in Finland)
Delicate wash	Delicate wash program at 30 degrees	Bosch program table 2014 (Bosch, 2014)
Dry-cleaning	Dry-cleaning with perchloroethylene (PERC, C_2Cl_4)	Laitala et al. (2018)
Electricity conversion to emissions	Energy consumption in MJ or kWh converted into emissions. The emission factor for the electricity consumed in Finland in 2023 was 0,038 kg CO_2/kWh	Fingrid (2025)

Assumptions and limitations about the use of data:

- The burden of washing was calculated for the weight of the studied garment. Energy consumption for delicate wash was for a 2 kg load, but it was assumed to be the same for a 1 kg load, and the consumption was calculated for the weight of one garment. In dry-cleaning, energy consumption was reported for 1 kg of textile, from which the value for garment weight was calculated.
- When GHG emissions were not available, energy consumption in MJ or kWh was considered and converted into emissions. The emission factor

for the electricity consumed in Finland in 2023 was 38 gCO_2/kWh, equalling 0.038 kg CO_2/kWh (Finngrid, 2025).

2.3 Rental scenarios

Different scenarios were created to show the potential impact of the estimated number of uses during the life cycle of rental clothes. When considering a person renting a garment, the most logical option for renting is buying it from retail, which is why it is used as a benchmark for the study. Rental garments can be used by a higher number of users, washed and transported more often, while retail garments are generally used by one user, and (depending on the owner) might be worn less and washed more rarely during the garment's life cycle (Amasawa et al., 2023; Johnson & Plepys, 2021). The transport distance is estimated to be 5 km for both rental and retail stores in all scenarios, but the journey is only one way for the garment purchased from retail, and back and forth for the rented garment (pick-up and return).

Five alternative use scenarios were created for both of the studied garments.

The scenarios were built with the following variables:

- Garment ownership:
    - Rental: potentially rented by many users
    - Retail: only one user
- Times worn:
    - Rental: how many times rented and worn during one rental
    - Retail: use occasions of one's own garment
- Transportation:
    - Rental: 10 km round-trip (pick-up and return), different transportation methods
        - Car drive with the sole purpose of the garment pick-up,
        - Bike with zero emissions, or
        - Car pick-up when bypassing the store when anyway when returning home from work, emissions are marked as zero.
    - Retail: 5 km in one direction (only pick-up), car drive from the store to home.
- Washing method:
    - Delicate wash in the machine
    - Dry-cleaning + transportation to the dry cleaner by car for 10 km round-trip.
- Washing frequency:
    - Rental: one wash per rental, before returning
    - Retail: infrequently washed

In the scenarios calculated per wear, **allocation is done for the times a garment was worn**. This means that, for example, the transportation of the rental garment was calculated per unit of time. If one customer rents and uses the garment 10 times, the burden of one rental transport is divided by 10. Additionally, if the garment was not washed after every use, the burden of washing per wear was calculated from the ratio of washed and worn, e.g. if the garment was worn

15 times but washed only three times, the burden of washing per wear was the burden of one washing divided by five.

2.3.1 Silk dress scenarios

The rented dress was assumed to be used **only once during one rental**. The first three scenarios represent the rental garment, and two the retail garment.

The rental dresses are rented, used and washed 40, 95 and 15 times, respectively. Customers wash the rental dress at home with a delicate wash before returning the dress to the store. Transportation for the first rental scenario is a car, 10 km/rental, with the sole purpose of picking up and returning the dress. For the second and third rental scenarios, emissions from transportation are allocated as zero, since the drive in the second scenario is combined with other errands and bypassing the store, and the third with pick-ups and returns by bicycle.

The two retail scenarios with one's own dress are calculated to be used and washed 50 or 6 times. Both retail dresses are transported home from the store by a 5 km car drive. The dress worn 50 times is washed after every use with a delicate wash, and the last scenario's retail dress, with 6 uses, is washed with dry-cleaning. When the dress is dry-cleaned, transportation to the dry cleaner is assumed to be a 10 km round-trip by car.

The estimated carbon footprint for the silk dress (either rental or retail dress) is presented in Figure 14. Included life cycle stages were fabric manufacturing, transportation to home (and back to the rental), and washing of the dress.

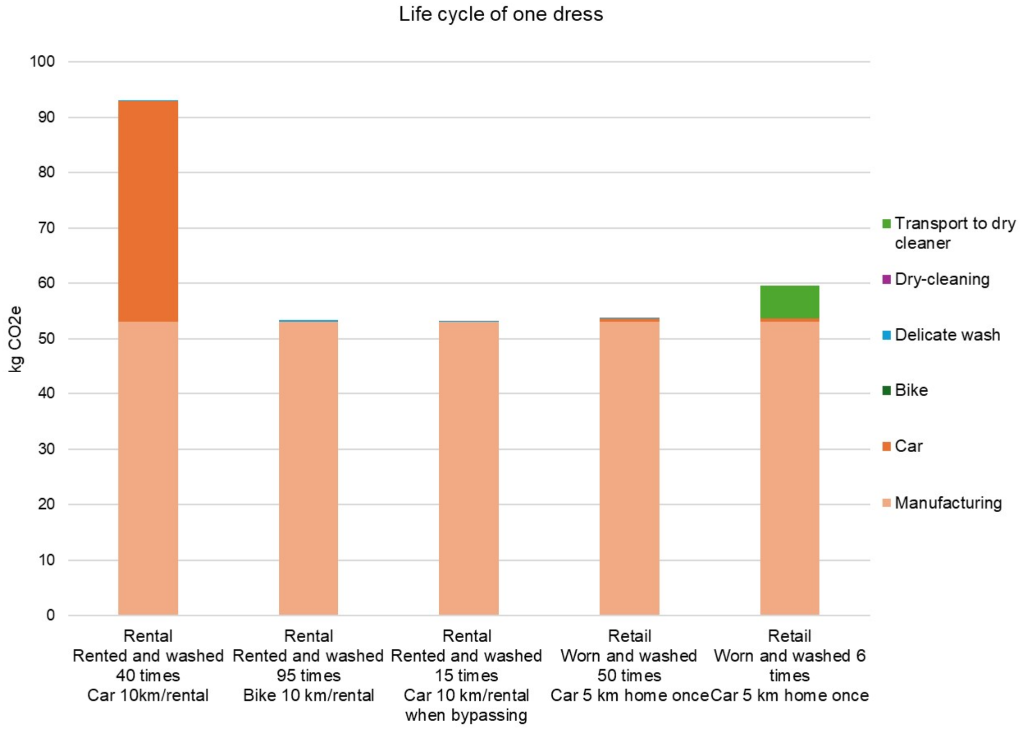

Figure 14. Results for the life cycle of one dress (incl. fabric manufacturing, transportation to the user, and washing) in five scenarios

The estimated impact for the studied life cycle (manufacturing + use) of silk dress in rental scenarios varied between 53 - 93 kg CO_2e per dress, and when purchased from retail, 54 - 60 kg CO_2e per dress. As can be seen in Figure 14, the overall emissions of a dress's life cycle are the biggest when the dress is rented multiple times and transported by car each time. If each customer walks or rides a bike, emissions originating from dress manufacturing remain the biggest contributor. Variability in potential GHG emissions originating from silk manufacturing is studied further with in Chapter 2.4.2.

Potential impacts from the washing method are in a minor role, when the energy use related to the washing step was quite low (due to using delicate wash in a mild temperature) and to the rather low GHG emission factor of Finnish electricity. The estimated emissions from washing one dress during its life cycle can be seen in Figure 15, without the emissions from manufacturing and transportation.

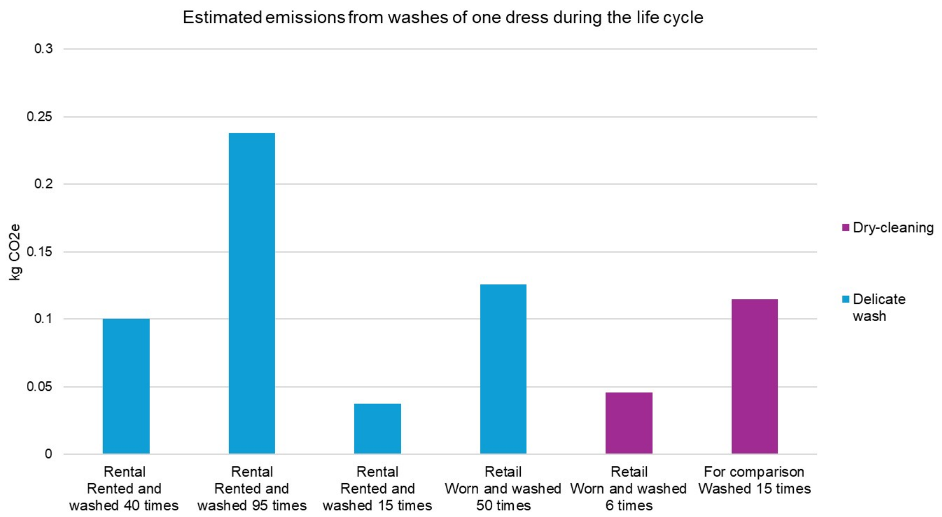

Figure 15. Estimated emissions from washing one dress during its life cycle

As Figure 15 shows, the estimated GHG emissions from washing increase with the number of times the dress is washed. GHG emissions from dry-cleaning are more than double compared to delicate wash, which can be seen by comparing the third rental and the last retail scenario.

When the emissions related to the dress were studied per one wear of the garment, the ranking of these same scenarios was completely different, as can be seen in Figure 16.

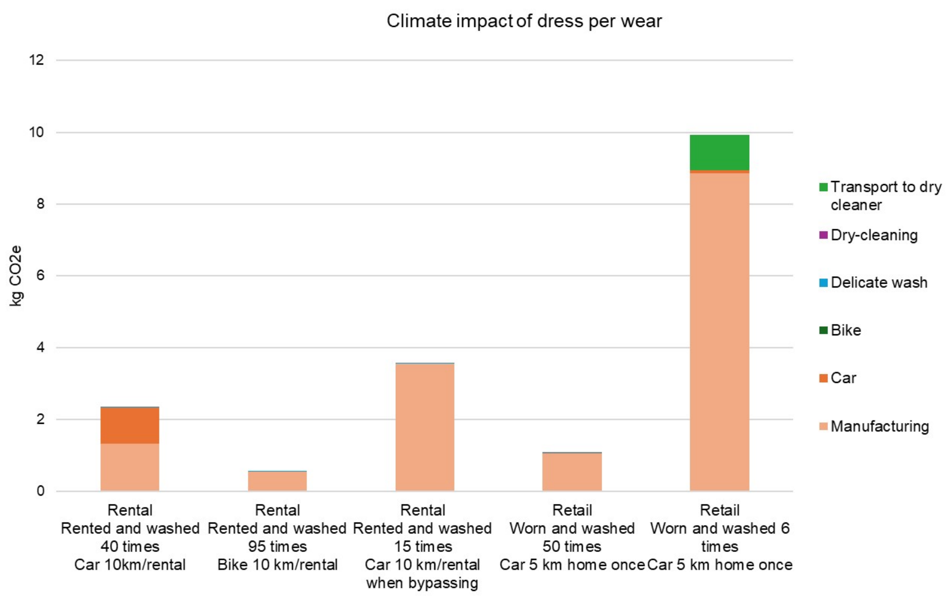

Figure 16. Results per one wear of the dress in five scenarios, including fabric manufacturing, transportation to the user, and washing

The impacts of the dress life cycle divided by the number it was worn show that manufacturing was still the biggest contributor. The impacts per wear varied in rental dress scenarios from 0.6 – 3.5 kg CO_2e/wear and in retail scenarios from 1.1 – 9.9 kg CO_2e/wear. If a purchased retail dress was worn rarely, for example, 6 times, the emissions per wear were multifold compared to a dress that was used more often, either with rental or retail. The scenario of wearing one's retail dress 50 times might be wishful thinking, but that was the scenario that reached the same level compared to other rental dresses worn often. Even if a rental dress is not that popular among customers and is rented only 15 times, the impacts per wear are still lower compared to a dress that is worn only six times. Or compared to people buying the garment as their own and not eventually wearing it. The range of emissions per wear was from 0.5 kg to almost 9 kg CO_2e/wear.

2.3.2 Wool/polyamide cardigan

In cardigan rental scenarios, the cardigan was **assumed to be used more than once** during one rental. Cardigan was only cleaned with a delicate wash, and dry-cleaning was not used. The first three scenarios represent the rental garment, and two the retail garment.

The rental cardigans are rented and washed 16, 80 and 15 times, respectively. During these rentals, the cardigan is worn several times by the same user, 10, 4 and 2 times, respectively. Transportation for the first and third rental scenarios is a car, 10 km/rental, with the sole purpose of picking up and returning the cardigan. For the second rental scenario, emissions from transportation are allocated as zero, since the drive in the second scenario is combined with other errands and bypassing the store.

The two retail scenarios with one's own cardigan are calculated to be used 15 or 60 times. Both retail cardigans are transported home from the store with a car drive of 5 km. The cardigan worn 15 times is calculated to be washed three times, based on a 0.2 washing cycle (Wiedemann et al., 2021). The last scenario's retail cardigan is calculated to be washed after every use with a delicate wash.

One cardigan's total emissions for the studied life cycle for five scenarios are presented in Figure 17.

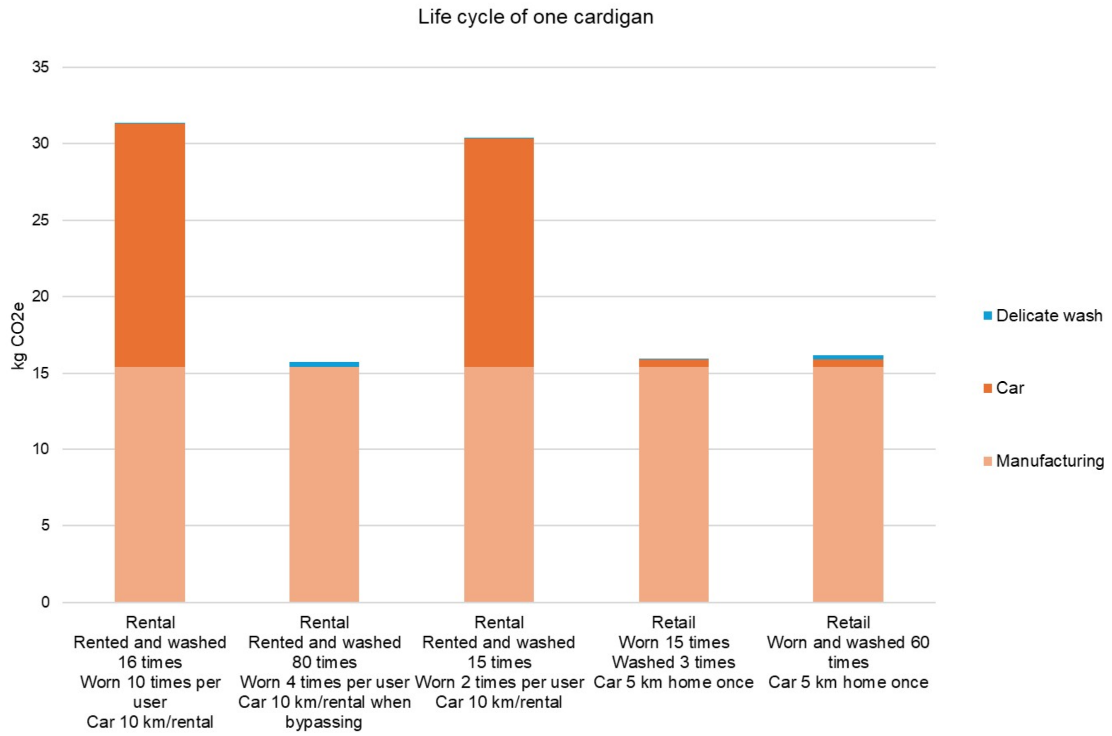

Figure 17. Result for the life cycle of one cardigan (incl. fabric manufacturing, transportation to the user, washing), in five scenarios

The impact of the cardigan life cycle (manufacturing + use) when rented was 16 - 31 kg CO_2e/cardigan, and when purchased from retail, 15.9 – 16.1 kg CO_2e/cardigan. The two scenarios with customer car transportation appeared to have the highest emissions of the scenarios. The impact of manufacturing and transportation was equal, meaning that manufacturing one cardigan has the same amount of environmental impacts as driving a car for 10 km about 16 times. In these cases with rental garments, it is worth noticing that the manufacturing of other cardigans might be avoided by using the rental option. The impact of washing was invisible in all scenarios, but vaguely distinct (2%) in the scenario of renting and washing a cardigan 80 times. The impact of only washing is shown in Figure 18, without manufacturing and transportation emissions.

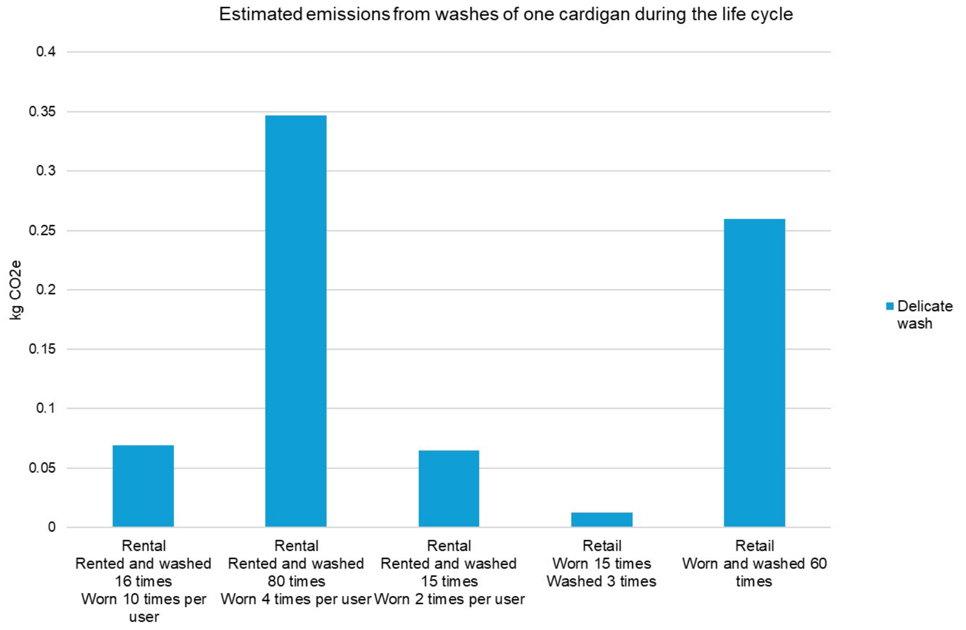

Figure 18. Estimated emissions from washing one cardigan during its life cycle

As can be seen from Figure 18, the emissions from washing are directly multiplied by the times a cardigan is washed. Results per one wear of the cardigan are presented in Figure 19.

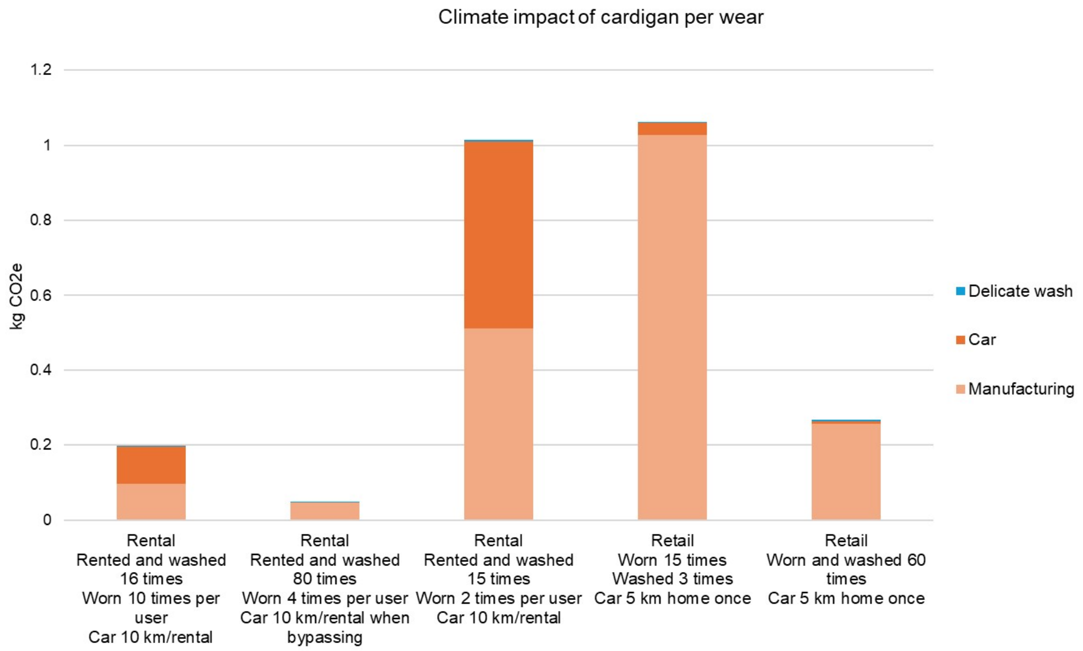

Figure 19. Results per one wear of the cardigan in five scenarios, including fabric manufacturing, transportation to the user, and washing

The impacts per wear were for rental cardigan 0.05 – 1.02 kg CO_2e/wear, and for retail cardigan 0.3- 1.1 kg CO_2e/wear. The largest emissions were caused by the retail scenario, with 15 times worn, and on rental scenario, with reasonably low rental interest, caused by the car transportation of the customers. The lowest impact was on the rental cardigan, which is rented 80 times, and during the rentals used 4 times per user. The range between the values was not much, the largest being 1 kg CO_2e/wear, and the lowest 50 g CO_2e/wear.

2.4 Discussion

2.4.1 Interpretation of the results

In both the dress and cardigan cases, the largest share of impacts was caused by the manufacturing. The data used for manufacturing was estimated, based on the weight of the garment, and excluding the garment sewing. The dataset used for silk was the production of unprocessed textile, without bleaching or dyeing. In the case of the cardigan, the dataset for wool was an estimation from various values and data for polyamide from nylon 6-6 fabric. Even if the values for garment manufacturing were underestimates, it gives the idea of garment manufacturing being the biggest contributor to the garment's life cycle. The more realistic burden of manufacturing would possibly be larger, and the presented impacts would be emphasised. This underlines that the choices made in the scenario modelling could cause different results, and the variety of choices causes uncertainty.

The impact of rental transportation was also significant, if the rental garment was picked up and returned with a car and only purpose of transporting the garment. If other errands were combined with the drive, or the garment was picked up and returned while passing the rental store anyway, the emissions were allocated as zero for the garment transportation. If this were not the case, the impacts of transportation could be increased. The car drive for 5 km was the only option used for retail scenarios, and the zero-burden options (bike or bypassing with car) were not used. This was done to have the highest possible impact on customer transport from retail, but its impact was still quite minimal. If some other option had been used, the impact of retail transportation would have been even less.

The number of times a garment is worn was quite high in the scenarios, and it can be challenged how realistic that is. This also raises the question of how many times they can be worn and still remain in good condition. The default production duration for dresses should be at least 70 uses, based on the final PEFCR (Quantis, 2025). The garments that are chosen for the rental store's selection should be durable in use and also popular among customers, so that they will be rented often. In this case study, the entrepreneur has a good understanding of what is popular, and the garments in the store have high instances of use.

It is very difficult to define a certain number after which the garment is better (with lower environmental impacts) to own oneself, compared to renting. In the study of Monticelli and Costamagna (2023), an owned dress was estimated to be used more than 7 times for it to be more environmentally friendly compared to a rental dress. In the scenarios calculated in this study, the number of times a dress needs to be worn seems much higher, something between 30 and 50, depending on the rental scenario it is compared to and assuming that the largest possible emissions from transportation are included. The final impacts depend on the real number a garment is worn, and in some studies the garments were rented for only max 17 times, and the caused increased transports (transports also to laundry were included) could reduce the potential environmental impact savings gained with rental business model (Johnson & Plepys, 2021). The cases of rental garments with a low number of wears are still more desirable and less emission-intensive than one customer purchasing a garment and not using it enough. The impact of the rental company as a force for limiting the number of manufactured garments is significant. If all consumers were to purchase the garments for themselves, it would create much higher impacts compared to only some purchasing and some renting. For example, in the case of the cardigan, it is very possible that the same customers rent the same garment several times, maybe during two or more winters.

The silk dress is probably not washed after every single wear when it is owned by one user, but in the scenarios, it was calculated that way. The impact of both delicate wash and dry-cleaning was minimal, and washing garments less frequently would lower the emissions even more. Similarly, in the cardigan case, the emissions from washing were low. The study of Amasawa et al. (2023) argued that dry-cleaning causes 15 to 36 times higher emissions compared to wet washing, but this was not visible in this case study, where both delicate wash and dry-cleaning had a minimal role in the life cycle emissions. The impact of changing washing methods is limited, at least in the climate impact category, when total life cycle impact is mostly caused by the manufacturing.

In some literature sources, the rental options were seen as less favourable compared to owned garments, because of increased transportation (Amicarelli et al., 2022; Johnson & Plepys, 2021; Levänen et al., 2021; Monticelli & Costamagna, 2023; Munasinghe et al., 2021; Piontek et al., 2020; Zamani et al., 2017) or continuous dry-cleaning (Amasawa et al., 2023) of the rental garment. At least in this Finnish case study, the emissions from transportation and washing look very minor, and the biggest impact is on the garment manufacturing, especially in the case of a silk dress. If the rental garments are well-liked and have many users, the emissions per wear of the rental garments fall significantly.

2.4.2 Sensitivity analysis

Since the biggest part of the emissions was caused by the manufacturing of the garment, the choice of data is questioned in this chapter. In Table 10 the data options for different materials or life cycle stages were listed, and if some other choices had been made within the data ranges, the results could be very different.

If the burden of manufacturing were lower, for example, only 40 kg CO_2e for one silk dress (instead of around 50 kg CO_2e/dress), manufacturing would still cause the largest part of the results. The order of magnitude would still be the same, with slightly lower burden from manufacturing. If silk manufacturing had been chosen from the lowest values given in the range in Table 10, the results for the dress life cycle would look as presented in Figure 20.

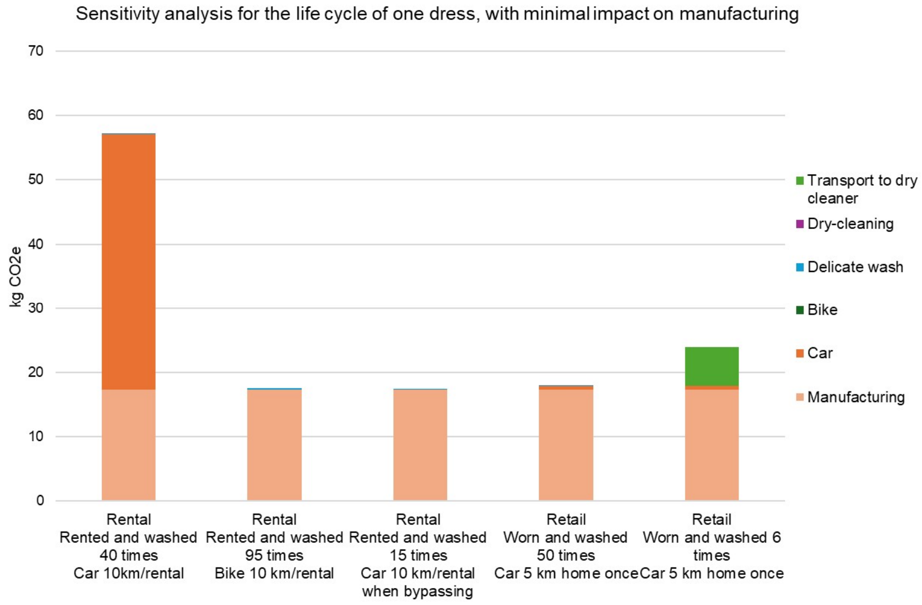

Figure 20. Sensitivity analysis of the life cycle impacts of one dress, if silk manufacturing is calculated with minimal impact

As can be seen from Figure 20, the role of transportation is emphasised if the manufacturing emissions are low. If wool manufacturing had been chosen from the highest values given in the range, the results for the cardigan life cycle would look as presented in Figure 21.

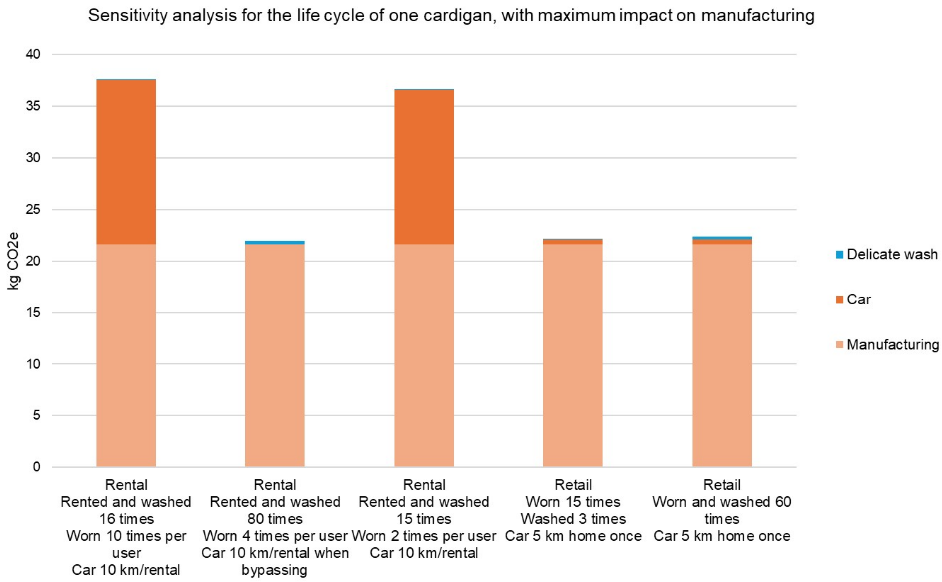

Figure 21. Sensitivity analysis of the life cycle impacts of one cardigan, if wool manufacturing is calculated with maximum impact

As presented in Figure 21, increasing the impact of wool manufacturing increases the share of manufacturing, and the impact of transportation is decreased.

In both dress and cardigan cases, the emissions caused by manufacturing are high. Theoretically, when manufacturing emissions are lower, the number of times the garment needs to be worn is lower, for the emissions per wear to be similar. For example, a silk dress that causes 50 kg from manufacturing needs to be worn more times, compared to 17 kg, to have the same emissions per wear. Purchasing garments with less burden from manufacturing is no reason to respect and wear the garment less, since the manufacturing of the garment has consumed natural resources in the first place.

The transportations were all calculated for the same 5 km distance from the customer to the rental or retail store, but the real distances can be much more in rural areas or less in city areas. The impact of transportation in rental cases is emphasised, since the distance is round-trip, consisting of the pick-up and return, doubling the distance a garment travels. Also, the emissions from transportation vary, since not all passenger vehicles are the newest kind with lower emissions. If emissions from an older fleet of passenger vehicles were used, transportation emissions would increase. In many of the calculated scenarios, the transportation was allocated as zero, when customers were reported to visit the rental store when leaving the workplace nearby, and then driving home. If some transportation emissions were to be allocated, the total impact of rental garments would increase with the increased transportation emissions. The car type, driving distance, and combination of other errands to the same drive impact the calculated results.

The emissions of washing were very low, and they were calculated per the weight of one garment. If garments were washed in the machine alone, without other laundry, the allocated emissions from washing could increase. Since the emissions of washing were so low with the Finnish electricity's emissions factor, increasing the impact by multifold would not have an impact on the total results.

2.4.3 Future potential of rental

According to the company, many customers have stopped buying new clothes for their own, excluding the everyday basics, e.g. underwear, socks, T-shirts, etc. As noticed by Amasawa et al. (2020), rentals are seen as "giving freedom to try things without committing to it", and when customers feel they need something new, they just rent it. In this company, the driver for rental can often be a wish to renew one's style all the while, and test new clothes. While sustainability is not the major driver for the customers (Amasawa et al., 2023), there seems to be a common understanding among entrepreneurs in the sector of the positive contribution they can have on sustainability. In some studies, the key driver for rentals is seen as the ability to wear garments which would be too expensive to purchase (Monticelli & Costamagna, 2023). In the case of a doubtful consumer, who might not end up using the garment enough for it to be environmentally or economically viable, it is better to use rental services.

Rental can then be seen as replacing something other, but it is argued that some people renting clothes may not abstain from purchasing new garments, and can just rent clothes to increase the options hanging in their wardrobe (Johnson & Plepys, 2021). Replacement rate was studied in Johnson and Plepys (2021), and it was noticed that ownership is never 100% replaced by rental, and for example, in the case of rental dress, customers responded to replace 70% of the purchased dress, but still 53% stated that they still purchase some dresses. This implies that not all manufacturing of new garments can be replaced with rental services, but it has great potential to replace at least some part.

Because the studied rental options do not seem to have larger emissions compared to traditional retail scenarios, caused by the increased transportation and washing, as was implied by literary sources, there is no reason to hold back the development of rental services. However, this strongly depends on consumer behaviour: if transport due to rental service only would significantly increase, this would jeopardise the benefits achieved from rental services.

3. Case 3: Tailor-made clothing

Case Company 3, Week of Wonder (later “the company”), is a Danish micro company that focuses on sustainable fashion and operates on a made-to-measure business model. The company is located in the CRAFT-IT4SD pilot site in the Central Region of Denmark. The company’s approach to fashion is centred around slow fashion and mindful consumption, aiming to create high-quality, long-lasting garments that fit perfectly and meet the individual needs of each customer. This model is rooted in classic menswear and involves creating garments based on precise customer measurements, ensuring minimal overproduction and eliminating excess inventory.

The company offers a range of customisable clothing items, including blazers, trousers, and shirts for women. Customers can book appointments to visit the design studio, where they can choose fabrics and customise their garments to fit their unique measurements. The production process is carried out in collaboration with selected production partners in Europe, who share the same sustainability values.

The made-to-measure model used by the company is based on an IT program that allows for specific measurements to be connected to each design. This system enables the alteration of standard designs to fit the unique measurements of each customer. The materials used are carefully selected, utilising both leftover fabrics and carefully selected primary fabrics, to ensure that the value chain is known and as sustainable as possible. The company operates locally as it requires physical face-to-face appointments for fittings.

The aim was to study the climate impact of one blouse manufactured with a tailor-made (also referred to as a made-to-measure) business model. A high-quality, tailor-made blouse can be assumed to have twice as long a lifespan as a conventional blouse. This would mean that in the best case, by choosing a tailor-made blouse, emissions of one new conventional blouse could be avoided. Therefore, the assumed benchmark for a tailor-made blouse could be the manufacturing of two conventional blouses (with a shorter lifespan).

3.1 Aim and scope of the carbon footprint study

3.1.1 Aim and product system description

The aim was to study the climate impact of one blouse manufactured with a tailor-made (also referred to as a made-to-measure) business model. The company has a design studio-showroom, where customers can come and order the garments. They can choose the style, fabric type and other details. Their measurements are also taken in the studio. Then the order is sent to a made-to-measure specialised company in Portugal, Unua, where the made-to-measure garment is manufactured.

The studied tailor-made women’s blouse is manufactured in Portugal from fabric manufactured by the blouse manufacturing company. The fabric for the blouse is 100% cotton, which is 60% to 90% organic, and sourced from Turkey. In this study, the fabric used for the blouse was virgin material and did not include leftovers. The pattern of the blouse is created digitally, and the customer's measurements are inserted into the design programme to modify the pattern automatically. Patterns are digitally transposed to the fabric and cut with motorised scissors. The garment is sewn manually with a sewing machine, taking three to five hours.

As the garment is produced using readily available materials and tailored to individual measurements, this model can help eliminate the back-and-forth exchange of materials, production, and collection samples typical of conventional business models before the final product reaches the end-user. Although these aspects were not considered in the calculations, they suggest that tailor-made clothing has the potential to reduce emissions and textile waste by minimising the need to send production samples

3.1.2 Scope of the study

The unit of analysis for which the carbon footprint results were calculated (**functional unit**) was a women's blouse, made from white cotton. The data for manufacturing calculations was collected from the manufacturer.

As illustrated in Figure 22, the **system boundary** was cradle-to-showroom, meaning that the scope includes the transportation after manufacturing to the company's studio-showroom, where customers come pick-up their tailor-made garment. The use stage was considered based on literature and a survey that the company conducted among its customers. The focus of the study was on the impact of longer use stage and replacement of mass-produced garments, but these were not quantified in the carbon footprint calculations. The end-of-life phase of the blouse was excluded since the company has a very limited possibility to control and influence that phase.

Figure 22. System boundary of the tailor-made clothing study

The primary data collected from the manufacturer of the tailor-made garment is presented in Table 14.

Table 14. Primary data collected from the manufacturer of the tailor-made garment

	Primary data received	Given range	Used value	Unit
Origin of cotton material	Turkey			
Share of organic cotton		60 -90	75	%
Location of fabric manufacturing	Portugal			
Transportation of cotton to fabric manufacturing	truck		4800	km
Density of fabric			115	g/m2
Cotton needed for one blouse	Width of fabric 1.4 m	1.5-2	1.6	m
Type and weight of buttons	Polyester, 8-10 pc	0.2-0.4	0.4	g
Origin of buttons	Asia			
Type and weight of thread	Cotton	200-300 m, equalling 20-40 g	30	g
Origin of the thread	Italy or Asia		Asia	
Power of the cutting machine	Cutting with Electric Manual Cutting Machines for 10 minutes	60-150	150	W
Leftover fabric	From cutting fabric	0.1-0.42	0.3	m^2
Power of the sewing machine		150-200	175	W
Operation time of sewing		3-5	4	hours
Power of ironing/steaming	For 15 minutes	2.2-3	2.6	kW
Water for the steamer		30-60	60	ml
Weight of finalised blouse		150-250	257	g
Packaging	Individual protective plastic film and carton box			
Transportation from manufacturing to the design studio-showroom	10 pieces at once, with a truck		3000	km

For the modelling, the following assumptions were made:

- Data on organic cotton was based on the data of Bangladesh. Data on normal cotton is based on the data of China, India and the USA, when data for Turkey was not available.
- Transportation of fabric from manufacturing to garment manufacturing was excluded for the close distance between the facilities.
- Transportation of thread and buttons was included with average estimations from the market dataset.
- The energy consumption for the pattern was excluded, since the created pattern can be used for an unlimited number of blouses, and personal measurements are automatically adapted to the pattern.

- Leftover fabric from cutting was estimated to be from 0.1-0.42 m^2 of the fabric handled, meaning the waste varies between 4 and 20%. In this case, estimation of 0.3 m^2 was used, equalling 34.5 grams and 13.4%.
- The blouse is sent to the company's design studio-showroom with the truck that was estimated to have 1 metric ton of transposable goods.

The company provided estimates on the cotton fabrics mass, the origin of cotton and the manufacturing location. No primary inventory data of the fabric manufacturing was available, which led to the use of secondary data originating from life cycle inventory databases (ecoinvent 3.11) and scientific publications. The product modelling was carried out using the Sulca software, version 5.3.4.

As shown in Table 15, the losses and waste along the garment manufacturing value chain were accounted for in the modelling based on the draft PEFCR (Quantis, 2021) and the losses in the cutting phase were sourced from the company.

Table 15. Garment losses at different life cycle stages along the apparel value chain (cradle-to-gate, without considering overproduction)

Manufacturing stage	**Losses***
Spinning, weaving and knitting	6.06%
Dyeing	0.15%
Finishing	0.40%
Cutting, sewing	13.40%

*Calculations based on Table 28 (Quantis, 2021)

3.2 Life Cycle Inventory Analysis

The following **production processes were included** in the study:

- Manufacturing of buttons, modelled as unsaturated polyester resin
- Manufacturing of thread for sewing, modelled as the raw material of cotton yarn
- Fabric manufacturing, from the production of cotton fibres (both organic and conventional), followed by the related processes of weaving, dyeing and finishing, to the production of one blouse. As for the share of fibres, organic cotton was assumed to be 75% of the fibre and 25% conventional cotton.
- The production waste related to the following textile production processes: weaving, dyeing, and finishing.
- Transportation of the cotton fibre to fabric manufacturing
- Cutting the fabric according to the pattern with motorised scissors
- The leftover fabric from the cutting process
- Sewing the blouse manually with a sewing machine

- Ironing or steaming the finished blouse
- Product packaging for transport, including protective plastic film and a corrugated cardboard box
- Transportation from manufacturing to the customers by truck

The following production processes **were excluded** from the carbon footprint calculations:

- Pattern creation and its energy consumption
- Use stage, which is addressed in the *Discussion* section
- End of life of the garment.

The data used for modelling is detailed in Table 16.

Table 16. Data used for modelling materials and production processes for the tailor-made blouse

Life cycle stage	Material/ component	Input	Output	Unit	Material dataset
Functional unit	One women's blouse		1	pc	Data delivery from the manufacturing company
Cotton production	Organic cotton, 75%		206.7	g	Ecoinvent 3.11: fibre production, cotton, organic, ginning, RoW
	Conventional cotton, 25%		68.9	g	Ecoinvent 3.11: Fibre production, cotton, ginning, RoW
Cotton transportation	Cotton fibre from Turkey to Portugal	4800		km	Ecoinvent 3.11: market for transport, freight, lorry, unspecified, RER
Fabric production	Fabric production from fibre. Spinning, knitting, and weaving	275.6	258.9	g	Ecoinvent 3.11: textile production, cotton, weaving, RoW
	Waste from spinning, knitting, and weaving		16.7	g	Ecoinvent 3.11: market for municipal solid waste, Portugal
	Fabric dyeing/washing	258.9	258.5	g	Ecoinvent 3.11: batch dyeing, fibre, cotton, RoW
	Waste from fabric dyeing/washing		0.4	g	Ecoinvent 3.11: market for municipal solid waste, Portugal
	Fabric finishing	258.5	257.5	g	Ecoinvent 3.11: finishing, textile, woven cotton, GLO
	Waste from fabric finishing		1.0	g	Ecoinvent 3.11: market for municipal solid waste, Portugal
Primary components				g	
Fabric	Cutting 100% cotton fabric	257.5	223	g	
Fabric losses	Leftover fabric from cutting		34.5		Ecoinvent 3.11: market for municipal solid waste, Portugal
Buttons	10 buttons made of Polyester (plastic resin)	4		g	Ecoinvent 3.11: market for polyester resin, unsaturated, RoW
Thread	Cotton thread, 200-300 meters	30		g	Ecoinvent 3.11: market for yarn, cotton, GLO
Life cycle stage	**Material/ component**	**Input**	**Output**	**Unit**	**Material dataset**
Production process					

Cutting	Motorized Scissors	0.025		kWh	Ecoinvent 3.11: market for electricity, medium voltage, Portugal
Sewing	Sewing machine	0.7		kWh	Ecoinvent 3.11: market for electricity, medium voltage, Portugal
Steaming	Power of the steamer	0.65		kWh	Ecoinvent 3.11: market for electricity, medium voltage, Portugal
	Water for the steamer	60		ml	
	Weight of the final blouse		257	g	
Packaging material					
Protective plastic film	Individually wrapped	10		g	Ecoinvent 3.11: market for packaging film, low-density polyethene, GLO
Carton box	Box to fit 10 blouses, weight 240 g	24		g	Ecoinvent 3.11: market for corrugated board box, RER
Transportation					
Blouse transportation	From Portugal to Denmark	3 000		km	Ecoinvent 3.11: market for transport, freight, lorry, unspecified, RER

3.3 Life Cycle Impact Assessment

3.3.1 Carbon footprint results

The total carbon footprint of one tailor-made blouse amounted to 5.2 kg CO2e. The footprint is detailed by production steps in Figure 23.

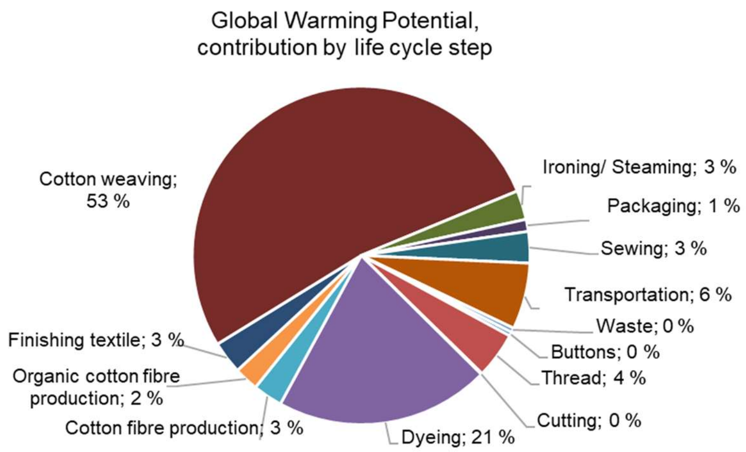

Figure 23. Carbon footprint of the tailor-made blouse (cradle-to-showroom), by production steps, according to the EF 3.1 method in impact category Climate change

Among the processes in the blouse's life cycle, fabric manufacturing has the highest climate change impact (4.2 kg CO_2e, 81% of total). Most of the emissions caused by fabric manufacturing originate from cotton weaving (53% total) and cotton dyeing (21% of total). The processes used in fabric manufacturing were modelled on secondary datasets, which are not located in Portugal, where the fabric is actually produced, but describe the process in Asia. The emissions from cotton weaving are sourced from electricity use, and cotton dying from electricity and chemicals.

Transportation processes are accountable for 6% of the cradle-to-showroom emissions, consisting of the cotton fibre transportation from Turkey to fabric manufacturing in Portugal (0.19 kg CO_2e) and transportation from manufacturing in Portugal to the design studio-showroom in Denmark (0.13 kg CO_2e).

The processes involved in the garment manufacturing, as cutting, sewing and ironing/steaming (total 6%), are all caused by the electricity consumption, which was estimated based on the Portuguese electricity grid mix. Other material needed for the blouse, as buttons and thread, are accountable for 5%, which consists mostly of (92%) the manufacturing of thread material.

Concerning the emission type, 93% are of fossil origin, 2% are biogenic emissions, and 5% are caused by land use and land use change. The largest portion of the fossil emissions is caused by the air emissions of the fabric manufacturing (81%), with the main part caused by textile weaving, and the biggest emissions being carbon dioxide, nitrogen dioxide, and methane. The remaining part of the fossil air emissions mainly comes from transportation and thread manufacturing.

3.3.2 Sensitivity analysis

The sensitivity analysis was carried out for the primary data values, which were given as a range. For the carbon footprint calculations, some assumptions were made, for example, the fabric amount used was 1.6 meters, when 1.5-2 meters was the given range.

The uncertainty analysis included five values: three electricity consumptions (used in cutting, sewing and ironing), and two values about fabric amount (amount of used fabric and amount of leftover fabric).

The uncertainty factors about fabric use were included only in the cutting process. The needed fabric amount from upstream in fabric manufacturing, or the cut fabric amount after the cutting process, was not updated with uncertainty factors. This may cause some deficiency if the uncertain fabric amount does not affect the flow amount in the previous or following steps.

If only the average values of the given ranges had been used in the calculations, the carbon footprint of the blouse would have been 5.6 kg CO_2e. The aforementioned results of 5.2 kg CO_2e were made with assumptions within the given ranges.

When the range is considered in the calculation tool, the minimum possible carbon footprint for the blouse is 5.1 kg CO_2e, and the maximum carbon footprint is 6.2 kg CO_2e.

These values for carbon footprint are all on the same scale as illustrated in Figure 24.

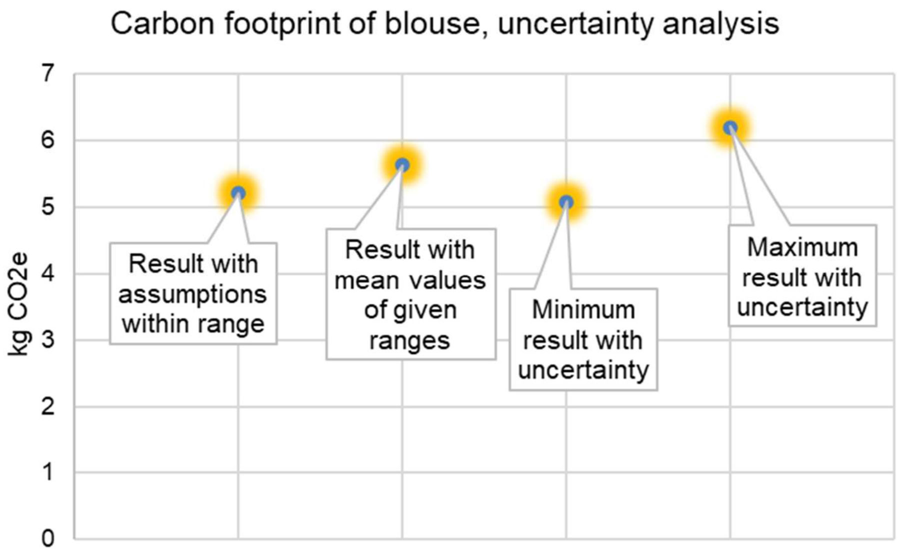

Figure 24. Uncertainty analysis of the data used for the tailor-made blouse

3.4 Discussion

3.4.1 Interpretation of the carbon footprint results

The study highlights the impacts caused by the fabric manufacturing supply chain over the direct emissions from manufacturing the blouse. The fabric manufacturing is responsible for most of the emissions (81%), mostly caused by the cotton weaving process (65% thereof). The process of fabric manufacturing was modelled on secondary data, with a dataset of weaving including global average data based on data from Bangladesh. The cotton fabric manufacturing was located in Portugal, but due to the lack of data, average data was used.

The study was limited to a cradle-to-showroom assessment, while the use phase or end-of-life phase was expected to be rather similar compared to a normal blouse with size chart fit and sourced from serial production. Other than the selection of the system boundary, methodological choices do not significantly influence the outcomes.

The highest climate impacts were caused by the fabric manufacturing, which was modelled relying on generic data (low regional and far technological representativeness) and is therefore subject to high uncertainty. The company has limited influence on the purchased primary components, and primary data would be needed to calculate the true impact of fabric production and its share of the garment manufacturing.

A specific benchmark was not calculated for the blouse, but the carbon footprint of the tailor-made blouse (5.2 kg CO_2e/blouse) was compared to carbon footprints for different shirt types found from literature, compiled in Table 17.

Table 17. Comparison of carbon footprint calculations for different shirts and differing system boundaries

Shirt type	Carbon footprint, kg CO_2e/ shirt	Weight of the shirt	System boundary	Source
Tailor-made blouse	5.1 -6.2	257 g	Cradle-to-showroom	This study
Shirt or blouse, materials calculated from an average product	12.28	250 g	Cradle-to-use	The final PEFCR (Quantis, 2025), calculated from the average number of uses (40) and characterised impact per wear (0,307 kg CO_2e excl. use)
Polo shirt made of jersey	8.81	250 g	Cradle-to-retailer	Amin et al. (2021)
T-shirt	5.33	150 g	Cradle-to-retailer	Amin et al. (2021)
Pure cotton shirt produced in China	8.771	280 g	Cradle-to-use	Wang et al. (2015) 2014
T-shirt	9.18	180 g	Cottonseed to garment	Wang et al. (2025)

As can be seen from Table 17, the value calculated in this study is in the same scale, or lower than, compared to literature sources. The location of production can explain the results to some extent, since China has more fossil fuels in the electricity mix compared to Europe.

3.4.2 Tailor-made clothing and garment longevity

When the garment, e.g. blouse, is made to measure, there is a high chance and expectations that the well-fitting form it is worn more often compared to non-made-to-measure clothing. Therefore, it could be assumed that a customer purchasing a tailor-made blouse doesn’t have to buy so many other, non-fitting blouses to fulfil the same need to be fulfilled. It can also be assumed that a fitting, tailor-made blouse will stay in use longer, assuming that the quality is good and the garment is maintained well with an appropriate washing method, etc.

For the tailor-made clothing case study, the longevity of the clothing was surveyed among the company’s customers by the company representative.

The questions in the customer survey were:

- Do you still have your shirt?
- Is it still part of the wardrobe you are using?
- In what condition is the shirt now?

12 respondents were quizzed about the blouses they had purchased in autumn 2020 or spring 2021. At the time of the survey, the blouses had been used for at least four years, and all respondents mentioned still had their blouses and still had them as part of their wardrobe. All respondents replied that the shirt was still in good condition: “super”, “they look like new shirts”, “very good condition”, “the condition is still fine”, “it looks completely new”. The quality was complimented, and the condition was said to still be fine even if they had used the blouse a lot and washed and ironed it often. While all respondents still use the blouse, six respondents especially mentioned using the blouse often. One respondent owning two blouses mentioned the condition to be perfect even after a lot of washing and ironing, and added that this is their independent opinion (“I am not trying to be nice”). Based on the status of the blouse after 4-4.5 years of use, it can be assumed that the blouses still have at least a few years of use ahead.

For comparison, according to the final PEFCR for apparel and footwear (Quantis, 2025), average shirts and blouses are estimated to be used 40 times during their life cycle, including all kinds of reuses. In Gray (2023), a shirt in a conventional wardrobe is estimated to have a lifespan of 4.4 years, with 38.5 wears per life, washing after every two wears, and a total number of owned shirts being 8.9 (Gray, 2023). In the study of de Albuquerque Landi et al. (2023), the shirt was calculated to have 240 days of use (meaning a total of 8 months) and was used for 2 years.

The high-quality, tailor-made blouses can be assumed to be used for longer than average blouses. Based on the current and ongoing lifespan, they have the potential to have twice as long a lifespan as conventional blouses. This would mean that by choosing a tailor-made blouse, emissions from manufacturing one new conventional blouse could be avoided, as customers wouldn’t have to buy a new one. Therefore, the benchmark for a tailor-made blouse could be the manufacturing of two conventional blouses with a shorter lifespan.

4. Case 4: Clothing pre-order

Case Company 4, TWOTHIRDS (later “the company”), is a Spanish small-medium-sized[7] company that has built its business on a pre-order service. The company is located in the CRAFT-IT4SD pilot site in Northeastern Spain in Catalonia. With its business model, the company primarily aims to tackle the overstock problem in the fashion industry. As defined by Hejlova (2025), overstock refers to surplus inventory that exceeds current demand, which typically results from overproduction or inaccurate demand forecasting, leading to excess products that need to be sold off, often at discounted prices.

The company initially sold their products in a brick-and-mortar store but later began running an online pre-order service to reduce waste and overproduction. The company focuses on sustainability, using local suppliers, sometimes turning deadstock materials into limited-edition collections. As explained in Chapter 1 in Appendix 1, deadstock refers to unsold inventory that remains unused and is often left over from previous seasons or cancelled orders, and it can include both fabric and finished garments that were never sold (Hejlova et al., 2025).

The company offers both women's and men’s wear, including items such as t-shirts, blouses, shirts, sweaters, dresses, jackets and pants. They produce all their clothing in close locations in Europe, and also source many of their fabrics and yarns from Europe. The company’s customers are located in several European countries.

The company has been working on improving product quality, eco-design, durability, longevity, and recyclability of its products. This has included working on obtaining sustainability certifications and providing more detailed certifications and sustainability data for their product. They have also been considering implementing a take-back system and repair platform.

4.1 Aim and scope of the carbon footprint study

4.1.1 Aim and product system description

The aim of the study was to investigate the **climate impact** of a pre-ordered pair of jeans delivered directly to the customer’s home **without retail involvement**. The primary material used for the jeans is organic cotton. The **fibre production** takes place outside of Europe, while the textile production occurs in Portugal. **Additional components** include a zipper and a brass button, assumed to be imported from outside of Europe. Sales primarily occur in the European market°, although there are clients on five different continents.

To identify the impact of the **pre-order business model** on the product’s climate impact, particular attention was devoted to the contribution analysis. The focus was on the relationship between production (which is reduced through the pre-

[7] EURATEX (2024) defines small companies as consisting of 10 to 49 employees and medium companies as consisting of 50 to 249 employees.

order business model, aimed at combating overproduction) and delivery, which was assumed to require more transport in a pre-order business model compared to a **traditional retail business model.**

It should be noted that the conclusions on the climate impacts of different business models were drawn at a screening level. These are not intended (and shall not be communicated) as a comparative study, since data with different levels of representativeness were used for the different life cycle stages.

The results of the study serve to inform the company's management about the climate impacts of their business model based on the analysed product. Similar to the other company cases presented in this deliverable, this knowledge can be used to steer procurement decisions and product design. If the study is intended for consumer communication, it is recommended to ensure that legislative requirements (e.g., national and EU-level consumer protection legislation) are considered carefully.

4.1.2 Scope of the study

The **functional unit** was a pair of jeans, packaged, delivered to the client. The **reporting flow** was defined as a piece of apparel with 0.5 kg net mass and 0.255 kg packaging.

The **system boundary** was cradle-to-client's doorstep, since the focus was on the business model specificity of reducing production (by fighting overproduction) and relying on doorstep delivery as a method to hand over goods. Given the considerable return rate of apparel sold online and the company's no-waste policy, the delivery of the returned share of the product to three successive clients was taken into account. The system boundary is illustrated in Figure 25 below, highlighting the life cycle and product return steps included in the analysis.

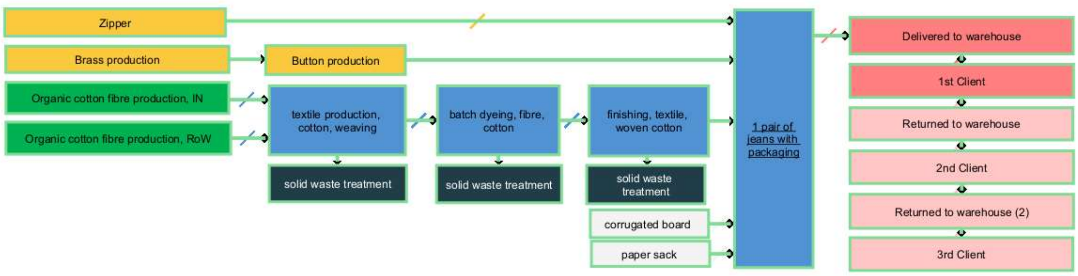

Figure 25. System boundary of the study

The company provided estimates on the jeans' mass, the origin of the organic cotton, the manufacturing steps and locations, the sales countries and their share of total sales, and the return rate. No primary inventory data was available, which led to the use of secondary data originating from life cycle inventory databases (ecoinvent 3.11) and scientific publications. The product system model was carried out using the Sulca software, version 5.3.4.

Assumptions regarding both the production waste that originates at each step of the production process and the means of transport used were based on the draft PEFCR (Quantis, 2021). The losses and waste along the garment manufacturing value chain were accounted for in the modelling according to the same source, and are detailed in Table 18 below. Transportation distances, modes, and packaging specifications provided by the draft PEFCR were used to address data gaps within the supply chain and delivery with estimates.

Table 18. Garment mass at different life cycle stages based on losses and waste along the apparel value chain (cradle-to-gate, without considering overproduction)

Manufacturing stage	Mass [kg]*
Mass before spinning	1.357
Mass before knitting	1.275
Mass before weaving	1.274
Mass before dyeing	1.259
Mass before finishing	1.256
Mass before assembly	1.250
Final mass	1.000

* Calculations based on Quantis (2021)

From a **data quality** perspective, the study aimed at achieving fair to good regional, temporal and technological data representativeness for the delivery phase. A lower data quality was expected for the production phase, whose assessment was solely based on the secondary data.

A **cut-off** criterion of 1% was established. **Processes** that were expected to contribute to less than 1% of the product's mass or energy consumption were not included in the model. This led to the exclusion of infrastructure processes such as machinery production, logistics, and secondary packaging along the supply chain. The end-of-life of the product's packaging, on the other hand, remained unconsidered because it lay outside of the system boundary. Also, the environmental impact related to the headquarters of the company, which administers the sales platform and commissions the jeans production, was not considered due to a lack of data. It was, however, expected to amount to less than 1%.

4.2 Life Cycle Inventory Analysis

The following **production processes** were modelled in the study:

- The production of the jeans button, which involved sequential processes of brass production followed by button manufacturing.
- Textile production value chain, from the organic cotton fibre production, through weaving, dyeing and finishing, to the production of one pair of jeans. As for the origin of organic cotton fibres, these were assumed to come from India (23%) and other cotton-producing countries (77%). This was the most precise proxy, taking into account India's share of global cotton production (Government of India, 2022) as well as the limited regionalisation of ecoinvent datasets.
- The production waste related to the following textile production processes: weaving, dyeing, and finishing.
- Product packaging, including corrugated paperboard and a paper bag.

A detailed overview of the data used for modelling materials and production processes is provided in Table 19.

Table 19. Data used for modelling materials and production processes

Life cycle stage	Material /component	Input/ output/ waste	Amount	Unit	Material (specification)	Location	Material datasets
Cotton production	cotton	output	660.7467	g	Organic cotton (producer's GOTS certification available)	unknown; 23% India, 77% RoW assumed due to regional shares and availability of life cycle inventory data.	Ecoinvent: Fibre production, cotton, organic, ginning.
Fabric production (spinning, weaving)	cotton	input	660.7467	g	Organic cotton	Portugal	Ecoinvent, textile production, cotton, weaving, RoW
Fabric production (spinning, weaving)	cotton	output	612.9466	g	Organic cotton	Portugal	
Fabric production (spinning, weaving)	cotton	waste	47.80011	g	Organic cotton	Portugal	Ecoinvent: market for municipal solid waste, Portugal
Fabric washing	yarn	input	612,9466	g	Organic cotton	Portugal	Ecoinvent: batch dyeing, fibre, cotton, RoW
Fabric washing	yarn	output	611.7938	g	Organic cotton	Portugal	

Life cycle stage	Material /component	Input/ output/ waste	Amount	Unit	Material (specification)	Location	Material datasets
Fabric washing	yarn	waste	1.152849	g	Organic cotton	Portugal	Ecoinvent: market for municipal solid waste, PT
Component production	button	input	3	g	Brass	China	Ecoinvent: brass production, RoW; metal working, average for metal production manufacturing, RoW
Component production	zipper	input	10	g		China	Zhou et al. (2023)
Jeans Finishing and Assembly	fabric	input	611.7938	g		Portugal	Ecoinvent: finishing, textile, woven cotton, GLO
Jeans Finishing and Assembly	fabric	output	487	g		Portugal	
Jeans Finishing and Assembly	fabric	waste	124.7938	g		Portugal	Ecoinvent: market for municipal solid waste, PT
Packaging	corrugated cardboard	output	250	g	corrugated cardboard	Portugal	Ecoinvent: corrugated board box production, RER
Packaging	paper bag	output	5	g	paper	Portugal	Ecoinvent: paper sack production, RER
1 pair of jeans with packaging	Functional unit	output	755	g			

The following production-related **transport processes** were included in the study:

- Transport cotton from fibre production to fabric production: assuming the cotton fibre production takes place outside of Europe, a distance of 19,000 km was assumed (18,000 km ship transport, 1,000 km EURO 4 lorry), in line with the draft PEFCR guidelines (Quantis, 2021). The same applied to the transportation of buttons and zippers.
- Transport of fabrics from production to dyeing and from dyeing and from dyeing to finishing: the three locations were very close to each other (distances: 6.9 km and 11.6 km), therefore transport between the locations was assumed to be carried out via van.

Transport processes were also involved in the **distribution phase**. First, the transport from the jeans production facility in Portugal to a warehouse in Germany was modelled according to the specific distance between the locations and the transport mode assumptions required by the draft PEFCR (Quantis, 2021) (truck, capacity >32t, EURO4). For the transportation from the logistics centre to clients, the geographical distribution of the orders of the company (a total of 40 countries plus one unknown category) was taken as a starting point.

The following procedure was followed for further calculations:

1. The top nine countries by number of sales, which were responsible together for 90% of total sales, were selected.
2. A proxy for country-specific delivery transport distances for these countries was calculated based on the distance between the warehouse and the capital city.
3. All nine countries being located in Europe, the draft PEFCR (Quantis, 2021) transport assumptions were considered. The transportation took place via truck (>32t, EURO 4) for all countries except for the UK. In this case, transportation partly via plane was considered as well.
4. As a proxy for non-European and unknown countries, deliveries to the US were used (via plane and truck).
5. In the end, a weighted average of the transport distances for each means of transport was taken into account to assess the transportation to the 1st client.
6. For the following transportation processes, a return rate R=27,4% was considered. This factor was applied to the transportation processes: *1st client à returned to warehouse à 2nd client*. For the transportation processes *2nd client à returned to the warehouse (2) à 3rd client*, a return rate amounting to R^2 was applied.

4.3 Life Cycle Impact Assessment

The application of the EF 3.1 method allowed for the identification of the climate impacts of the product system (a pair of jeans) within the system boundary illustrated above (cradle-to-client's doorstep), measured as GWP in kg of CO_2e.

The total climate impact amounts to 5.38 kg CO_2e. The analysis is visualised in Figure 26, showing that about 90% of the climate impacts occur between raw material production and the finishing step.

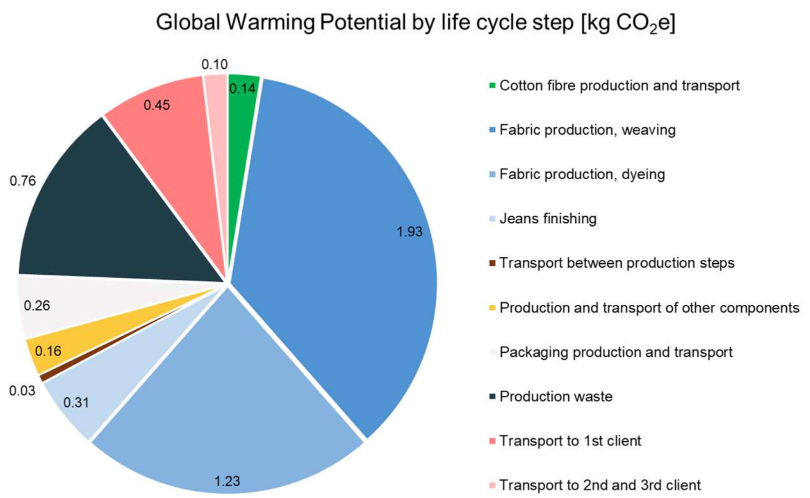

Figure 26. Climate impacts of a pair of jeans by life cycle step, as GWP (kg CO_2e)

The production and transport of cotton fibres and other components (the zipper and button) accounted for 3% of the climate impacts each. The largest share was caused by the fabrics production and jeans finishing category (65%), followed by the treatment of production waste (14%) and the packaging, production and transport (5%).

Downstream (i.e., post-production) logistics were responsible for about 10% of total impacts, with the transportation to the first client accounting for 8% and further transport (to the second and third client) for about 2%.

Among the processes involved in the production of fabrics and jeans, cotton weaving and dying had the highest impact shares (55% and 35%, respectively), while the finishing process accounted for 9%.

The climate change impacts were predominantly of fossil origin (89%), mainly driven by the carbon dioxide emissions taking place in textile production and transport processes. Biogenic emissions (8% of total) mainly originated during the solid waste treatment processes related to the production waste generated at different manufacturing steps. Land use and land use change (LULUC) emissions played a minor role (3%) in this product system and are mainly linked to the production of cotton fibres.

4.4 Discussion

4.4.1 Interpretation of the carbon footprint results

The results presented above need to be interpreted regarding the selected system boundary, the selected datasets and their quality. The system boundary was cradle-to-client's doorstep, i.e., the use and end-of-life phase of the jeans were not considered. This approach is in line with the aim of the study, which addressed the effects of the specific system model (pre-order and no-waste in the distribution phase), which can be expected only in the first part of the value chain of a textile product. Still, it should be acknowledged that, depending on the washing temperature and the energy source used to heat the water, the share of the cradle-to-grave carbon footprint related to washing can strongly vary. More insights on this topic can be found in section 3.2, which presents the case study of clothing rental. Similar considerations apply to the product's lifetime and end-of-life phase. These strongly differ depending on consumer behaviour and initiatives in place at the local level that allow for making use of the upper steps of the post-purchase opportunities offered by the waste hierarchy, e.g. reuse and recycling.

Particular attention in results interpretation needs to be dedicated to the quality of the data used. For the different production steps, which ranged from cotton harvesting through cotton weaving, fabric dyeing and jeans finishing, no primary data from the involved processes were available. To allow for an estimate, secondary data from the LCA database was used. Such datasets mainly rely on generic production mixes (world averages) and do not always allow accounting for all relevant characteristics, such as the regional specificity, e.g. the efficiency of applied technologies and the local energy mix. However, the origin of the organic cotton was able to be accounted for due to the availability of a specific dataset in the ecoinvent database.

A certain level of uncertainty is also determined by the calculation procedure for the transport processes for delivery. The transport distance was calculated based on the distance between the production facility and the logistics centre (both known), and the distance between the logistics centre and the country of delivery. For the latter, the location of the capital city (and therefore its distance from the logistics centre) was taken as a proxy. This might have led to an underestimation of the transport distances, since capital cities are mainly located closer to main routes or airports, while the average transportation way to be covered might also include routes in the suburbs and countryside.

To sum up, the highest climate impacts were detected for the production processes, which were modelled relying on generic production data and lack representativeness. To obtain more precise data, the company should analyse in depth the impact of production in the three different locations by collecting specific data from the producers on energy and chemicals consumption. A detailed analysis of the specific production steps would help identify and plan targeted mitigation measures. Specific data from the very beginning of the supply chain (cotton producers) would allow for a more precise estimate of the agricultural processes as well.

More conclusions can be drawn from the analysis of the transport to the client. It can be estimated that sales to overseas (with aeroplane as assumed mode of transport) are far more carbon intensive than those to continental Europe, assumed to be carried out via road (0.84kg CO_2e/tkm vs 0.15 kg CO_2e/tkm according to ecoinvent 3.11 datasets). It would therefore be recommendable to steer marketing to countries situated as close as possible to the production location to limit transport-related emissions. This can be obtained by concentrated marketing efforts in South-West and Western European countries.

A last consideration regards the use and end-of-life phase, not accounted for in this study, but highly dependent on consumer behaviour. To leverage this, the company could provide via e-mail tips regarding the washing frequency and temperature and indications about the most environmentally favourable way to handle textile waste in the buyer’s country.

4.4.2 Benchmark product and impact of the business model

What effects does the company’s pre-order business model, coupled with the firm’s no-waste policy, have on the product’s climate impact? To carry out an estimate, the impact of the business model needs to be taken into account, i.e., the difference in emissions between a pre-order model (for which no waste in the distribution phase is assumed) and a production model that does not avoid overproduction.

According to Duhoux et al. (2024), out of 100 produced textile products, 21 remain unsold because they do not meet a real demand. Considering also the fact that in a “baseline scenario” the delivery to the 2nd and 3rd customer do not take place, because no no-waste policy is in place, a pre-order system following a no-waste policy allows avoiding one fourth of jeans production and 19.4% of climate-related impacts, i.e., 1.35 kg CO_2e per pair of jeans. This is illustrated in Figure 27.

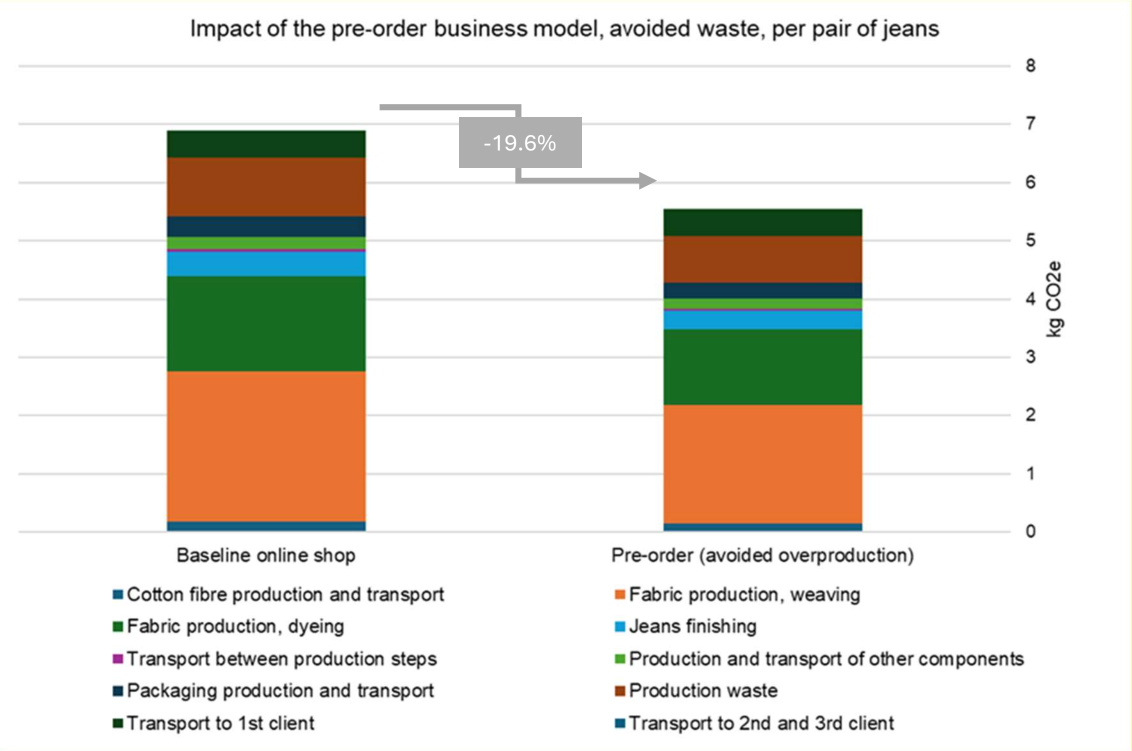

Figure 27. Impact of the pre-order business model

Appendix B: Literature review on climate impacts of the take-back business model

1. Introduction

A literature review was performed for a take-back business model in which a garment is resold by the brand that manufactured the garment or commissioned the manufacturing of the garment to its supply chain partners. This business model is hereafter referred to as the take-back business model. This take-back business model was selected among other take-back business models because it enables the take-back service offering company to have the most control and/or visibility over the supply chain activities and related data.

Previously, similar literature reviews have been performed. Abagnato et al. (2024) carried out a review on LCA studies on reuse, recycling and circular practices for textiles. Moazzem et al. (2022) reviewed literature on the environmental impacts of the apparel supply chain of textile products. Sandin and Peters (2018) focused on reviewing literature on textile reuse and recycling. The literature review presented in this deliverable presents a novel view by reviewing only articles related to the climate impact of the take-back business model.

1.1 Goal

Compared to the other case studies presented in this deliverable, this business model assessment does not apply LCA methodology in a case study. Instead, a literature review is carried out to answer the following research questions:

1. What is the potential climate impact of the take-back business model compared to the business-as-usual model?
2. What are the potential climate hotspots of the take-back business model?
3. What are the uncertainties and data gaps which should be considered when evaluating the potential climate impacts of the take-back business model?

2. Methodology

The review was based on a search of academic scientific articles, either from scientific journals, conferences, books or book chapters. Publications of industrial associations or companies were excluded from the review. The articles were searched on March 25th 2025, from Scopus and Web of Science academic research and publications databases. The detailed article selection process is described in Figure 28, and the search terms are in Figure 29. The search contained keywords such as take-back, resale, reuse and second-hand, LCA, carbon footprint and fashion. The article selection process follows the principle of the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) model by Page et al. (2021) was followed to select the studied articles. Additionally, articles which are not included in the database search results are included if they are considered relevant. These articles are shown separately in Figure 28.

As seen in Figure 28, at the identification stage, in total of 355 articles were found, 175 from Scopus and 180 from Web of Science. From these, 105 duplicates were removed, resulting in 250 individual articles. In the screening stage, the articles which do not belong to the fashion sector are excluded. At this stage, in total of 126 were excluded, and 124 articles were included in the eligibility assessment step 1. In step 1, the articles were screened again to check was their content was in line with the search terms. At this stage, in total, 73 articles were excluded due to the reasons listed in Figure 28. Hence, 51 articles continued to the eligibility assessment step 2, in which it was checked if the article contained a quantitative climate impact assessment. 30 articles were excluded at this step. Therefore, 21 articles continue to step 3, in which the articles were screened in more detail. At this stage, 11 articles were excluded for the reasons listed in Figure 28. Finally, 10 articles from the database searches were included in the review. Additionally, one article outside the database search was included in the assessment. This article was discovered in the screening stage as it was cited in the screened articles. Articles from all geographic areas and years were included. However, during the screening process, one article was removed due to too old data used in the LCA. In total, 11 articles were included in the review.

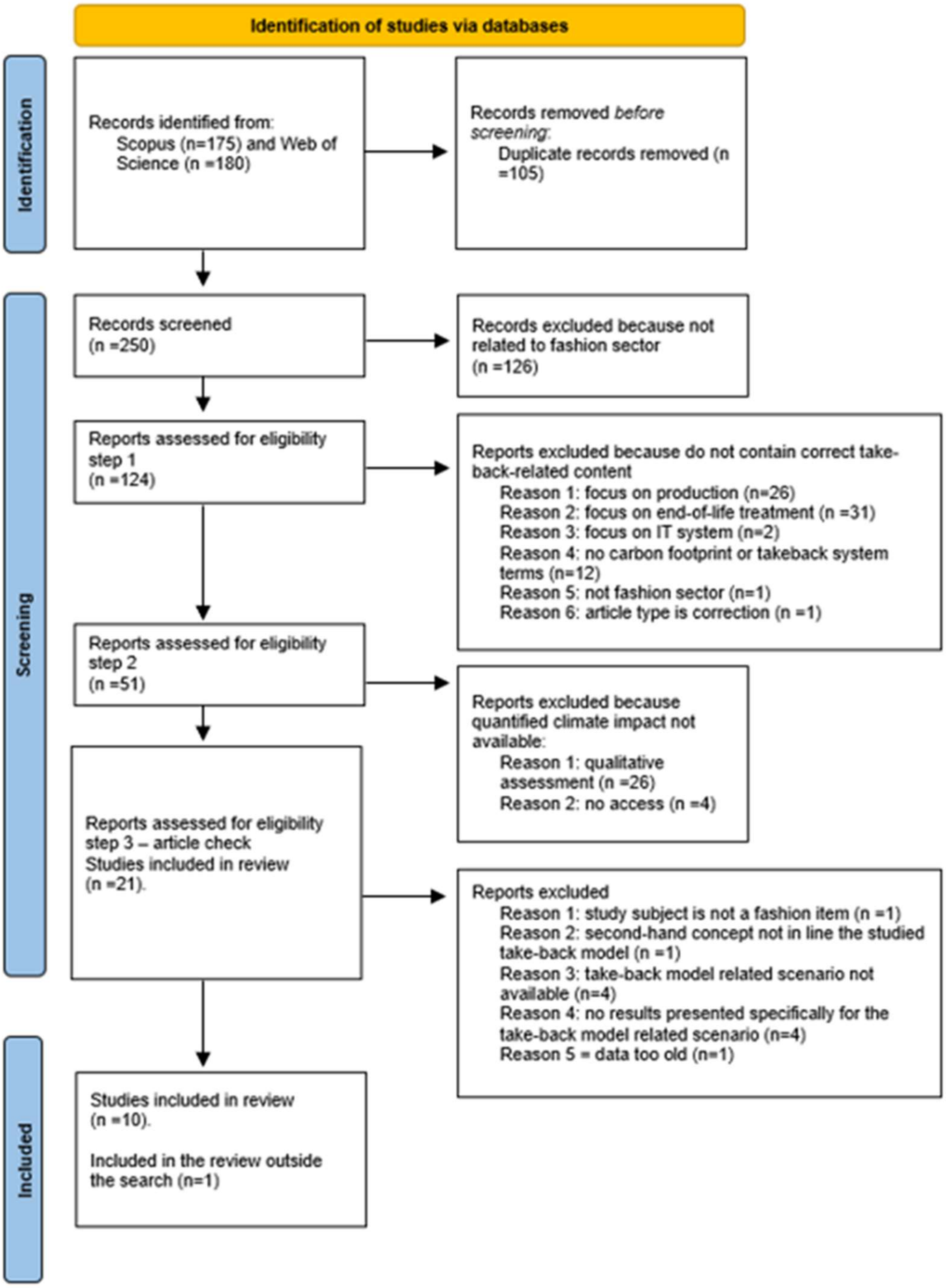

Figure 28. Take-back business model literature review article search process

Scopus	(TITLE-ABS-KEY ("take back") OR TITLE-ABS-KEY ("take-back") OR TITLE-ABS-KEY ("takeback") OR TITLE-ABS-KEY ("resale") OR TITLE-ABS-KEY ("re-sale") OR TITLE-ABS-KEY ("second hand") OR TITLE-ABS-KEY ("second-hand") OR TITLE-ABS-KEY ("secondhand") OR TITLE-ABS-KEY ("reuse") OR TITLE-ABS-KEY ("re-use") AND TITLE-ABS-KEY ("life cycle assessment") OR TITLE-ABS-KEY ("LCA") OR TITLE-ABS-KEY ("carbon footprint") OR TITLE-ABS-KEY ("climate") AND TITLE-ABS-KEY ("textile") OR TITLE-ABS-KEY (cloth*) OR TITLE-ABS-KEY ("fashion"))
Web of Science	((ALL=("take back") OR ALL=("take-back") OR ALL=("takeback") OR ALL=("resale") OR ALL=("re-sale") OR ALL=("second hand") OR ALL=("second-hand") OR ALL=("secondhand") OR ALL=("reuse") OR ALL=("re-use")) AND (ALL=("life cycle assessment") OR ALL=("LCA") OR ALL=("carbon footprint") OR ALL=("climate")) AND (ALL=("textile") OR ALL=(cloth*) OR ALL=("fashion")))

Figure 29. Search terms of the take-back business model literature review

3. Reviewed articles

The reviewed articles are shown in Table 20 where the following information about the articles was compiled:

- Author(s)
- Studied geographic area
- Used methodology
- Scenario most related to the take-back business model
- Business-as-usual scenario
- Functional unit
- Which life cycle stages are included in the article (system boundary)
- Take-back business model climate impact compared to the business-as-usual scenario
- Take-back business model climate impact sensitivity analysis
- Take-back business model climate impact contribution analysis per life cycle stage
- Inclusion of the garment's environmental impact from its previous life in the climate impact assessment
- Inclusion of the displacement ratio of new clothing in the assessment and used ratios
- Uncertainties and data gaps.

Information about the previous life environmental burden and displacement ratio was included because, during the article analysis process, these methodological choices typically have an impact on LCA studies.

Based on the column *Scenario most related to the take-back business model* in Table 20, none of the included articles studied the take-back model, where the consumer returns the garment to the same brand where he/she bought the garment. Hence, this literature review does not provide sufficient information to answer directly the research questions. However, the articles listed this column study garment reuse and resale through second-hand scenarios, providing information from a related system, which can be used to gather initial information about the climate impact of the take-back business model.

As shown in Table 20, three articles were review studies (Abagnato et al., 2024; Moazzem et al., 2022; Sandin & Peters, 2018). The other eight articles are LCA studies. Within the LCA studies, different second-hand sales channels were examined. In two articles, a scenario for a second-hand shop was studied (André, 2024; Levänen et al., 2021; Wiedemann et al., 2021). In one article online second-hand market platform was studied (Moon, 2024). In two assessments, both the second-hand shop and online platform are examined (Li et al., 2024; Mora-Sojo et al., 2023). And in three articles, the second-hand acquisition channel is not defined (Shou & Domenech, 2022; Wiedemann et al., 2021; Wiprächtiger et al., 2022). Some of the studied articles also contained other circular economy scenarios than the second-hand and baseline, such as rental and recycling. These other scenarios were excluded from this literature review.

Table 20. Reviewed articles in the take-back business model literature review

Author(s)	Geography	Method	Scenario most related to the take-back business model	Business as usual scenario (baseline)	Functional unit	System boundary	Take-back climate impact compared to the baseline. How many % smaller (-) or bigger (+) the scenario most related to the take-back business model impact is than the baseline	Take-back sensitivity analysis parameter – result	Take-back contribution analysis,% of the total climate impact	Burden from previous life included (yes/no)	Displacement ratio	Uncertainty and/or data gaps (take-back related)
Abagnato et al. (2024)	-	review	-	-	-	-	-	-	-	-	-	-
André (2024)	Sweden	LCA	Shell jacket purchased from a premium second-hand store of the garment type	One user of the shell jacket	1 year's use of a shell jacket that is trusted not to break and to keep its user comfortably warm and dry. Sensitivity analysis contains various FUs.	Jacket production and use	In state-of-the art LCA: -34% In the studied framework LCA: +6%	1) functional unit definition two-user scenario is +18-+53% 2) reference scenarios for the first life cycle: two-user scenario is -55% - +13% 3) displacement rates a) FU 1 year use (constant functionality +6% - -11% b) FU 100 use occasions (constant functionality) + 78- + 43%	No breakdown analysis available	Yes	Tested 0.75, 0.89 and 1	Limited sample of user survey respondents for use stage parameters

								4) rebound effects +6-+98%				
Li et al. (2024)	global	LCA	online and offline second-hand platform	Fast fashion and traditional fashion	One wear of jeans	Production of fibre and jeans, distribution and retailing, storage, consumption, and disposal	C2B2C online: fast fashion -90%, traditional +0.1%, C2B2C offline: fast fashion -90%, traditional + 0.1	-	C2B2C online: 45% consumption and 30% production (jeans) C2B2C offline: 45% consumption and 31% production (jeans)	Yes	-	The wear lifespan of second-hand garments under different mitigation strategies
Levänen et al. (2021)	EU	LCA	Second-hand domestic shop	Basic use with waste incineration	200 uses of jeans and electricity, and heat associated with disposal, the reuse of used jeans, and produced textile fibre	Manufacturing, delivery, use, end-of-life or second life and alternative production processes	Base -35*%,	-	Production 90*%, delivery+use+end of life 6*%	Yes	1:0.5	Limited understanding of behavioural changes which are needed for circular practices
Moazzem et al. (2022)	-	review	-	-	-	-	-	-	-	-	-	-
Moon (2024)	Japan	LCA	Online flea market platform	Offline store shopping and incineration	Item	Second-hand: distribution and usage New clothing: production, distribution, usage and EOL	- 45 to -96% depending on the clothing type If replacement takes place, 61%	-	98.5% usage and 1.5% distribution	No	Depends on the garment condition, ranging from 85.1% to 75%	Need to take into account the potential increase in consumption when purchasing second-hand clothing for money savings. And studying the climate impact of product types
Mora-Sojo et al. (2023)	Norway	Material flow analysis (MFA)	Second-hand physical retail and	Physical retail and e-commerce	Whole study: one year of Norwegians'	Production, transport of goods, consumer	Physical retail second-hand:	Type of garment – no changes in the climate	Physical retail second-hand: ca. 100*% consumer mobility	No	1:1	Possibly too optimistic replacement ratio 1:1,

		and LCA.	second-hand ecommerce	of new garments	households' apparel needs met by acquisitions -More detailed per process: kg of garment	mobility, facility management, laundry and incineration	physical retail new - 91*%, e-commerce new - 90*% e-commerce second-hand: physical retail new - 98*%, e-commerce new -98*%	impact of the physical retail, second-hand and e-commerce second-hand, impact visible in other acquisition channels	e-commerce second-hand: ca. 100*% consumer mobility			transport and mobility assumptions
Sandin & Peters (2018)	-	Review	-	-	-	-	-	-	-	-	-	-
Shou & Domenech (2022)	Europe	LCA	Second-hand handbag	One-user handbag	One handbag	Leather production, handbag manufacturing, distribution, end-of-life	-58%	-	83% production unreplaced handbags, 13% disposal, 4% transport from 1st to 2nd user	No	0.65	Displacement rates specifically for handbags, durability and biodegradability of handbags, lack of specific process data
Wiedemann et al. (2021)	global	LCA	Second+third user and the same user continues to wear the garment	Current practice (various parameters)	One wear of a wool sweater (pullover) weighing 0.3 kg is used in Western Europe.	Merino wool production in Australia, wool processing and garment manufacture in China, retail, use and disposal in Western Europe.	Best reuse practice compared to other best use practices: **-28% current practice**, -21 % use of more efficient washing machines, -29%reduced use of machine clothing dryers, +140% increasing number of garment	-	-	Yes	-	- inventory data from limited geographic area - more representative use phase inventory data needed - in the future more fibre types should be studied

							wears before disposal, +200% combined options					
Wiprächtiger et al. (2022)	Switzerland	MFA and LCA	Reuse as garments exported for reuse abroad are reused as second-hand clothing	Continuation of current practices with consumption and disposal manners	The clothing needs of the Swiss population in 1 year	production, transport, use and waste management	+5%	Substitution 60%: 0% Substitution 100% - 9%	garment production 81%, use 13%, retail 8%, local reuse substitution -7% rebounds 5%, other between - 0,57% to 1.04%	Yes	34%	Obtaining values for diffusion, substitutability and rebounds, variation of rebounds. A tailor-made consumer survey could reduce uncertainties.

4. Results

4.1 Research question 1: What is the potential climate impact of the take-back business model compared to the business-as-usual model?

It should be noted that the results of an LCA study are always valid only for the studied article, which applies specific modelling decisions. These decisions are, for example, which garment life cycle stages are included, what assumptions are used and what benchmark is applied. Hence, drawing conclusions based on a single article is not possible and nor are the articles comparable to each other. Instead, the following result chapters highlight trends found in the articles to demonstrate the key aspects of evaluating the second-hand business model climate impact.

Based on the reviewed literature, the second-hand business model climate impact is not always smaller than the business-as-usual business models (hereafter referred to as baseline scenario). In four out of the eight reviewed articles, the climate impact of the second-hand business model was smaller than the baseline scenario and in four articles, in some of the studied scenarios, the second-hand business model had a higher climate impact than the baseline scenario.

In the four articles where the second-hand business model had a lower climate impact, the extent of the impact compared to the baseline varied. The highest decrease in the climate impact was reported by Mora-Sojo et al. (2023) with a 98% smaller climate impact of the second-hand business model compared to the baseline scenario. Also, the results by Moon (2024) and Shou and Domenech (2022) showed a substantial decrease in climate impact with decreases of 45% to 96%, depending on the clothing type and 58%, respectively. These three studies had in common that the garment production phase was excluded from the LCA. Oppositely, Levänen et al. (2021) included the garment production in the second-hand scenario and reported a climate impact with a more modest decrease of 35% compared to the baseline study. These four studies differed in terms of the applied replacement rates. Only the assessment by Mora-Sojo et al. (2023) assumed that the second-hand garments completely replaced (100%) the purchasing of new clothing. Other applied rates are 75% to 85.1% depending on garment condition (Moon, 2024), 65% (Shou & Domenech, 2022) and 50% (Levänen et al., 2021). Among the four articles, only Mora-Sojo et al. (2023) carried out a sensitivity analysis related to the second-hand clothing scenarios. The analysis showed that the climate impact of garments purchased as second-hand is similar for various clothing types.

In the four studies in which the second-hand scenario did not show a smaller climate impact in all the studied scenarios, various assumptions were used in the LCA studies. In the article by André (2024), the two-user scenario of a shell-jacked had a 34% smaller climate impact when the state-of-the-art LCA method was applied. But if the framework proposed in the study was applied, the climate impact of the two-user scenario was 6% greater than the baseline. André (2024) performed various sensitivity analyses in which the climate impact of the two-user scenario compared to the baseline varied widely depending on the sensitivity analysis parameters. The analysis was performed on functional unit definition, reference scenario for the first life, displacement rate on how much the second-hand garment replaces new clothing and rebound effects related to the first user re-spending the potential income from selling the jacket. The climate impact of the second-hand business model compared to the baseline in the sensitivity analysis is shown in Table 20.

In the study by Li et al. (2024), the climate impact of second-hand clothing in store or online had 90% smaller climate impact than the fast fashion baseline, but 0.1% higher climate impact than the traditional fashion scenario. In the study of Wiedemann et al. (2021) related to merino wool sweaters, the climate impact of the best reuse practice had a 28% smaller climate impact than the baseline current practice. In the assessment of Wiedemann et al. (2021), other practices (use of more efficient washing machines, reduced use of machine dryers, increasing the number of garment wears and combined practices) were also analysed, and the reuse practice's impact ranged from being 29% smaller to being 200% higher compared to the other best practices. Wiprächtiger et al. (2022) studied the Swiss clothing system as a whole and included a scenario related to reuse in which the exportable garments were directed to be reused as second-hand clothing in Switzerland. This scenario's climate impact was 5% higher than the baseline. Also, different substitution rates were applied. With a 60% substitution rate, the reuse scenario's climate impact was equal to the baseline and with 100% substitution, the climate impact of the reuse scenario was 9% smaller than the baseline's.

4.2 Research question 2: What are the potential climate hotpots of the take-back business model?

As seen in the column *System boundary* in Table 20, the analysed studies included different life cycle stages in the LCA. These differences in system boundaries impact the analysis of this research question. The draft PEFCR for apparel and footwear (Quantis, 2021) indicate that the main apparel life cycle stages are raw materials acquisition and pre-processing, manufacturing, distribution, use and end-of-life. Under these main life cycle stages, there are various sub-life cycle stages in the draft PEFCR, which are also included differently in the studied articles. Among the analysed LCA articles, all the main life cycle stages were included in the assessments of Li et al. (2024), Levänen et al. (2021), Moon (2024), Wiedemann et al. (2021) and Wiprächtiger et al. (2022). Shou and Domenech (2022) included all the other main life cycle stages except use, and André (2024) only raw material acquisition, production and use.

Based on the column *Take-back contribution analysis,% of the total climate impact* in Table 20, it can be observed that the hotspots of the second-hand business models varied in each of the studied articles. In the studies by Levänen et al. (2021) and Wiprächtiger et al. (2022), raw material acquisition and production life cycle stages contributed significantly the most to the climate impact of the studied scenarios, corresponding to 90% and 81% of the total climate impact, respectively. Use-stage dominated the results of Li et al. (2024) and Mora-Sojo et al. (2023) with shares of 45% and 98.5% of the total climate impact, respectively. Mora-Sojo et al. (2023) evaluated that consumer mobility covered almost all the climate impact. The hotspot of the article by Shou and Domenech (2022) was the production of the unreplaced handbags of second-hand handbags.

4.3 Research question 3: What are the uncertainties and data gaps which should be considered when evaluating potential climate impacts of take-back business model?

The following uncertainties and data gaps were identified per theme in the second-hand climate impact studies. The list was compiled based on the column *Uncertainty and/or data gaps (take-back related)* in Table 20.

- Modelling parameters:
    - use stage (André & Björklund, 2023; Wiedemann et al., 2021)
    - replacement ratio (Mora-Sojo et al., 2023; Wiprächtiger et al., 2022)
    - transport and consumer mobility (Mora-Sojo et al., 2023)
    - the wear life span of second-hand garments (Li et al., 2024)
    - process specific data (Shou & Domenech, 2022)
    - data from a limited geographic area (Wiedemann et al., 2021)
    - obtaining values for diffusion and rebound effects (Wiprächtiger et al., 2022)

- LCA scope:
    - including the increased consumption related to money savings when second-hand garments are purchased (Moon, 2024)
    - studying the climate impact of various clothing types (Moon, 2024)
    - product-specific replacement ratios (Shou & Domenech, 2022)
    - studies for various fibre types (Wiedemann et al., 2021)

- Behavioural changes which are needed for circular practices (Levänen et al., 2021).

As seen from the list above, the uncertainties and data gaps were mostly related to the LCA modelling parameters and definition of activities included in the LCA study.

4. Discussion

The main observation of the literature review is that second-hand sales scenarios do not always have a smaller climate impact than business-as-usual scenarios where the garment is used by one user. The observation is in line with Sandin and Peters (2018), who performed a review of the environmental impact of textile reuse and recycling. However, Abagnato et al. (2024) reviewed literature on reuse, recycling and circular practices for textiles and concluded that among the studied circular economy practices, most environmental benefits arise from actions which extend the lifetime of textile products.

The results of LCA studies are highly dependent on the assumptions and modelling choices made during the assessment process. This was particularly visible in the diverse climate impact results and hotspots of the second-hand business model. This variability underscores the challenge of drawing direct and universal conclusions based on a single study. As highlighted by André (2024), conclusions regarding the environmental performance of reuse can be significantly influenced by the definition of the functional unit, the use of actual user behaviour data and the values used for displacement and rebound effects. Furthermore, Abagnato et al. (2024) compiled reuse-related LCA aspects which influence the results: modelling the use phase and the virgin production of replaced products, energy mix, burden allocation method, substitution factor and modelling of the transportation processes.

Conducting sensitivity assessments, as demonstrated in André (2024), provides additional insights and strengthens the robustness of the findings. Such approaches will be important in reducing variability and facilitating more consistent outcomes. While exclusions in garment production stages have been shown to yield higher decreases in greenhouse gas emissions, including a broader range of life cycle stages in LCA assessments significantly improves the robustness of the results. This is in line with Sandin and Peters (2018) who concluded that the environmental impact studies of textile reuse and recycling should be made from a life cycle perspective, considering collection and sorting processes, all relevant impact categories and state clearly key methodological choices and assumptions. Overall, there is a need for a more standardised approach to LCA methodologies to enhance the reliability and comparability of findings. The draft PEFCR for apparel and footwear (Quantis, 2021) serves as commendable initiatives aimed at standardising these calculations.

In addition, tailor-made consumer surveys, as recommended by Wiprächtiger et al. (2022) could serve as a valuable tool to mitigate uncertainties in LCA studies. This is especially relevant for the studied take-back business model, where brand loyalty potentially can play a role in extending the lifetime of the second-hand garment and make customers buy less new clothing and hence increase the replacement ratio of the second-hand garment.

5. Conclusions

The main observation of the literature review is that second-hand sales scenarios do not always have a smaller climate impact than business-as-usual scenarios where the garment is used by one user. This indicates that various aspects, especially the use phase, replacement of new clothing and burden allocation, are encouraged to be included in the climate impact assessment of take-back business models to ensure that the take-back business models' climate impact assessments are studied robustly.

It is recommended to use real user data for the use stage modelling decisions regarding the actual use of the garment and do they substitute buying new garments. In this type of survey, the potential climate benefits of the take-back business model could be realised if customers use second-hand items more frequently than the average second-hand user and if second-hand garments from preferred brands significantly replace the purchase of new garments.

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