Master's thesis

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Quantifying the Norwegian households' clothing system and its environmental impacts for a transition towards a more circular economy

Master's thesis in Circular Economy
Supervisor: Johan Berg Pettersen
Co-supervisor: Kamila Krych
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The following paragraph corresponds to the problem description presented in the master's agreement, approved by the Department of Energy and Process Engineering at the Faculty of Engineering at NTNU. This agreement was the base upon which this master's thesis has been elaborated.

Problem description

Based on the findings from the quantification of the Norwegian clothing system, for the year 2018, previously done by the candidate, she should elaborate different scenarios considering circular economy strategies for the lifetime extension of garments. For each scenario she should quantify the impacts that lifetime extension of garments could have on the Norwegian clothing system, and the environmental footprint of each scenario, making use of Life Cycle Assessment.

Summary

Norway has the ambition to be at the forefront of the transition towards a Circular Economy. To achieve this the country needs to drastically increase its circularity metric, which in 2020 indicated that only 2.4% of the total amount of materials, input to the economy every year, were cycled back. In addition, previous analyses of the Norwegian consumption have identified household consumption as one of the main contributors to Norway's environmental footprint. Within their consumption, clothing has stood out as one of the commodities driving their environmental impacts.

The clothing industry has been recognized for its linearity, which increases the pressure on the resources been used, and links the industry to environmental problems such as climate change, and chemical toxicity. This has made necessary to call for a disruptive change in the industry. Increasing clothing utilization and their lifespan, together with new business model that can satisfy the clothing needs in a more sustainable way, have been highlighted among the most relevant strategies to achieve this change. The potential of these strategies lies in their capacity to close, slow or narrow down the loops in the system, decreasing the demand for new garments, and consequently the environmental impacts associated to them.

Therefore, aiming to have a better understanding of the Norwegian households' clothing consumption, this master's thesis investigates the flows of clothing within Norway, and its environmental impacts for the year 2018. This is done using a Material Flow Analysis (MFA), as this tool provides a systemic approach to identify the flows and processes within the system. In addition, MFA allows to reach a level of detail that enables the analysis of the composition of these flows, which is highly relevant to understand the consumption patterns of clothes, and the opportunities for improving the circularity of the system. Furthermore, the results from the MFA are used as base to elaborate a Life Cycle Assessment (LCA) of the system on SimaPro. With the elaborated model, the impacts the system has on climate change, water scarcity and energy consumption, are analyzed. Lastly, the results from the MFA are modified to investigate how increasing the share of circular business models in the system can impact the flows and its environmental impacts.

Results from the MFA indicate that the overall consumption of garments for the year 2018 was of 62 400 tonnes of clothes, and that 7% of this consumption corresponded to garments recirculating within the Norwegian households' clothing system. The consumption of used garments was dominated by articles such as trousers and pullovers, whereas the consumption of new garments was dominated by articles such as underwear, which are considered as not suitable for reuse. The environmental impacts associated to the consumption, use and disposal of garments led to a climate change impact of 317 kg CO_2 per capita (3% of the Norwegian households' carbon footprint). When increasing the circularity of the system all the environmental impacts were reduced in approximately 8%.

The results obtained in this research, through the integrated approach using MFA and LCA, provide a good understanding of the complexity in the system and allows the identification of improvement opportunities, that are relevant in the transition towards a more circular economy.

Acknowledgements

First of all, I want to thank God for giving me this opportunity, and for connecting all the dots in such a perfect and amazing way. I could not feel more blessed and grateful for what all this process has been.

Thanks to my parents, for everything they have done to see me get here, giving me all I needed, including the courage to pursue this program. And to my brothers who have always been a huge inspiration and support. Since long ago you all built this dream together with me and you were key in every step to make it happen.

Thanks to Johan Berg Pettersen, my supervisor, for all your dedication, and engagement with this research, and all the interesting discussions along the way. And to Kamila Krych, my co-supervisor, not only for your technical contributions, but for being such a great support throughout the process. Both of you made of this project a very nice experience.

To Elisa, for being such a great company throughout this journey. Thanks for all the adventures, the endless talks, and all your support. I have really enjoyed sharing this part of the ride with you.

To all my family and friends in Costa Rica, who were always there before this started and despite the distance have been supporting me and demonstrating me their love.

And to all my friends in Chalmers and NTNU, I am really happy life has made us coincide, you have made of this a great adventure.

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Abbreviations

BAU Business as usual

BM Business model

CBM Circular business model

CN Combined Nomenclature

G garment category

LCA Life Cycle Assessment

MFA Material Flow Analysis

RG representative garment

RPP representative production process

RQ research question

1. Introduction

The Norwegian consumption

In a world where there is an increasing pressure on trying to diverge from the current linear socioeconomic system, the Norwegian government has announced that "Norway will be a pioneer in the development of a green, circular economy that makes better use of resources" (Regjeringen.no, 2020). However, the results presented in The Circularity Gap Report for Norway (de Wit et al., 2020) indicate that this is going to be a big challenge for the country, as its circularity gap was estimated at 97.6%, meaning that its circularity metric is only 2.4%. This last indicator measures the share of cycled materials as a proportion of the total material inputs into the economy on a yearly basis (de Wit et al., 2020).

The Circularity Gap Report for Norway also indicates that the country has one of the highest global rates of consumption per capita, with 44.3 tonnes of resources used per person. Therefore, the authors concluded that Norway should not only aim for an increase in circularity, but should also carry out strategies to reduce its overall consumption (de Wit et al., 2020). Otherwise, there is a risk of offsetting the environmental benefits obtained through technological improvements with a growth in environmental impacts due to an increase in demand (Bjelle et al., 2018).

The high levels of household consumption that have been identified in Norway reveal the importance of analyzing what is being consumed and the environmental impacts associated with it. This has been the subject of study of several authors (Ivanova et al., 2016; Steen-Olsen et al., 2016). For instance, Steen-Olsen et al. (2016) analyzed the composition of Norwegian household consumption in 2012, and identified that transport, furniture, and clothing were the three commodities with the highest carbon footprint per NOK expended.

The clothing challenge

For the purpose of this master's thesis, there is special interest in the consumption of clothing, as it is associated with high environmental impacts. Research from the European Topic Centre on Waste and Materials in a Green Economy (ETC/WMGE, 2019) indicate that within the EU, the consumption of clothing, footwear and household textiles is ranked as the fourth consumption domain with the highest pressure for primary raw materials use and for water use, and it is ranked in fifth place for greenhouse gas emissions. This links the consumption of these goods to environmental problems such as resource and water depletion, land use, climate change and chemical toxicity (ETC/WMGE, 2019).

Regarding the Norwegian clothing consumption, the study carried out by Steen-Olsen et al. (2016), also revealed that for the period between 1999 to 2012, the annual change in expenditure for the category of clothing and footwear, as well as the annual change in its carbon footprint, were always positive, meaning that both were increasing. These results coincide with the growth in the average amount of clothing imported per person in Norway, as it has been indicated that from 1988 to 2015, this figure grew from over 8kg per person to 15 kg per person (Thoring, 2016).

The described pattern of clothing consumption in Norway represents a challenge when addressing its circularity, as the environmental impacts described above are also linked to the fact that the textile industry is recognized for operating in an almost completely linear way (Ellen MacArthur Foundation, 2017; ETC/WMGE, 2019). For instance the fibres used are mainly composed from virgin materials, both renewable and non-renewable (ETC/WMGE, 2019). In addition, fast fashion has made people think about clothes as "perishable goods that are 'nearly disposable'" (Nikolina, 2019), making garments end up in the landfill or the incinerator after only a couple of uses (Ellen MacArthur Foundation, 2017).

Tackling the problem

The Ellen MacArthur Foundation in its report called "A New Textiles Economy: Redesigning Fashion's Future", indicates that most of the efforts that have been carried out to reduce the environmental impacts of the textiles industry, have been focused on technological improvements that aim to reduce the negative impacts associated with its linear nature. However, the report indicates that this approach neglects the importance of tackling the problem from a systems perspective and addressing the main causes such as the low clothing utilization, and low rates of recycling after use. For instance, it is mentioned that garments' underutilization and the lack of recycling results in losses in the system of more than USD 500billion, part of which is lost because of people throwing away garments that were still wearable. Based on this, the authors argue for the necessity of a disruptive change in the system (Ellen MacArthur Foundation, 2017).

The linearity of the textile industry is underpinned by the current business models which foster fast fashion. The latter delivers new styles in a short time, with garments at cheap prices and often made of lower quality materials (Nikolina, 2019). Hence, the disruption of the system requires not only technological improvements, but also a shift in people's mindset and new business models that satisfy customer needs in a more sustainable way. Production and consumption systems need to be "re-imagined" using a more circular way of thinking (Smith et al., 2017). This change can be influenced by implementing circular business models (CBMs).

For the purpose of this study a circular business model is defined as a "a business model in which the conceptual logic for value creation is based on utilizing economic value retained in products after use in the production of new offerings" (Linder & Williander, 2017). The environmental benefits that can be obtained through CBMs lie in their capacity to close resource loops, as well as to slow and narrow their flows (OECD, 2018). Regarding clothes, the environmental benefits derived from the implementation of CBMs could be attained in different ways. For example, Watson et al. (2014), identified activities that could be part of CBMs in the textile industry (e.g. resell, leasing, and designing for a long life), which are expected to be able to achieve one or more of the following outcomes: extend the lifetime of textile products; increase collection, reuse or recycling rates; and increase demand for recycled fibres (Watson et al., 2014). For instance, the biggest potential of increasing the lifetime of garments is that it can prevent the purchase of a new garment, hence, also the impacts associated with its production and selling (Klepp et al., 2020).

The necessity of moving towards a more circular textile system has also been acknowledged at the policy level. The new circular economy action plan, stablished by the European Commission in 2020, selected the textile value chain as one of the 7 key product value chains to be addressed in the plan. This action plan calls for the improvement of the "business and regulatory environment for sustainable and circular textiles in the EU, in particular by providing incentives and support to products-as-service models, circular materials and production processes" (European Commission, 2020). In Norway, the project called "Tekstil 2025" that is being carried out by Avfall Norge (a Norwegian waste management and recycling association) aims to improve the handling and disposal of textiles as waste, in order to create value within circular value chains (Måge, 2020). However, the CEO of this association indicated that Norway should speed up in these matters, as the country is lagging behind its Nordic neighbors, which have been already improving their processes to handle discarded textiles (e.g., sorting, recycling). This situation could lead to competitive disadvantages for Norwegian actors in the industry (Måge, 2021).

What should we consider?

When defining strategies and policies to support different BMs and to improve the clothing industry, it is important to consider the following:

- *A life cycle thinking approach* when analyzing the environmental impacts of different BMs. This is important as it has been demonstrated that there is a potential risk of problem shifting between life cycle phases of different CBMs, compared to their linear alternative (Zamani et al., 2017).
- *The scale* at which the BMs are going to be implemented. This is relevant, as all BMs are associated with environmental impacts, however, their magnitude is what makes the difference. However, the magnitude of the impacts and benefits that can be derived from CBMs are dependent on their market penetration, which could be reinforced with policy instruments and regulations (ETC/WMGE, 2019).
- *Good understanding of the current system*. This is highly relevant as the impacts of a system, in this case the Norwegian clothing system, are defined based on several factors, such as the processes in the system (e.g., use phase, waste management), the magnitude of the flows between processes, and their composition (e.g., type of garment and fibre). For instance, understanding the composition of the flows is important when investigating the impacts, as the type of garments acquired are associated with specific production processes, and it also influences the laundry habits during the use phase (Sandin et al., 2019).

As part of the efforts that have been taking place to increase the understanding of the Norwegian clothing system, Watson et al. (2020) carried out a research for the Norwegian Environment Agency, where they mapped out the textile flows within Norway for the year 2018. In their research they considered the purchases of new textiles by private households and other actors, and the paths these textiles underwent when they were disposed of. However, this report considers both household textiles and clothing at an aggregated level, and it is mainly focused on the quantification of the flows, rather than on its environmental impacts.

Using the results from Watson et al. (2020) I elaborated a preliminary Material Flow Analysis of the Norwegian clothing system, estimating the shares the clothing represents from the textiles system, the preliminary results from the MFA of the Norwegian clothing system showed that approximately 7% of the Norwegian consumption of clothing comes from used garments, either purchased or inherited. The study also indicates that from all the garments disposed of by households, between 6% and 8% is destined for reuse domestically (including inheritance) (Mora Sojo, 2020). These results reveal the existing potential to improve the circularity of the system. Nevertheless, the study done by Mora Sojo (2020) only aimed at quantifying the flows and characterizing their composition, but it did not investigate the environmental impacts associated with the system.

Aim of the study

The purpose of this master's thesis is to extend the previous work I have done, by revising the MFA of the Norwegian clothing system and supplement it with a Life Cycle Assessment (LCA) to investigate the environmental impacts of the system, and how the introduction of CBMs could change them. Therefore, one scenario is elaborated to consider the impacts of a higher penetration rate of CBMs (compared to the year 2018).

LCA is chosen for the analysis as, according to Baumann & Tillman (2004), it can be described as a methodology that investigates the use of natural resources and emissions of a system, throughout its life cycle. By doing this, the tool allows to identify improvement opportunities, supports decision making, and promotes the exploration of the environmental properties of a system. Due to its life cycle thinking approach it also prevents the sub-optimisation that may occur when focusing on specific processes of the system (Baumann & Tillman, 2004). By investigating the system at a national scale, the results will provide a better understanding of the impacts associated with the implementation of CBMs at national level, and not as isolated cases.

The data required for the LCA of the baseline and the scenarios is retrieved from literature review, and the system is modeled in in SimaPro v9. using the Ecoinvent database. The environmental aspects analyzed correspond to climate change, and water scarcity, along with the indicator of energy use. For climate change the characterization method used correspond to Global Warming Potential with a 100-year perspective (GWP100), as suggested by IPCC 2013. In the case of water scarcity, the AWARE method (Boulay et al. 2018) was used. With respect to energy use the cumulative energy demand (CED) indicator from Simapro was used. These environmental aspects were chosen considering the goal of the study, the availability of data and suggestions from Sandin et al. (2019).

Therefore, considering the purpose of this master's thesis the following research questions (RQ) have been formulated:

- **RQ1.** How did the flows related to the Norwegian households' clothing system look in the year 2018?
- **RQ2.** What were the environmental impacts associated to the system for the year 2018?
- **RQ3.** How would the flows of the MFA model be affected when introducing CBMs in the system?
- **RQ4**. How would the introduction of CBMs affect the environmental impacts of the system?

By answering these questions, this study aims to provide relevant insights for Norway's transition towards a more circular economy, and are expected to be useful for different stakeholders, such as policy makers, manufacturers, and retailers, together with consumers, and the actors handling the disposal of garments.

However, to answer the defined research questions, it is important to have a good understanding of the system and the variables associated with different business models, as well as the methodological choices of the LCA. Hence, the second chapter of this study presents the literature review done on the application of MFA and LCA to investigate the environmental impacts associated with textile systems and different business models. The third chapter describes the methodology used to answer the research questions, and the data sources that were used to elaborate the study. In answer to the research questions, chapter 4 shows the results of the study and their discussion. Lastly, chapter 5 presents the conclusions and recommendations derived from this study.

2. Literature review

2.1 Mapping flows in the textile industry and their environmental impact

To understand which are the main processes and flows within clothing systems at national level, a literature review of research on flows in the textile industry at national and regional level was done. Among the analyzed aspects are the processes considered and whether they focus on the mapping of the flows, on the environmental impacts of the system or both. Table 1 resumes the main findings of this review.

Table 1 Summary of the literature review done on mapping of flows in the textile industry and their environmental impacts.

Study	Scope	Mapping of flows	Environmental impacts	Comments
Environmental Improvement Potential of textiles (IMPRO Textiles) (Beton et al., 2014)	Regional: EU.-27, for the year 2007. Analyzed 63 products of clothing, and 27 products of household textiles.	Only analyzed apparent consumption (Production + import - export), and estimates reused items.	Analyzed using LCA, from a cradle to grave perspective[1].	An evaluation of 13 improvement options was done, considering changes along the whole life cycle of the system. Promotion of reuse and recycling stood out as one of the options with the highest potential.
Increasing textile circulation — Consequences and requirements (Dahlbo et al., 2017)	National: Finland, for the year 2012. Analyzed	Mapped the flows between the supply phase, use phase, and disposal phase, based on the principle of material balances.	Analyzed the impacts of the discarded textiles using LCA.	2 scenarios were elaborated to analyzed the impacts of increasing the amount in separate collection and destined them either for reuse or for recycling.
Environmental assessment of Swedish clothing consumption - six garments, sustainable futures (Sandin et al. 2019)	National: Sweden, for the year 2017. Analyzed 6 categories of garments (aggregating 34 products)	Only analyzed apparent consumption (Production + import - export), and estimates reused items.	Analyzed using LCA, from a cradle to grave perspective[1].	An evaluation of 3 different interventions was done, considering prolonging the life of clothing, cleaner production, and changes in user behavior.
Exports of Nordic Used Textiles: Fate, benefits and impacts (Watson, Palm, et al., 2016)	Regional: 4 Nordic countries, including Norway. Analyzed the period between 2011 and 2014. Considers mainly used textiles (household textiles and clothing).	Despite having a focus on exports and the path they follow, presents data also for supply of new textiles, separate collection, going into waste, reuse and recycling.	Analyzed the impacts of exports from Nordic countries using LCA.	Concludes that there is a net environmental benefit derived from the exports of textiles.
Mapping of textile flows in Denmark (Watson et al., 2018)	National: Denmark, for the year 2016. Analyzed clothing and household textiles at an aggregated level.	Mapped the flows between the supply phase, use phase, and disposal phase, based on the principle of material balances.	Not considered.	Results for some flows are presented per garment category.
Kartlegging av brukte tekstiler og tekstilavfall i Norge (Mapping of used textiles and textile waste in Norway) (Watson et al., 2020)	National: Norway, for the year 2018. Analyzed clothing and household textiles at an aggregated level.	Mapped the flows between the supply phase, use phase, and disposal phase, based on the principle of material balances.	Not considered.	Part of the data was retrieved from UN Comtrade database, using the CN classification. The outflows were quantified through surveys applied to relevant stakeholders.
Notes: 1. Cradle-to-grave considers production and processing, distribution, use phase and end of life.				

The literature review indicates that in some cases MFA and LCA are combined to evaluate not only the magnitude of the flows, but also their environmental impacts. From this perspective, MFA, besides allowing a better understanding of the system under study, can also be considered as a useful tool to defined the inventory for an LCA (Brunner & Rechberger, 2004). Brunner & Rechberger (2004) indicate that this is mainly the case when LCA is used to evaluate the environmental impacts of a system, rather than the impacts of a single good.

In addition, it has been pointed out that when MFA and LCA are combined to analyze a system, their results can be similar in value to results from Input-Output studies evaluating the carbon footprint of the system. With the advantage the by combining MFA and LCA it is possible to reach a higher level of detail, as it is possible to analyze the composition of the system, rather than getting the results aggregated by sectors (Lavers Westin et al., 2019)

2.2. Circular approaches in the clothing industry

As this study aims to investigate the impacts that increasing the share of CBMs on the market has on the Norwegian household's clothing system, is also relevant to understand which are the circular approaches that have been identified for the clothing industry.

As previously mentioned in the introduction of this project, the Ellen MacArthur Foundation in its report called "A New Textiles Economy: Redesigning Fashion's Future", highlights the importance of making a disruptive change on the industry (Ellen MacArthur Foundation, 2017). In their report, they defined 4 main ambitions, that should be reached for this disruption to take place, and which are consistent with the principles of circular economy, which were also defined by the foundation (Ellen MacArthur Foundation, 2017). This ambitious and how they relate to the principles of circular economy, together with a summary of the actions proposed by the foundation are presented in Figure 1.

Figure 1 Overview of the ambitions and actions required to disrupt the textiles' industry according to Ellen MacArthur Foundation (2017).

Ambition	Actions
Eliminate the use of hazardous substances and avoid the release of microfibre. (CEP.1)[1]	-Elaborate safe material cycles -Decrease the release of plastic microfibres
Eradicate the disposable nature of clothes, by changing how they are designed, sold and used. (CEP.2)[1]	-Identify different approaches that fulfil the different needs related to clothing -Increase the share of rental models in the market -Promote durability -Decrease clothing underutilisation
Upgrade recycling through modifications in the design of clothes, their collection and reprocessing. (CEP.2)[1]	-Scale up clothing recycling -Design taking recycling into consideration -Improve the technology for recycling -Increase recycled materials' demand -Scale up the collection of clothing
Use resources effectively and use inputs that are renewable. (CEP.1, CEP.2, CEP.3)[1]	-Overcome the barriers for innovation in the production processes, in their introduction at scale -Improve the management of resources by assuming externalities. -To opt for renewable inputs. -Become more efficient

Note:
1.Related circular economy principle (CEP), which are as follow:
-CEP1. "Designing out of waste and pollution"
-CEP2. "Keep products and materials in use"
-CEP3. "Regenerate natural systems"

Based on Figure 1, it can be seen that a true circular economy for textiles, comprises more than just narrowing and closing the loops. However, for this study, the main interest is on aspects of the business models that can support ambition number 2. Therefore, it was decided to use the definition of CBM provided by Linder & Williander (2017), which was previously presented in the introduction, and that focuses on retaining the value of the products after use, in the production of new offerings. With this definition, business models that are associated with the downcycling of the quality of the garments (ETC/WMGE, 2019) are not considered for the scenarios.

However, introducing these CBMs in the system requires to consider several aspects that revealed the complexity of clothing. The ones identified as the most relevant for this study are listed below.

1. **Not all users have the same needs, and not all business models fulfill the needs in the same way.** Hence, not all the CBMs are suitable for all the users (Armstrong et al., 2015; Ellen MacArthur Foundation, 2017). For instance, rental services have been associated with users that want to stand out, but also that could opt for this business for environmental reasons, whereas there are not consider that relevant for those who only buy clothes when they need to (Ellen MacArthur Foundation, 2017). On the other hand, resale through secondhand stores has also been associated with users that take into account environmental aspects, but also with those that opt for this business model considering aspects such as the price. However, resale has not been considered that suitable for those who want to follow the current fashion trends.

2. **One garment can fulfill different functions.** Klepp et al. (2020) indicate that garments have a function that is not only associated to their use, arguing that also the fact of just having them in the wardrobe fulfills a function. This increases the complexity when deciding what should be measure or quantified, especially when carrying out an LCA, as it has been pointed out by several authors who have analyzed different functional units (Johnson, 2020; Klepp et al., 2020; Piontek, Rapaport, et al., 2019; Piontek, Rehberger, et al., 2019).

3. **Different garments have different functions.** They are used on different contexts and depends on for what the garment is needed (Klepp et al., 2020)

4. **Not all the garments are equally suitable for all the business models.** This has been identified in several studies. Some of the studies have made conclusions about this when analyzing what kind of garments are acquired through different acquisition channels (Laitala & Klepp, 2020). In addition, others studies have investigated the perception that users have regarding the acquisition of specific types of garments through alternative business models, different than retailers of new garments (Armstrong et al., 2015; Mukendi & Henninger, 2020).

Furthermore, Mukendi & Henninger (2020), identified some factors that are considered relevant when implementing rental business models. Their results indicate that practical aspects such as price, on time delivery, availability of the right size, and hygiene, are key for the success of rental business models but are not the only relevant factors. They also indicate that for consumers is very important to know that the service is safe and reliable, and for this a good communication between the consumer and the service is fundamental.

In addition, when implementing CBMs in the clothing industry, it has been identified that a challenge in achieving their full potential to reduce the environmental impacts of the current system is up to what extent the garments acquired through the CBMs replace the acquisition of new garments (Fisher et al., 2011). As it could be the case that garments acquired through CBMs are acquired in addition to those purchased through retailers, thus increasing the consumption even more (Laitala & Klepp, 2020). This is associated to the replacement rate or substitution factor, which has also been analyzed by several authors, who had concluded that this replacement rate is likely less than 1 (Johnson, 2020; Nørup et al., 2019b; Zamani et al., 2017).

3. Methodology

This section introduces the methodology followed to answer the research questions defined in this study. To select the adequate tools for the study it is important to consider its purpose. This was previously stated as to quantify the flows and environmental impacts associated with the Norwegians households' apparel needs for the year 2018, and to investigate how the system would be affected when introducing more CBMs in the system. Figure 2 presents the tools that have been selected to answer the research questions defined in this study, and the rationale for selecting them.

Figure 2 Selection of tools

	Material Flow Analysis (MFA)	Life Cycle Assessment (LCA)	Descriptive Scenario Analysis
Aspect to be addressed	Understanding of the flows taking place in the Norwegian clothing system, and their magnitude and composition for the year 2018. (RQ1 and RQ 3)	Quantification of the environmental impacts associated with the quantified flows of the system. (RQ2 and RQ 4)	Investigate the effects on the flows and environmental impacts of the system derived from increasing the market share of CBMs. (RQ 3 and RQ4)
Definition and suitability	Useful to analyze a system using a systematic approach to quantify its flows and stocks. This approach allows the identification of improvement opportunities regarding the use of resources and the generation of waste (Brunner & Rechberger, 2004).	It is a systemic approach to evaluate the environmental aspects and impacts of product systems (International Organization for Standardization, 2006). An attributional LCA is chosen as it accounts for the environmental impacts of the whole system, and it uses average data (UNEP, 2011).	An approach to describe how a situation could develop based on the knowledge of current conditions and trends. By doing this it investigates the consequences of articulating alternative plausible future societal developments (Swart et al., 2004).
Steps	1. Problem definition, 2. System definition 3. Determination of flows and stocks 4. Illustration and interpretation. (Brunner & Rechberger, 2004)	1. Goal and scope definition 2. Inventory analysis 3. Impact assessment 4. Iterative process of interpretation of all the phases. (International Organization for Standardization, 2006)	1. Scenario development 2. Scenario analysis (Alcamo & Henrichs, 2008)

Therefore, based on Figure 2, subsection 3.1 presents the scope of the project, addressing the selection of categories of garments to be analyzed and the system definition. Subsection 3.2 explains the methodological aspects considered for the MFA, followed by subsection 3.3 where the development of the scenario is explained. Lastly, the methodological choices associated to the LCA are presented in subsection 0

3.1 Scope

From an MFA and LCA perspective it is important to define the good that is been investigated (Baumann & Tillman, 2004; Brunner & Rechberger, 2004). Based on the goal defined in this study, the good to be analyzed corresponds to clothing (excluding those made of leather and footwear).

In addition, considering the interest on investigating how CBMs could affect the Norwegian clothing system, it is important to define which type of CBMs are going to be analyzed together with the BMs that were already part of the system in the year 2018. Defining which CBMs to analyze is important as this also determines which aspects of the garments should be taken into account.

Based on the ambitious for the textile industry defined by the Ellen MacArthur foundation (Ellen MacArthur Foundation, 2017), see section 5.2.2, it has been decided to focus on the CBMs of rental (subscription), and resale. These two BMs are part of the BMs that could underpin the ambition of transforming the processes by which clothes are designed, sold and used, in order to avoid their disposal as waste (Ellen MacArthur Foundation, 2017). Hence, when defining the scenarios these are the business models prioritized, focusing on how the garments are sold, used and disposed of, as it is explained in section 3.3. How garments are designed is out the scope of this study, and it is only discussed from a qualitative point of view when presenting the results.

3.1.1 Selection of garment categories

For this study, the following aspects of the garments have been identified as relevant, in order to investigate their environmental impact:

- Type of fibre
- Production process
- Function
- How suitable is the garment for reuse (either through second hand stores, or rental schemes).

The first 3 aspects correspond to the ones presented in Sandin et al. (2019), which is one of the main sources of data for the present study. These 3 aspects matter for the quantification of the environmental impacts, as they define the processes that the garments must go through, the required materials, and the associated emissions.

In addition, to investigate how the implementation of the selected CBMs could affect the Norwegian households' clothing system it is important to consider that not all the types of garments are equally suitable for the different business models (Granello et al., n.d.), hence, the fourth aspect is included.

Although the first 3 aspects are relevant for the quantification of the environmental impacts, the fourth aspect is considered of greater importance when defining how the transactions could be re-allocated between alternative BMs (see section 3.3). Therefore, it was decided to classify the garments based on the third and fourth aspects, as it is explained below. However, to account for the first 2 aspects, when addressing the environmental impacts, the selected categories of garments are modeled in such a way that they consider different fibre composition, and production processes, based on data from (Sandin et al., 2019), as it is explained in section 0, when modeling the production phase.

As previously stated, this study is based on the MFA of the Norwegian clothing system elaborated by Mora Sojo (2020). In order to analyze the composition of the flows of clothing in Norway, Mora Sojo (2020) used the Combined Nomenclature (CN) classification of goods, which is a tool for classifying most of the goods when they are declared to customs in the EU

(European Commission, 2016). The items considered in Mora Sojo (2020) correspond to the ones belonging to chapters 61 (Articles of apparel and clothing accessories, knitted or crocheted), and 62 (articles of apparel and clothing accessories, not knitted or crocheted), and the ones included in the code 6309 00 (worn clothing and other worn articles), at a 4-digit code level. Based on the CN classification Mora Sojo (2020) defined 15 categories of clothing. However, these 15 categories only took the third aspect into account, without considering how suitable are the garments for reuse. Because of this and considering that most of the data used in this study is at the level of these 15 categories, it was decided to use the categories of Mora Sojo (2020) as a base but with some modifications. Therefore, aiming to include the fourth aspect, and to simplify the system, the 15 categories defined by Mora Sojo (2020) were aggregated according to their function and how suitable are the garments for reuse. This aggregation resulted in 7 categories of garments (G), as presented in Table 2. Each of the 7 categories of garments is associated to one layer of the MFA, as it is explained in section 3.2.

The classification presented in Table 2, allows to analyze the system at 2 different levels of detail:

- Level 1: correspond to the highest level of aggregation, where the flows are described in terms of tonnes of clothes/ year.
- Level 2: the composition of the flow is described in tonnes of type of garment/ year.

Table 2 Selected garment categories based on aggregation of CN codes and clothing categories defined by Mora (2020).

G[1]	Name (G)[1]	C[2]	Name (C)[2]	Description	Suitable for reuse	CN Codes[3]			
						Knitted or crocheted		Not Knitted or crocheted	
						M or B[4]	W or G[4]	M or B[4]	W or G[4]
1	**Overcoats**	1	Overcoats, anoraks, wind-jackets	Overcoats, car coats, capes, cloaks, anoraks (including ski jackets), windcheaters, wind-jackets, and similar articles, other than those of heading 6104, 6103, 6203, and 6204	Yes	6101	6102	6201	6202
		7	Tracksuits, ski suits, and swimwear	Tracksuits, ski suits and swimwear	Yes	6112	6112	6211	6211
		8	Impregnated with plastic [5]	Garments made up of rubberised textile fabrics, or fabrics otherwise impregnated, coated, covered, or laminated or nonwovens, whether or not impregnated, coated, covered or laminated.	Yes	6113	6113	6210	6210
2	**Pullovers**	5	Jerseys and pullovers	Jerseys, pullovers, cardigans, waistcoats, and similar articles	Yes	6110	6110	-	-
3	**Trousers / ensembles**	2	Suits, skirts, shorts, dresses	Suits, ensembles, jackets, blazers, dresses, skirts, divided skirts, trousers, bib and brace overalls, breeches, and shorts (other than swimwear)	Yes	6103	6104	6203	6204
4	**Shirts**	3	Blouses, shirts	Blouses, shirts, and shirt-blouses	Yes	6105	6106	6205	6206
5	**Baby's garments**	6	Baby's garments	Babies' garments and clothing accessories	Yes	6111	6111	6209	6209
6	**Accessories**	11	Gloves	Gloves, mittens, and mitts	Yes	6116	6116	6216	6216
		12	Scarves and other accessories[6]	Other made-up clothing accessories, or parts of garments or of clothing accessories, other than those of heading 6212 (Shawls, scarves, mufflers, mantillas, veils, and the like + other accessories + parts)	Yes	6117	6117	6214, 6217	6214, 6217
		15	Tie and bows	Ties, bow ties and cravats	Yes	-	-	6215	-

G[1]	Name (G)[1]	C[2]	Name (C)[2]	Description	Suitable for reuse	CN Codes[3]			
						Knitted or crocheted		Not Knitted or crocheted	
						M or B[4]	W or G[4]	M or B[4]	W or G[4]
7	**Not suitable for reuse (socks, underwear, nightwear, others)**	4	Underwear and nightewear[6]	Underpants, briefs, nightshirts, pyjamas, bathrobes, dressing gowns, slips, petticoats, panties, nightdresses, négligés and, T-shirts, singlets and other vests, and similar articles	No	6107,6109	6108,6109	6207	6208
		9	Other garments[7]	Other garments	No	6114	6114	-	-
		10	Tights and socks	Pantyhose, tights, stockings, socks, and other hosiery, including graduated compression hosiery and footwear without applied soles	No	6115	6115	-	-
		13	Brassieres	Brassières, girdles, corsets, braces, suspenders, garters and similar articles and parts thereof, whether or not knitted or crocheted	No	-	6212	-	6212
		14	Handkerchiefs	Handkerchiefs	No	-	-	6213	6213

Notes:

1. Classification defined for the purpose of this study.
2. Original classification used on the MFA study about Norwegian Household consumption of clothing, elaborated by Mora (2020).
3. Codes that appear under both, Women and Men classification, or under both Knitted or not Knitted classification, is either because the code does not make distinction of these classifications or because the distinction between classification takes place at 6-digit level of the CN classification, and not at 4-digit level.
4. M or B: Men's or boys', W or G: Women's or girls'

5.Category 8 considers: garments made up of rubberised textile fabrics, or fabrics otherwise impregnated, coated, covered or laminated, garments made up of fabrics of heading 5602 (Felt, whether or not impregnated, coated, covered or laminated), 5603 (Nonwovens, whether or not impregnated, coated, covered or laminated), 5903 (Textile fabrics impregnated, coated, covered or laminated with plastics, other than those of heading 5902), 5906 (Rubberised textile fabrics, other than those of heading 5902) or 5907 (Textile fabrics otherwise impregnated, coated or covered; painted canvas being theatrical scenery, studio backcloths or the like)

6. At a 4-digit code level, garments such as T-shirts, singlets and other vests appear under a specific code (6109) in the case of knitted and or crocheted garments. However, this is not the case of not knitted or crocheted, where they appear under the same code as other garments, such a underpants, briefs, and pyjamas (6207, and 6208). As it is not possible, at a 6-digit level, to identify the share from codes 6207, and 6208, that correspond to T-shirts, singlets and other vests, it is decided to manage the code 6109 together with 6107, and 6108. The same situation happens with codes 6214, and 6217, that comprise the same garments as the code 6117 does at a more aggregate level. Therefore, it is decided to treat 6214, and 6217 together.

7. There is uncertainty on what the category "others" contains, therefore, even if some articles could be suitable for reuse, it is decided to assume that 100% of this category is not suitable. This would consider a pessimistic scenario. However, Mora (2020), estimated that this category represents less than 1% (weight based) of the garments purchased by Norwegian households in 2018, hence it is not expected to affect the conclusions of the present study.

3.1.2 System definition

As previously mentioned, the system under study corresponds to the Norwegian households' clothing system, and the reference year is 2018. The reference year was decided considering that one of the main sources of data for the quantification of the flows in this study is the report of Watson et al. (2020). In this report the use of textiles and textile waste in Norway had already been mapped for the year 2018, including clothing and household textiles at an aggregated level.

Moreover, Mora Sojo (2020) had already mapped the Norwegian clothing system, based on the mapping done by Watson et al. (2020). However, that system only accounted for processes associated with 2 types of markets, supply of new textiles and supply of used textiles, regardless of the business models used in those markets. As for this study, it is relevant to know the flows associated to each business model, it has been decided to create one process for each business model identified in the system. In addition, the systems previously mapped considered two processes for the disposal of garments as waste, corresponding to garments discarded with household residual wastes, and garments discarded at recycling stations (small combustible). In order to reach the required level of detail in terms of type of garments, these two processes were merged into one process called waste management. Further modifications done to the system presented by Mora Sojo (2020), which can be observed in Appendix A.

The resulted system elaborated for this study is shown in Figure 3, which consist of 12 processes and 24 flows. Although transports are not shown in Figure 3, they are part of the system, as it is discussed in section 0. It is worth to notice that Figure 3 only considers the processes taking place within Norway, however, to evaluate the environmental impacts from a cradle-to-grave perspective, using LCA, it is also important to consider processes that take place abroad (e.g., production and distribution). Including these processes required the expansion of the system for the LCA, as it is described in section 0.

The color legend in Figure 3 shows the methods used to calculate each of the flows, this is also further explained in section3.2 where more information is given on how the data to quantify these flows was retrieved.

Table 3 provides a brief description of the processes identified in the system, and it indicates which processes are related to a business model. Further details of what they include are given when describing the inventory data for each of the processes in section 0. The flows presented in Figure 3 are described in Table 4, these flows correspond to the variables of the model elaborated for the Material Flow Analysis.

Figure 3 Norwegian clothing system, adapted from Mora (2020)

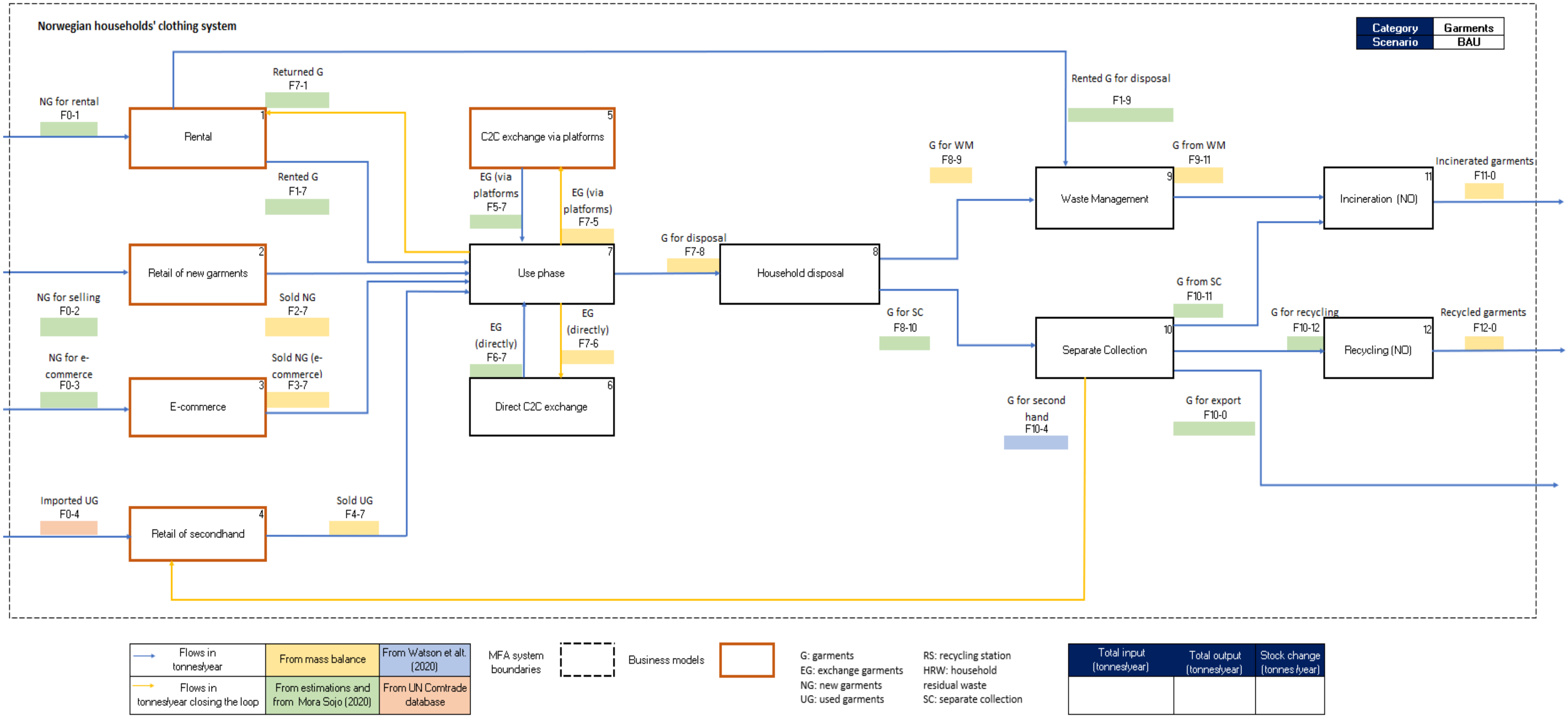


Table 3 Identified processes to satisfy Norwegian households' apparel needs.

P	Process	Description
1	Rental	Process of the business model through which people can rent garments for a certain period of time. Includes the transports of the users. Corresponds to the BM 1.
2	Retail of new garments	Process of the business model through which people purchase new garments at stores. Includes the transports of the users. Corresponds to the BM 2.
3	E-commerce	Process of the business model through which people purchase new garments online. Includes the transports of the users. Corresponds to the BM 3.
4	Retail of secondhand	Process of the business model through which people purchase used garments at stores. Includes the transports of the users. Corresponds to the BM 4.
5	C2C exchange via platforms	Process through which clothes are exchanged via platforms, in a customer-to-customer relationship, it does not consider retailer. The platforms could be online or offline (e.g., flea markets). Corresponds to the BM 5.
6	Direct C2C exchange	Process through which clothes are exchanged directly between people, without going through a retailer or a platform. Corresponds to the BM6.
7	Use phase	Corresponds to the use of the garments, including the associated laundry, drying, and ironing.
8	Household disposal	The process of disposing garments and giving them away to a third party. This means that it excludes garments given away through a customer-to-customer relationship, whether they use a platform for the exchange or not. Garments given back to the rental business, are not considered as disposed of.
9	Waste Management	Considers the collection carried out by the municipality or municipality engage waste collectors, at recycling stations, together with the collection of household residual waste that usually takes place in residential areas.
10	Separate Collection	Is the process associated with the collection of clothes done by charitable organizations, and private collectors, who pre-sort them to determine their fate, which could be domestic reuse, export, incineration, or recycling. It also considers the activities associated to the delivery of the garments to the collection point.
11	Incineration (NO)	The process by which clothes are incinerated to generate energy
12	Recycling (NO)	The process by which clothes are recycled.

Table 4 Flows of the Norwegian clothing system and their description, all of them to be quantified in tonnes/year.

j	Variable	Name of the flow	Description
1	F0-1	NG for rental	New garments that are being distributed to the rental business, in order to be rented.
2	F0-2	NG for selling	New garments thar are being distributed to the retailer in order to be sold.
3	F0-3	NG for e-commerce	New garments to be sold, associated with online purchases.
4	F0-4	Imported UG	Used garments that are imported under the code 6309 00
5	F1-7	Rented G	Garments rented going into the use phase.
6	F1-9	Rented G for disposal	Garments in the rental business model that reached their end of life and therefore need to be disposed of.
7	F2-7	Sold NG	New garments that are sold through retailers.
8	F3-7	Sold NG (e-commerce)	New garments that are sold through e-commerce.
9	F4-7	Sold UG	Used garments that are sold through secondhand stores.
10	F5-7	EG (via platforms)	Garments exchanged through platforms, in a customer-to-customer relationship, it does not go through a retailer.
11	F6-7	EG (directly)	Garments exchanged directly between people, without going through a retailer or other platforms.
12	F7-1	Returned G	Garments that were rented and are returned to the rental business, after been used by the customer.
13	F7-5	EG (via platforms)	Garments exchanged through platforms, in a customer-to-customer relationship, it does not go through a retailer.
14	F7-6	EG (directly)	Garments exchanged directly between people, without going through a retailer or other platforms.
15	F7-8	G for disposal	Amount of garments that are been disposed by the households, and that will end up either at municipal recycling stations, in the household residual waste or in containers for separate collection. Excludes garments disposed of by the user, but that are exchange with other customers immediately, either directly or via platforms (flows F7-5, and F7-6). Garments that are returned to the rental are not considered as disposed.
16	F8-9	G for WM	Garments that are disposed of through the waste management system.
17	F8-10	G for SC	Garments that are deliver at containers for separate collection.
18	F9-11	G from WM	Garments from the waste management system going into incineration.
19	F10-11	G from SC	Garments from separate collection going into incineration.

j	Variable	Name of the flow	Description
20	F10-12	G for recycling	Garments from separate collection destined for recycling.
21	F10-0	G for export	Garments from separate collection that are exported abroad, usually for further sorting.
22	F10-4	G for second hand	Garments from separate collection destined for domestic reuse.
23	F11-0	Incinerated garments	Weight of the total amount of garments been incinerated. Considered as leaving the system, as they are no longer in the form of clothes.
24	F12-0	Recycled garments	Weight of the total amount of garments been recycled. Considered as leaving the system, as they are no longer in the form of clothes.

3.2 Determination of flows

This section provides a brief introduction of the mass balance principle used in MFA, followed by an explanation on the approach took to quantify the system.

When elaborating an MFA, it is necessary to determine the flows and stocks (S_P) in the system. This corresponds to the step 3 of the MFA (see Figure 2), which implies the balancing of goods and determination of concentrations and balancing of substances (Brunner & Rechberger, 2004). As it has been introduced, the good to be analyzed in this study is clothes, and the equivalent to concentrations in this system would be the composition of the flows of clothing in terms of types of garments (level 2 of detail), resulting in 7 layers of the system. However, only the flows are investigated, the determination of the stocks is excluded from the study.

MFA is based on the mass balance principle, which indicates that for any given process (or system) the total sum of the inputs is equal to the total sum of the outflows plus a change in the stock (ΔS), where the latter indicates either a growth or depletion of the stock of the material in the process (Brunner & Rechberger, 2004). This principle is described in equation 1, given for a process (p).

$$\sum Input_p = \sum Output_p + \Delta S_p \quad (1)$$

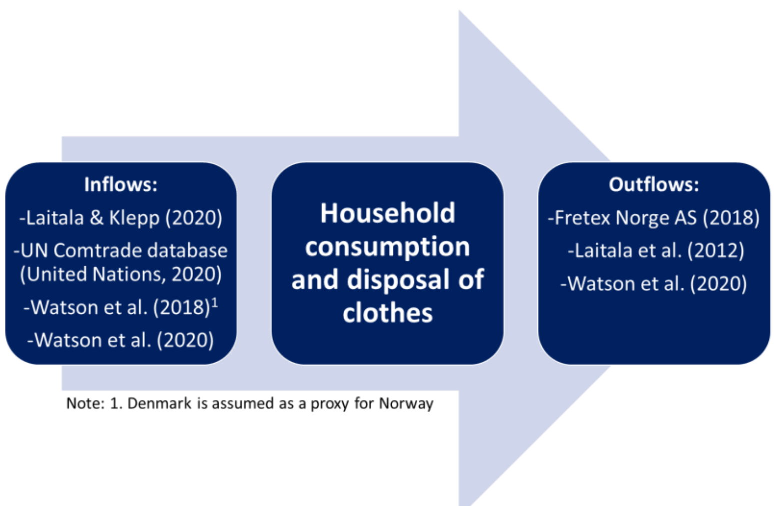
If $\Delta S_P = 0$, means that the inputs are equal to the outputs, as indicated in equation (2).

$$Input_p = Output_p \quad (2)$$

For this master thesis, it was assumed that for all the processes, except for P1. Rental, the $\Delta S_P = 0$. How the stock change of rental is considered is explain in section 3.3. This approach was taken to simplify the system and due to lack of data and to uncertainties analyzed by Mora Sojo (2020). For instance, the high uncertainty is reflected on the fact that three different approaches used to estimate the flow of garments for disposal from households (defined as $F_{7\text{-}8}$ in this study), led to opposite conclusions regarding the growth direction for the stock in Norwegian households (ΔS_7). One approach concluded that the stock was increasing ($\Delta S_7 > 0$), whereas the other two indicated that it was decreasing ($\Delta S_7 < 0$) (Mora Sojo, 2020). Despite the discrepancies found in the use phase, the results of Mora Sojo (2020) obtained through the three approaches indicate that the stock at a system level was increasing ($\Delta S>0$). This also reveals uncertainty on where in the system this probable stock accumulation is taking place.

Figure 4 presented below, shows the main sources of data that were used to quantify the inflows and outflows for the MFA of the Norwegian Household's clothing system. As it can be seen in Figure 4 the quantification of inflows done by Mora Sojo (2020) is based on national statistics for Norway, with adjustments from literature review. Therefore, this data is considered less uncertain than the one used for the estimation of the outflows, which was retrieved from literature review mainly presenting results from surveys done to private collectors of textiles and municipalities (Watson et al., 2020). Because of this, uncertainties, most of the inflows of households estimated by Mora Sojo (2020) were used in this study without major adjustments at the aggregated level (level 1: tonnes of clothes/year), further adjustments were done to reach level 2, when this was not done by Mora Sojo (2020). However, considering that all the process are mass balanced has an impact on the magnitude of the flows, mainly the ones associated with the disposal of garments, hence the outflows from Mora Sojo (2020) were modified to a greater extent than the inflows, using the sources of data presented in Figure 4. Appendix A presents a more detailed overview on how the flows defined in this study are related to the flows in Mora Sojo (2020), and how these were estimated.

Figure 4 Main sources of data for the elaboration of the MFA of the Norwegian households' clothing system



In addition, in order to estimate some flows, it was necessary to know the weight of the categories of the garments under study, as in some cases the information was obtained in terms of pieces instead of weight. In order to define an average weight per garment category, the information from imports 2018 retrieved from UN Comtrade database was used. As in most of the cases these statistics present the information in terms of number of pieces and weight. When the information in the database was not presented with this level detail, approximations based on the weight of similar items on the internet were done. The defined weights are shown in Appendix B.

3.3 Definition of the scenarios

As previously introduced, to investigate how a higher penetration rate of CBMs could impact the Norwegian clothing system it was decided to elaborate a Circular Business Model Scenario (CBM scenario). This scenario was elaborated based on two main aspects, willingness to rent and the potential for reuse of clothing that is currently disposed of as waste. Therefore, this can be classified as a descriptive scenario (Swart et al., 2004), aiming to investigate a plausible development of the Norwegian clothing system. How the two defined aspects were considered is shown in Figure 5.

Figure 5 Aspects considered to elaborate the CBM scenario.

Willingness to rent
(dependent on the type of garment)

- Based on interest in rental per type of garment estimated by Mukendi & Henninger (2020) and presented in a scale from 1 to 9.
- The interest per type of garment was associated with a percentage of transactions that would be reallocated from retail of new garments to rental.
  - **-Interest from 1 to 2: 0% reallocation**
  - **-Interest from 3 to 5: 10% reallocation**
  - **-Interest from 6 to 9: 20% reallocation**
- The defined percentages of reallocation are assumptions made for this study.

Potential for reuse of clothing
(currently disposed of as waste)

- A waste picking analysis done in Denmark by Nørup, et al. (2019), revealed the potential of garments disposed of as waste, to be reused and recycled. This was done per type of garment.
- Nørup, et al. (2019), made distinction between reuse class A, and reuse class B, where the class A is defined as of better quality.
- Considering Denmark as a proxy for Norway, a **100% of the potential of class A,** found by Nørup, et al. (2019), is assumed to be redirected to separate collection, instead of be treated as waste.
- The defined 100% is an assumption done for this study.

The aspects presented in Figure 5 and the associated assumptions were used to modify the results of the MFA obtained for the Norwegian clothing system in the year 2018. These modifications derive into the CBM scenario. How this intervention to the MFA was done is described in detailed in Figure 6.

In addition to the previous factors defined when setting up the CBM scenario, there are other aspects that should be considered when introducing the rental business model, and when analyzing its environmental impacts. These aspects are presented in Figure 7 and were defined considering the scenarios created by Zamani et al. (2017), when investigating the environmental impacts of clothing libraries.

Figure 6 Steps to calculate number of transactions in the CBM scenarios.

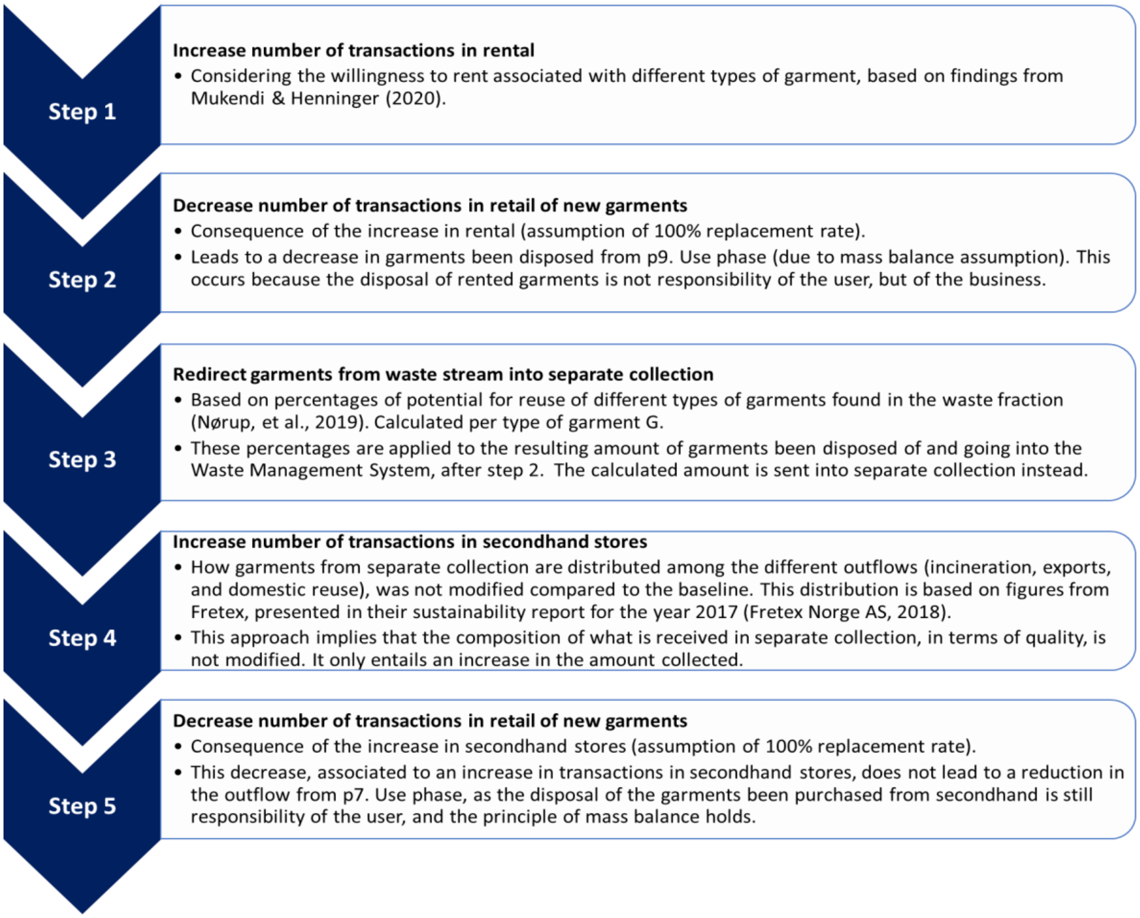
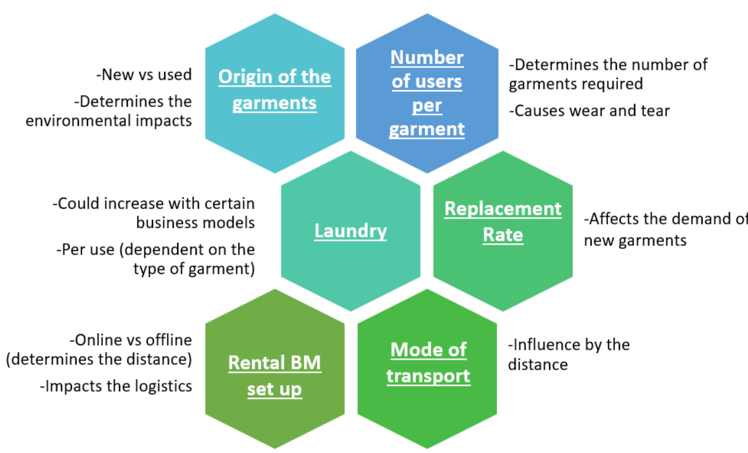


Figure 7 Factors that could affect the environmental impacts of the system when introducing rental business models.



According to the aspects introduce in Figure 7, for the CBM scenario it is decided that the garments in the rental business model are new, assuming that it could be a shift in the business model of current retailers of new garments. Figure 7 also highlights the importance of considering number of uses per garments when analyzing rental business models, as this will influence how many garments are required to satisfy the defined number of transactions. How rental business models are set up can vary a lot, ranging from short period rentals to long period rentals, and in some cases there is not return date defined (Rent the Runway, 2021). For the CBM scenario it was decided that each garment can be rented for a period of 1 month, and it was assumed that if rented all year long, each garment will satisfy 12 users or transactions. Hence, the number of garments required to satisfy the transaction through rental is initially estimated using equation 3, where the total number of transactions in rental corresponds to the number of pieces in flow $F_{1\text{-}7}$.

$$Required\ number\ of\ garments = \frac{total\ number\ of\ transactions\ in\ rental}{number\ of\ users\ per\ garment}\ (3)$$

One month rental was decided as the rental business that were analyzed offer the modality of monthly subscriptions, where the user gets access to certain number of garments for 1 month and can exchange them after this period (Future Closets AB, 2021; Rent the Runway, 2021).

The way the rental is set up has some limitations and important aspects to consider. It assumes that all garments can be used all year long, which is not true for all types of garments. Perhaps, garments such as overcoats do not have the same demand during the summer as in winter. However, for simplification purposes this aspect is not considered. Moreover, it can be assumed that the rental business needs to have some garments in stock to guarantee a good service rate and be able to fulfill the demand. Hence, it is decided to define an adjustment factor for availability, based on the number of garments required (equation 3) to satisfy the transactions. For this study, this availability factor (AV_F) is assumed to be 20%. As a result of this adjustment, the number of garments to be purchased by the rental business model (flow $F_{0\text{-}1}$ NG for rental) can be defined using equation 4.

$$F_{0-1} = Required\ number\ of\ garments * (1 + AV_F) * Weight\ of\ the\ garment\ (4)$$

In addition, it could be argued that the rental business model increases the wear and tear due to an increase in laundry and an increase in the active use of the garment as it is also shown in Figure 7. In this project it is assumed that 2 laundry cycles take place associated with the transaction (when receiving and returning the garment). Up to what extent garments could stand the use of 12 users depends on the technical lifespan of the garment, as well as the frequency of use during each rental (Zamani et al., 2017). Due to the complexity of modeling these aspects, it was decided to account for wear and tear assuming that 15% of the garments required to satisfy the transactions are going to be disposed of at some point. This 15% is refer to as wear and tear adjustment factor (WT_F). This aspect is represented in the system as the flow $F_{1\text{-}9}$ Rented garments for disposal, which is calculated using equation 5. The environmental impacts associated with the waste treatment of this flow are considered in the LCA, whereas the environmental impact of the production required to replace these losses are not considered, as they are allocated to the demand of the next year.

$$F_{1-9} = Required\ number\ of\ garments * WT\_F\ * Weight\ of\ the\ garment\ (5)$$

It is worth to notice, that by doing these adjustments in the flows related to rental and considering the requirement of new garments to be produce, the process of rental in the MFA is not going to be balance, consequently the system either. This can be interpreted as if it was the first year of operation of the BM and thus it needs to create a stock of garments, to fulfill the orders. Therefore, for the first year of operation the stock change is positive.

Furthermore, it has been decided to model the use phase in such a way that is not dependent of the BMs, hence, the impact associated with laundry in the use-phase will remain constant between scenarios.

For the CBM scenario, the replacement rate, presented in Figure 7, is assumed to be one. It is worth to notice that this replacement rate applies not only for rental, but also for garments being acquired through secondhand stores. This implies that the number of transactions in the system is going to remain constant between scenarios, as the transactions are only reallocated. This means that the acquisition of garments through rental or secondhand stores, fulfills the need of acquisition of garments in the same way as retailers of new garments.

Figure 7 also introduces the importance of considering whether the rental business model is defined as online or offline, as this will impact the logistics of the store and the distance the user needs to travel, which also impacts the mode of transport. For the established CBM scenario it was decided to consider an online rental business model, that makes deliveries to a distribution point. The reason for this is that this is the most common method chosen for deliveries in Norway (61% of the deliveries) (PostNord, 2019). The distance to the distribution point was defined according to findings from a survey carried out in Norway, that investigated the potential of different models of e-commerce (Andersen, 2020). In addition, an average distribution of mode of transport used by Norwegians, according to the given distance, was assume. The distribution of mode of transport is based on Berge (2019), who presented the results from the National Travel Survey (Nasjonale reisevaneundersøkelser, RVU), for the year 2018. Furthermore, since transports in the rental business model are associated with a risk of problem shifting (Zamani et al., 2017), it was decided to investigate how the distance and the selection of mode of transport affects the environmental benefits of the system through a sensitivity analysis.

Table 5 summarizes the differences between the BAU and CBM scenario, as well as the aspects considered to model the rental business model, as described above. More information on how the scenario was modeled can be found in Appendix E.

Table 5 Summary of the defined scenarios

Factors	Baseline Scenario (BAU)	Circular Business Model Scenario (CBM)
Rental set up	N/A	Online
Rental user destination	N/A	Delivery pick-up point (3.7 km round trip)[2]
Transportation mode associated to rental	N/A	Distribution for the given distance in 2018[3]: • 40% Walking / Cycling • 54% Car (petrol and diesel) • 6% Bus
% of transactions – Retail new	Share in 2018[1]	To be reduced (↘)[4]
% of transactions – Rental	Share in 2018[1]	To be increased (↗)[5]
% of transactions – Secondhand stores	Share in 2018[1]	To be increased (↗)[5]
% of transactions – E- commerce (new)	Share in 2018[1]	Share in 2018 (=)[6]
% of transactions – C2C exchange via platforms	Share in 2018[1]	Share in 2018 (=)[6]
% of transactions – Direct C2C exchange	Share in 2018[1]	Share in 2018 (=)[6]

Notes:
1. The share of the transactions in 2018 for each of the BMs is defined according to the findings of the MFA of the Norwegian Clothing System.
2. Distance retrieved from Andersen (2020).
3. Distribution of mode of transport for a given distance according to Berge (2019).
4. (↘) The % of transactions assumed in the CBM scenario , is going to be decreased compared to the percentage of transactions taking place through the specific acquisition chanel in the year 2018. This is done according to the steps 2 and 5 previously presented in the methodology section.
5. (↗) The % of transactions assumed in the CBM scenario, is going to be increased compared to the percentage of transactions taking place through the specific acquisition chanel in the year 2018. The increase in rental is estimated according to step 1 previously explained in the methodology section. The increase in secondhand stores was estimated according to step 3 and 4.
6. In the CBM scenario no change was done in the percentage of transactions taking place through E-commerce, C2C Exchange via platforms, and Direct C2C Exchange.

By elaborating the CBM scenario in this way a plausible future, based on current aspects of the system can be analyzed. Therefore, it can also be considered as a scenario that investigates the existing potential of the "low-hanging fruits" in the transition of the Norwegian clothing system towards a more circular economy. The reason for this is that the first aspect considers the current willingness to rent, which could be materialized if underlying drivers such as the ones discussed by Mukendi & Henninger (2020) are considered when setting up a rental business model. In a similar way, the second aspect advocates for an existing potential in what users are currently considering as waste. Hence, it could be argued that this fraction could be easily redirected into the separate collection by educating users about their options to dispose of garments. The resulting estimated potential could always be increased with strong policy measures, such as taxes.

To evaluate the impact of the intervention on the flow of the system it has been decided to focus on the following aspects.

- Collection rate: corresponding to fraction of garments that is collected, and therefore not disposed into the waste management system. This includes garments going into separate collection, and garments exchange in a C2C relationship. This indicator is an adaptation from the one presented in Baumann & Tillman (2004).

$$Collection\ rate = \frac{F_{8-10} + F_{7-5} + F_{7-6}}{F_{8-10} + F_{7-5} + F_{7-6} + F_{8-9}} \quad (6)$$

- Reuse rate after losses: is an adaptation of the indicator of recycling rate after losses presented in Baumann & Tillman (2004), adjusted to consider reuse instead of recycling. Considers the percentage of garments destined for reuse that results from all the garments being disposed of. In this case only domestic reuse is consider, hence it includes garments from separate collection going into secondhand stores and garments exchange in a C2C relationship.

$$Reuse\ rate\ after\ losses = \frac{F_{10-4} + F_{7-5} + F_{7-6}}{F_{8-10} + F_{7-5} + F_{7-6} + F_{8-9}} \ (7)$$

- Return rate: considers the percentage that the amount of used garments going into the use phase represent from the total amount of garments being acquired. Used garments includes garments from separate collection going into secondhand stores garments exchange in a C2C relationship, and used garments being imported (Baumann & Tillman, 2004).

$$Return\ rate = \frac{F_{4-7} + F_{7-5} + F_{7-6}}{F_{4-7} + F_{7-5} + F_{7-6} + F_{2-7} + F_{3-7}} \ (8)$$

- Percentage of transactions satisfied from retail of new garments.

$$Percentage\ of\ garments\ acquired\ new = 1 - return\ rate \ (9)$$

- Demand for the production of new garment

$$New\ garments\ to\ be\ produced = F_{0-1} + F_{0-2} + F_{0-3} (10)$$

3.4 LCA Methodological Choices

To evaluate the environmental impacts of the Norwegian households' clothing system, and the environmental impacts of the scenario, it was decided to elaborate an attributional LCA of the system, from cradle to grave. Therefore, this section presents the methodological choices associated to the LCA.

First of all, as the LCA is going to be elaborated from a cradle to grave perspective, all the life cycle phases of clothing required to satisfy the Norwegians households' needs should be considered. This means that the system presented in Figure 3, should be expanded to include the raw material acquisition, the production and distribution phases. The demand for these new processes is given by the flows of F_{0-1}, F_{0-2} and F_{0-3} depicted in Figure 3, and that correspond to the demand of new garments. How these added processes are considered is discussed in more detail later in this section, when introducing the inventory data in section 3.4.2.

With respect to the geographical system boundaries, as the system should satisfy the Norwegian households' apparel needs for the year 2018, the system is being considered at a national level, and is consumption based. Therefore, the consumption/use phase takes place in Norway. However, where the production takes place depends on the place of origin of the garments. In this case it is assumed that all the new garments on the system were produced abroad, as it is further explained in section 3.4.2. Regarding the waste management, where this process takes places depends on the different alternatives that are defined in the system. However, to simplify the system, and due to availability of data, only disposal activities taking place within Norway are considered. This means that the fate of garments that are exported is not evaluated in this study.

With regards to the environmental impacts of production and maintenance of capital goods, these are not considered, neither personnel related environmental impacts.

For the scope of the LCA is also relevant to define the impact categories to be analyzed, the allocation methods to be used, the data requirements (Baumann & Tillman, 2004), these are presented in Figure 8.

Figure 8 LCA methodological choices

Impact categories and their characterization methods

- **Climate change (kgCO_2):** Global warming potential with a 100-year perspective (GWP100) (IPCC,2013).
- **Water scarcity (m^3):** : AWARE (available water remaining) method, midpoint impact category that "quantifies the potential of water deprivation, to either humans or ecosystems" (Boulay et al., 2018).
- **Energy consumption (MJ):** Cumulative Energy Demand, considering renewable, and non-renewable energy sources.

Allocation method

- **Mass allocation** used for transports, laundry, and retailing, meaning that their impact is scale by mass.
- **Cut-off allocation** used for activities involving recycling or reuse. This means that the burdens of the primary production are assigned to the first product (new garments), and this product does not get any credits for benefits derived from subsequent users. On the other hand, the burdens associated to the recycling or reuse processes are assigned to the secondary user (used garments), but the latter does not carry any environmental burden from the primary materials (Sandin et al. 2019).

Data quality requirements

- Average data is going to be used (attributional LCA).
- Data should represent the geographical region where processes takes place. If specific data is not found, proxies can be used, and its suitability should be justified.
- As 2018 is the year under study, the selected data should not be more than 10 years older. More recent data can be used.

The presented impact categories were selected considering the goal of the study and the availability of data. The 3 impact categories are among the ones considered by Sandin et al (2019), hence it is considered appropriate to use impact categories which they also used, as their report is one of the main sources of data for this study. Nevertheless, not all the impact categories considered by Sandin et al (2019) where considered in this master's thesis. The reason for this is that other sources were also consulted to retrieve the required information for the inventory analysis, and it has been noticed that different studies use different units for other environmental impacts (e.g., freshwater ecotoxicity, and human toxicity), making it difficult to aggregate their data into one system. However, for the selected impact categories the units that are used are the same in all the studies, allowing their aggregation.

In addition, the selected impact categories are considered appropriate, as they still allow to have an overview of the impacts associated to the Norwegian clothing system for the year 2018, and they are influenced by the different business models analyzed in this study. The latter allows for a comparison between the baseline and the scenario, based on this impact categories. Moreover, to analyze the impact that the system has on Global Warming, is considered highly relevant due to the climate change crisis that the world is facing, which is one of the main drivers for the transition to a circular economy. In addition, from a circular economy perspective to analyze the use of resources and their depletion is also relevant, making it important to analyze impacts such as water consumption and energy use.

The allocation methods presented in Figure 8 were also chosen in accordance with the methodological choices done by Sandin et al. (2019). However, Sandin et al. (2019) also included system expansion with substitution for the waste management, when incinerating materials, this was not considered in the present study in order to be consistent with the selection of an attributional LCA (Baumann & Tillman, 2004).

3.4.1 Functional unit

The definition of a functional unit determines how all the modeled flows in the system are related (Baumann & Tillman, 2004). When defining the functional unit, it is important to clarify the function of the system, mainly in comparative studies, as it is used as the basis for comparison (Baumann & Tillman, 2004). In this case the function is to satisfy the Norwegian households' apparel needs for the year 2018. When referring to needs, it considers the acquisition of garments, their use, and their disposal. As previously presented in the literature review of this study, garments could fulfill different functions. Hence, for the purpose of this study the apparels' need is going to be considered from an acquisition-based perspective.

An acquisition-based perspective assumes that the driver behind Norwegian consumption is the need for acquiring garments in itself, rather than the need for their use. From this perspective, the number of acquisitions or transactions taking place becomes the focus. An acquisition or transaction here is considered as the flow of the garment that occurs between the use phase and any of the defined business models, with the purpose of getting access to a garment. It is worth to mention that talking about purchases may hinder the mind-shift from owning to sharing that is required in a more circular economy. Hence, talking about acquisitions or transactions rather than purchases seems more appropriate to represent the access to garments.

Defining the functional unit based on an acquisition-based perspective implies that the number of transactions that took place in 2018 is going to be considered as a constant. Hence, when analyzing different scenarios, the same number of transactions is going to be satisfied, regardless of the business model used to acquire the garment, meaning that it could have been purchased or rented. For example, if Norwegians acquired 10 garments in a year, where 9 of them were acquired new and through a usual purchase scheme (retailers), and 1 through a secondhand store, these 10 garments are associated with 10 transactions, hence, the apparel needs for that year would be established in 10 transactions. However, in the scenario increasing the share of CBMs, these 10 transactions would still take place, but perhaps, 5 of them would have been purchased new from the retailer, 3 of them would have been rented, and 2 would have been bought from second hand. Based on this, the following functional unit is defined:

FU: One year of Norwegians households' apparel needs met by acquisitions

Then number of pieces acquired is going to be derived from the MFA, as it is explained in section 3.2. In addition, when analyzing this functional unit, it is important to keep certain aspects into consideration, as it is further explained below.

Keeping the number of pieces of garments acquired (transactions) as a constant regardless of the BM used to satisfied them, implies that it has been assumed that the replacement rate of rented garments or used garments is 1. In other words, it does not matter through which BM the garment is acquired, it will substitute the acquisition of the same type of garment that otherwise would have been done through a transaction taking place via other business model, in a 1:1 relation. Therefore, the transactions are just reallocated, as described in the definition of the scenarios (see 3.3). Hence, it is assumed that the purchase of a used garment or the acquisition of a rented garment, will avoid the processes linked to the purchase of a new garment. This assumption directly impacts the environmental benefits that will be obtained in the CBM scenario. As previously mentioned in the literature review this assumption is not right, as this relation is not likely to be 1:1 (Fisher et al., 2011). However, similar studies (Beton et al., 2014; Schmidt et al., 2016) take this approach for simplification purposes, and due to lack of data. The determination of more accurate replacement rates for a population requires investigating several factors such as the habits of the population and the alternatives they have to acquired garments (Nørup et al., 2019b).

Furthermore, it is important to consider that the Norwegians' apparel needs vary a lot, ranging from overcoats, and jackets, to nightwear and underwear, and that each type of garment has a different function. This increases the complexity of the system, as the different types of garments have different environmental impacts and they do not have the same degree of suitability for the analyzed business models, as it is explained in section 3.1.1. In addition, the fact that different garments fulfill different functions implies that it is necessary to keep track of the number of transactions per type of garment, and that transactions cannot be swapped between garments. Hence, it was decided to tackle this complexity from an MFA perspective. As previously mentioned, the system is defined considering 2 levels of detail, one aggregated level of tonnes of clothes/year, and another level described in terms of tonnes of type of garment/year. This second level of detail resulted in 7 layers of the MFA (one per each category of garment). The use of layers allows to keep track of the composition of the flows, permitting at the same time to make distinction of their environmental impacts, when required, and to know the number of transactions associated to each type of garment. Therefore, the Norwegian's apparel needs could be considered as a bundle of the needs of different garments, as it is depicted in equation 6.

$$\begin{gathered} One\ year\ of\ Norwegians\ households\ apparel\ needs\ met\ by\ acquisition \\ = \sum_{G=1}^{7} One\ year\ of\ Norwegian\ households\ needs\ of\ the\ type\ of\ garment\ G\ met\ by\ acquisitions. \quad (6) \end{gathered}$$

$Where\ G\ corresponds\ to\ a\ variable\ that\ can\ take\ the\ value\ from\ 1\ to\ 7, each\ value\ associated$

with one of the garment categories defined in this study, as explained in the next section Selection of garment categories

3.4.2 Life Cycle Inventory (LCI)

This section indicates the approaches and sources used to model the life cycle phases of the system in order to quantify their environmental impact. This was done based on literature review, as it can be seen in Table 6, where the main sources used to model each of the required elements is presented. Note that one or more elements could be required to model one phase of the LCA (e.g., laundry and drying in the use phase), and at the same time, one element of the system could be used in more than one phase (e.g., laundry, associated to the use phase and some transactions). For more details on how these phases were modeled and the reference flows, see the inventory in Appendix C.

In all the cases (except for production), the information retrieved from the different sources was introduced in SimaPro and were modeled making use of the library of Ecoinvent 3 – allocation, cut-off by classification system.

In the case of production, the impacts of the production per type of garment obtained in Sandin et al. (2019) were adjusted to obtain the environmental impact per kg of each garment. These impacts consider from the raw material acquisition required to produce the fibres, up to the point when they are ready to be distributed, and it accounts for losses through the production phase. The resulting factors of impact per kg were applied to the flows quantified in the MFA, and the obtained environmental impacts were aggregated with the results from SimaPro. The exact values for the impacts per type of garment were retrieved directly from S. Roos (personal communication, March 17, 2021), who is one of the authors of the Swedish report. The required adjustments that were done to model the production phase are further explained in Appendix D, together with the assumptions done to model the use phase.

Moreover, due to lack of data it was decided to treat domestic production as if it was produced abroad. This assumption most likely overestimates the environmental impacts associated to the domestic production. In addition, as previously introduced in the MFA, this project does not make distinction between household residual waste disposed of at residential areas and at recycling stations, even though they are not the same. Nevertheless, since just transports are considered, this assumption is not expected to have a great impact on the results. The latter since the larger transport is the one associated to the transport to the incineration facility, and this takes place in both cases.

Table 6 Elements modeled for the LCA and their data sources.

Elements to model	Associated processes	Sources
Garment production	P0a. Production	Sandin et al. (2019)
Ocean freight	P0b. Distribution	Own estimation considering information in Sandin et al. (2019)
Electricity -facility management	P1. Rental, P2. Retail (new), P3. E-commerce , and P4. Retail of seconhand	Sandin et al. (2019)
Laundry and detergent	P1. Rental, and P4. Retail of seconhand, P5. C2C exchange via platforms, P6. Direct C2C exchange, P7. Use phase.	Sandin et al. (2019)
Drying and ironing	P7. Usephase	Sandin et al. (2019)
Transport (user) - city center	P2. Retail (new), and P4. Retail of seconhand	Distance: Own estimation Mode of transport: Berge (2019)
Transport (user) - pick up delivery point	P1. Rental, P3. E-commerce, P5. C2C exchange via platforms, and P10, Separate collection.	Distance: Andersen (2020) Mode of transport: Berge (2019)
Transport from collection points to pre-sorting facilities	P10. Separate collection.	Schmidt et al (2016)
Transport from separate collection to secondhand stores	P4. Retail of second hand	Schmidt et al (2016)
Transport to incineration plant	P9. Waste Management	Lausselet et al., 2016
Incineration	P11. Incineration	Ecoinvent 3

4. Results and discussion

This section presents the results of the quantification of the Norwegian households' clothing system and its environmental impacts. In answer to the first research question the subsection 4.1 presents the results of the MFA for the BAU-scenario (baseline), followed by subsection 4.2 where, in answer to research question 2, the environmental impacts of the system are presented. The results in response to the research questions 3 and 4 are presented in subsection 4.3. This last subsection presents how the flows and their environmental impacts were affected when increasing the circularity of the system (CBM-scenario).

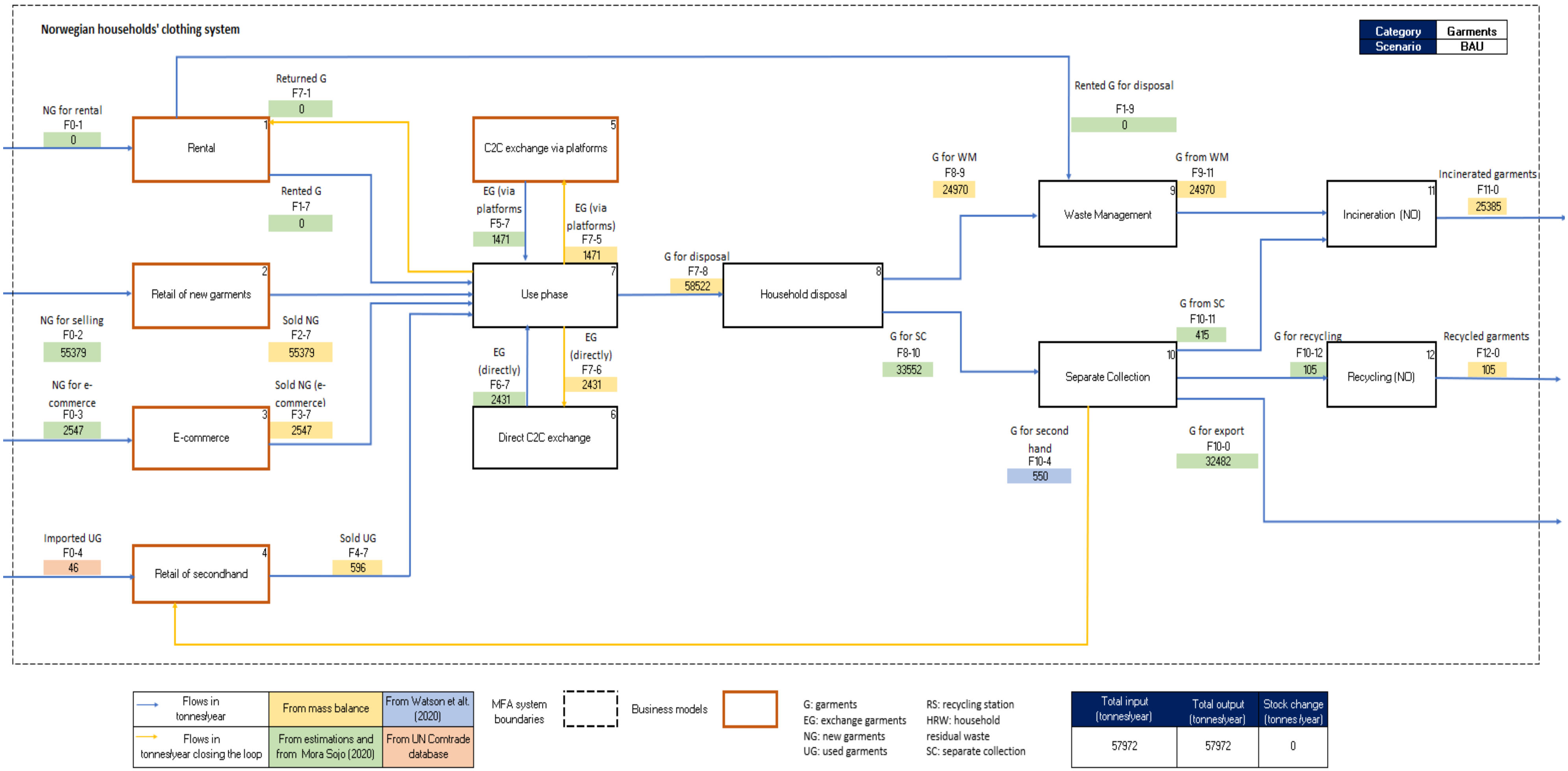
4.1 Material Flow Analysis of the Norwegian Households' clothing system in 2018

4.1.1 Mass balance of the system

Figure 9 shows the quantification of the Norwegian clothing system for the year 2018, at level 1 tonnes of clothes/year. Results for the 7 layers of the system, corresponding to each garment category are presented in Appendix F. As it can be seen from Figure 9 the total amount of clothes added into the system is 57972 tonnes. This figure considers the amount of used garments that were imported, the amount associated to online shopping, and the new garments acquired through retail (which considers imports and domestic production), all of them for household consumption. Due to the mass balance assumption done in this study, assuming that there was no stock change, the total amount added into the system is the same as the total amount leaving the system (see Figure 9). As it can be seen, garments leave the system either because they are exported or because they are incinerated or recycled. Due to the transformation that garments undergo through incineration and recycling, they do not account as garments anymore, so even if these processes take place within Norway, these garments are represented as leaving the system, and they imply a downcycling of their quality (ETC/WMGE, 2019).

It is worth to notice that it is most likely not true that the stock change of the system is 0 tonnes, but rather that it is probably increasing. Results from Watson et al. (2020), which considers clothing and household textiles in Norway, indicate an increase of 6845 tonnes of textiles in the system (approximately 10% of the total input). In addition, results from Denmark also reveal an increase of 10150 tonnes (13% of the inputs) (Watson et al., 2018), and a similar study performed in Finland also indicate that textiles were being accumulated by consumers (Dahlbo et al., 2017). Based on the results of those studies and previous discussions regarding the increase of clothing consumption (Steen-Olsen et al., 2016), it could have been expected to have an increase of the clothing stock in the system. Mora Sojo (2020) also estimated a positive stock change of the Norwegian household clothing system, lying between 836 tones and 5960 tonnes. However, due to the high uncertainties also revealed in Mora Sojo (2020), associated to the estimation of the outflows, and which were previously presented in the methodology section, it was decided to assume that the system was balanced. Although taking this approach simplified the estimation of the composition of

Figure 9 MFA of the Norwegian Households' clothing system for the year 2018, flows presented in tonnes of clothes/year.



4.1.2 Norwegian Households' consumption in 2018

The total input of 57927 tonnes added into the system (presented in Figure 9) does not correspond to the total amount of garments acquired by Norwegian households as there was a share of used garments acquired that were already part of the system in 2018, and that recirculated during this year. The total amount of garments acquired is presented in Table 7, in terms of tonnes and pieces. In this case each piece of clothing is associated to one transaction, hence, the number of pieces is equal to the number of transactions taking place through each business model. Table 7, also shows the results per type of garment and per acquisition channel. As it can be seen from Table 7, for the baseline scenario, the amount of rented garments was assumed to be 0, this because of limited data, and because it can be expected to be a small figure.

According to the results in Table 7, Norwegian households acquired a total of 62424 tonnes of clothes in the year 2018, considering new and used garments. This figure corresponds to approximately 12 kg per capita and a total of 42 pieces per person. Figure 10 shows that only 7% (weight based) of the acquired garments were used garments. Whereas the remaining 93% of garments acquired were new and obtained through retailers and e-commerce (see Table 7), generating a demand of 57926 tonnes of new clothing for the year 2018.

The demand of 57926 tonnes of new clothing represents 83% of the amount of new textiles estimated by Watson et al. (2020). This is consistent with their results, as they estimated that 77% of the consumption was clothing, and the remaining 23% was household textiles (Watson et al., 2020).

In terms of pieces, the consumption of new garments estimated in this study corresponds to approximately 40 new pieces per person, considering retail and e-commerce. Garments sold through retail consider those produced abroad, estimated in 53449 tonnes, and those domestically produced (1930 tonnes). The report of SIFO which investigates the acquisition, reuse and laundering of garments, estimated almost half of the figure found in this study. Their figure corresponds to 22.2 new garments per person (including purchases and gifrs) (Laitala & Klepp, 2020). Nevertheless, the SIFO report indicates that their figure is also smaller than the one presented by Virke in their report called "Handelsrapporten 2019/2020. Handlevaner på nett og butikk 2019". The estimates from Virke, which are mainly based on imports and presented in Laitala & Klepp (2020), indicate a consumption of 57.6 new garments per person. Virke's figure is closer to the result of 40 pieces per person, found in this thesis.

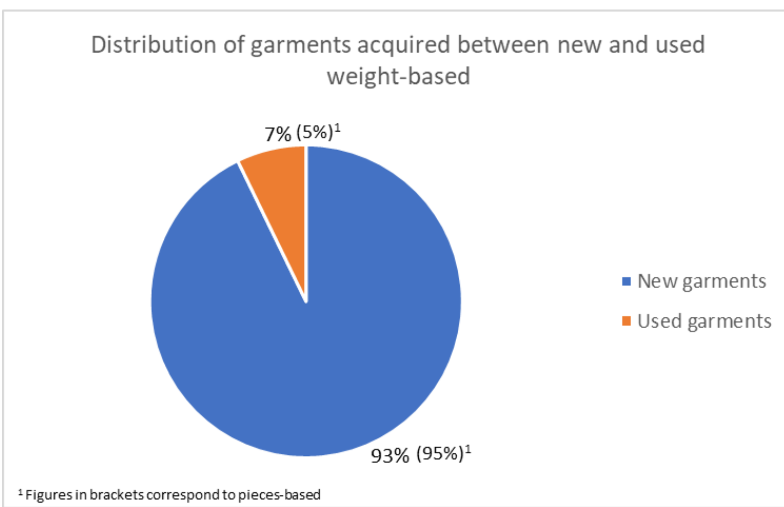
Laitala & Klepp (2020), pointed out possible explanations for the differences that were found between their figure and Virke's which also apply for this study. The first explanation provided by Laitala & Klepp (2020), is that their result (22.2 pieces per person) is based on a survey, whereas Virke's results are based on imports. They argued that when answering surveys respondents are more likely to forget some of their purchases, rather than to overestimate them. Their second explanation is that the survey only considered 10 categories of garments if more categories would had been considered their results would have increased. They also pointed out that the answers of the respondents could have been biased, as the theme of the survey was sustainability. Lastly, they indicate that Virke's figure probably overestimates consumption, as it does not exclude unsold garments (Laitala & Klepp, 2020). In this study, the clothes that are not sold are not considered either, hence it is also likely that the overall consumption of new garments is overestimated. Watson et al. (2020) estimated the amount of unsold garments for the year 2018, in 715 tonnes, however they indicated that this figure has a lot of uncertainties, and that more information is required to have a better estimate of the amount of unsold garments in the system.

Table 7 Clothes acquired by the Norwegian Households in 2018, per type of garment and acquisition channel.

G	Garment Category	Business as usual scenario (baseline 2018)												Total tonnes acquired	Total number of pieces (transactions)	Percentage per type of garment (weight based)	Total pieces/ person[4]
		1BM		2BM		3BM[1]		4BM[2]		5BM[2]		6BM					
		Rentals		Retailers (New)		E-commerce (New)		Second hand stores		C2C exhange via platforms		Direct C2C exchange					
		$F_{1\text{-}7}$ (Tonnes)	Pieces[3]	$F_{2\text{-}7}$ (Tonnes)	Pieces[3]	$F_{3\text{-}7}$ (Tonnes)	Pieces[3]	$F_{4\text{-}7}$ (Tonnes)	Pieces[3]	$F_{5\text{-}7}$ (Tonnes)	Pieces[3]	$F_{6\text{-}7}$ (Tonnes)	Pieces[3]				
1	Overcoats	0	0	9711	14511167	485	725208	95	141584	234	349447	488	729514	**11013**	**16456921**	**18%**	3.1
2	Pullovers	0	0	9246	24410744	419	1105899	157	413342	386	1020177	652	1720223	**10859**	**28670386**	**17%**	5.4
3	Trousers / ensemble	0	0	16111	36471036	741	1676724	270	611086	666	1508234	936	2119320	**18724**	**42386400**	**30%**	8.0
4	Shirts	0	0	3847	14544588	167	629675	64	240404	157	593347	176	667001	**4411**	**16675013**	**7%**	3.1
5	Baby's garments	0	0	911	5340699	42	246038	0	0	0	0	0	0	**953**	**5586736**	**2%**	1.1
6	Accessories	0	0	2158	20890217	90	867462	0	0	0	0	0	0	**2248**	**21757679**	**4%**	4.1
7	Not suitable for reuse (socks, underwear, nightwear, others)	0	0	13394	84398355	604	3806130	11	70399	28	173752	179	1125736	**14216**	**89574372**	**23%**	16.9
Total number acquired		**0**	**0**	**55379**	**200566806**	**2547**	**9057136**	**596**	**1476815**	**1471**	**3644957**	**2431**	**6361794**	62424	221107507	100%	42
% acquired through each BM		**0.0%**	**0.0%**	**88.7%**	**90.7%**	**4.1%**	**4.1%**	**1.0%**	**0.7%**	**2.4%**	**1.6%**	**3.9%**	**2.9%**				

Notes:
1. It was assumed that all the transactions that took place through e-commerce in 2018, were for household consumption.
2. The magnitude of the flows from Secondhand stores, and C2C exchange via platforms, were calculate at an aggregated level (level 1: tonnes of clothes/ year) by Mora Sojo (2020), but not their composition in terms of garment category. However, Mora Sojo (2020) estimated the composition per type of garment of all the purchases of used garments together (without making distintcion of the acquisition channel, secondhand stores or exchange via platforms). According to her results C2C exchange via platforms represent 71% (weight-base) of the purchases and the remaining 29% corresponds to used garments that were imported and obtained from separate collection and assumed to be sold through secondhand stores. These shares were applied at a garment category level to distribute the garments across the different acquisition channels.
3. Each piece of clothes is associated with one transaction.
4. Considering a total population of 5295619, according to data for the year 2018 retrieved from Statistics Norway (Statistics Norway, 2020). This is a rough estimate, which considers that everybody buys every type of garment.

Figure 10 Percentual distribution of garments acquired between new and used, weight based.



Furthermore, when comparing the Norwegian consumption of new garments through retail (approximately 10 kg per person), to results for Denmark and Sweden, they are almost the same. The consumption of new garments by households in Denmark was estimated in approximately 11kg per person (Watson et al., 2018). Using figures from Sweden, presented in Sandin et al. (2019), and considering the Swedish population for 2017 (SCB, 2020), the Swedish consumption of new garments is estimated in approximately 10kg per person. However, figures from Sweden include the consumption of the public sector and enterprises. Mora Sojo (2020) estimated the consumption of new garments from the public sector in 4223 tonnes, which would only increase the difference between the results for both countries, to almost 2kg per person. Nevertheless, it can only be concluded that the figures for the three countries are in the same order of magnitude, as their uncertainties do not allow to make conclusions regarding differences at a scale of kg.

With respect to the consumption of used garments, the results indicate that Norwegians acquired approximately 2 used pieces per person (considering both forms of C2C exchange and secondhand stores). Results from the survey performed by SIFO, indicated that this figure is approximately 1.3 pieces per person (Laitala & Klepp, 2020). The value reported by SIFO is almost half the figure reported in this study. However, this difference is associated to the way the number of used garments was estimated. To estimate the number of used garments presented in this report the figures presented by Laitala & Klepp (2020) were used to estimate the total number of garments acquired and the proportion of new garments and used garments. As the amount of new garments had already been calculated, the total supply and the amount of used garments were estimated using the percentages derived from Laitala & Klepp (2020). Nevertheless, as previously discussed, the amount of new garments estimated in this thesis, was found to be almost double the amount reported in Laitala & Klepp (2020), consequently the amount of used garments was also doubled. When analyzed the consumption of garments in terms of kg per person, this corresponds to 0.85 kg per person. This figure is smaller than the one found for Denmark, estimated in 3.32 kg of used garments per person (Watson et al., 2018).

Within the channels through which used garments are acquired, Direct C2C exchange is the one with the highest share, both in terms of weight and number of transactions. This result is consistent with results from previous studies that investigate the acquisition of used garments through purchases and informal exchange, where the latter also represented the highest share (Laitala & Klepp, 2017, 2020). However, despite the environmental benefits Direct C2C exchange, could generate from avoiding the production of new garments, if this transaction takes place without and exchange of money (e.g., inheritance) attention should be given to how households re-spend the money they saved from avoiding the purchases of clothes. This aspect is highly relevant to achieve an overall reduction of carbon emission, due to the risk of a rebound effect (Bjelle et al., 2018). In addition, this kind of exchange should be analyzed from a sustainability perspective, that accounts not only for environmental impacts, but also for social and economic impacts. However, the analysis of the social and economic impacts is out of the scope of this study.

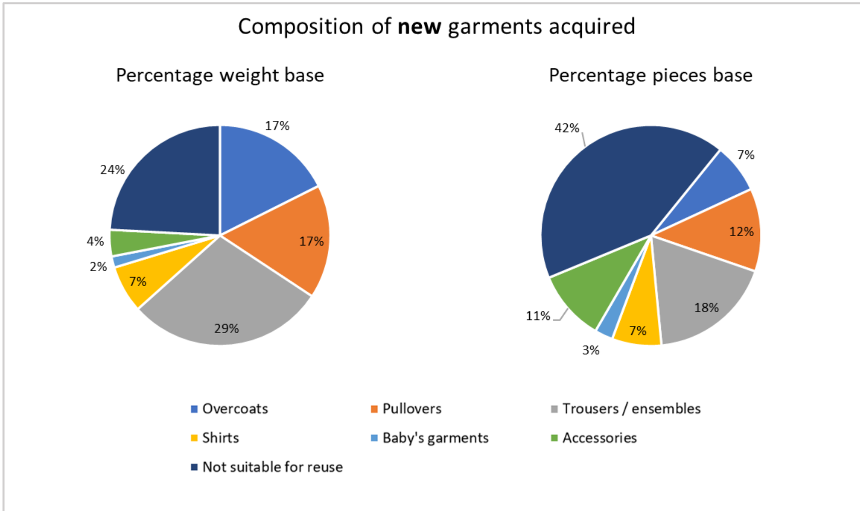
It is worth to notice that the results presented in this study are a first approximation of the magnitude of the flows $F_{5\text{-}7}$ (C2C exchange via platforms) and $F_{6\text{-}7}$ (Direct C2C exchange), presented in Table 7, as these flows were not included by Watson et al. (2020).

From Table 7 it can be seen that the magnitude of F_{5-7} is 1471 tonnes. This value was estimated thought mass balance (Mora Sojo, 2020). Its magnitude is considered reasonable, as it is on the same order of magnitude as estimates from Denmark, that quantified this flow in 1600 tonnes (including household textiles) (Watson et al., 2018). The magnitude of F_{6-7} was estimated in 2431 tonnes. The same report from Denmark quantified this flow in 6000 tonnes (including household textiles) (Watson et al., 2018). As indicated by Watson et al. (2018), the Danish study took the same approach as Bartlett et al (2013), in a study for UK, where informal exchange was assumed to be equal to 7% of new textiles purchase each year. Applying the same approach to the Norwegian clothing system would have resulted in 4000 tonnes of clothes exchanged through Direct C2C exchange. However, the initial estimation presented here is considered more appropriate, as it was based on a survey from SIFO, considered to be more representative of the Norwegian population, and representing the behavior of Norwegians during the year 2018 (Laitala & Klepp, 2020). However, it could be concluded that F_{5-7} (C2C exchange via platforms) and F_{6-7} (Direct C2C exchange) are underestimated, as they do not consider all the categories of garments under study (e.g., baby's clothes, and accessories), as it is explained below, when analyzing the composition of the Norwegian consumption.

Results from the MFA also demonstrate that there are differences between the composition of types of garments found in the business models offering new garments, and in the acquisition channels offering used garments. Figure 11 shows the composition of new garments acquired in terms of type of garment. This figure considers the total amount of garments that were purchased through retailers and e-commerce. Figure 12 shows the composition of used garments acquired in terms of type of garment, considering those acquired through secondhand stores, C2C exchange via platforms, and direct C2C exchange. Details on the exact amount acquired per acquisition channel and garment category can be seen in Table 7 and Appendix F.

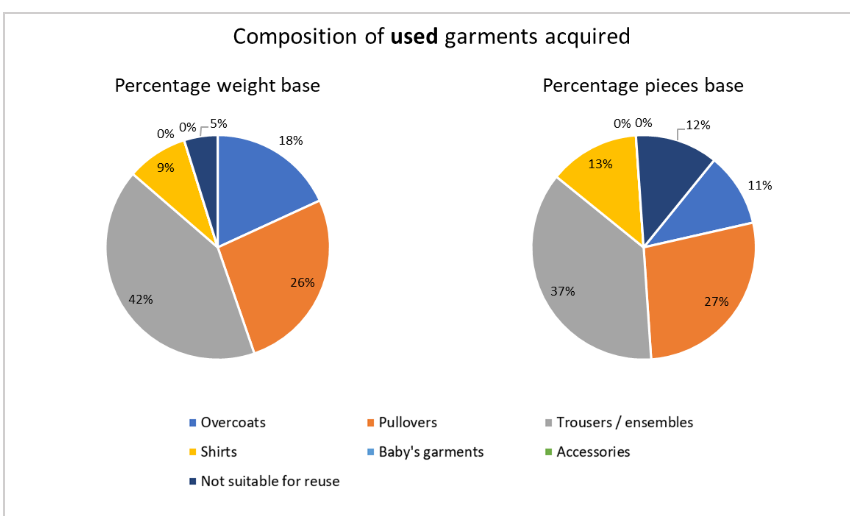
It should be noted that the composition of the flows in terms of garment category is less certain than the magnitude of the flow at an aggregated level. The main reason for this is that on some occasions there was not data at the level of garment category that could be used to analyze the composition of the flows. In such cases, it was decided to estimate a factor for the analyzed flows at an aggregated level, and these factors were applied to all the garment categories, without making distinction between garments. For example, this was the case when estimating the composition of secondhand stores (F_{4-7}) and C2C exchange via platforms (F_{5-7}), where the composition at an aggregated level was known from Mora Sojo (2020), but not the composition per acquisition channel. Therefore, it was decided to calculate the share that each flow represented at an aggregated level (tonnes of clothes) and these shares were applied at level 2 (garment category) to split the amount between these two flows. However, it could be the case that some garments do not follow the same distribution as the flow at an aggregated level. Perhaps it could be argued that garments that people want to try on (e.g., trousers) (Laitala & Klepp, 2020), are more likely to be acquired through secondhand stores rather than through platforms. A similar approach was taken when estimating the composition of the outflow from separate collection, as it is discussed in section 4.1.3.

Figure 11 Composition of new garments acquired at level 2, per type of garment.



From Figure 11 it can be seen that the acquisition of new garments is dominated by those that are not suitable for reuse, mainly in terms of pieces (42%), but also in terms of weight it represents the second largest share (24%). The reason why the share of garments not suitable for reuse is almost half in terms of weight compared to its share in terms of pieces, is due to the light weight of the garments associated to this category (e.g., socks, and underwear). The category of trousers and ensembles has also a high share, both in terms of weight and pieces. This could be explained because of two reasons, this type of garments has one of the highest weights per garment (see Appendix B), and it is also a category considering a broad variety of articles (e.g., trousers, ensembles, dresses, skirts, and overalls), whereas the other categories are more narrowed. The reason why all these articles were considered together is because of the CN classification (European Commission, 2016) used in this study, as it can be seen in Table 2.

Figure 12 Composition of used garments acquired at level 2, per type of garment.



From Figure 12 it can be concluded that the highest share of used garments, in both cases (weight and pieces), corresponds to the category of trousers and ensembles, followed by pullovers. As it was previously mentioned, Mora Sojo (2020) was not able to estimate the share that accessories and baby's garments have of the amount of used garments acquired. This as the studies that were used as a base to estimate these flows, do not consider these categories, hence, they were assumed as 0 (Mora Sojo, 2020). This assumption implies an underestimation of these categories and the magnitude of the flows associated to used garments, as it was previously explained, since articles such as baby's garments are likely to be acquired used (Opinion, 2019). However, more information is required to be able to estimate them.

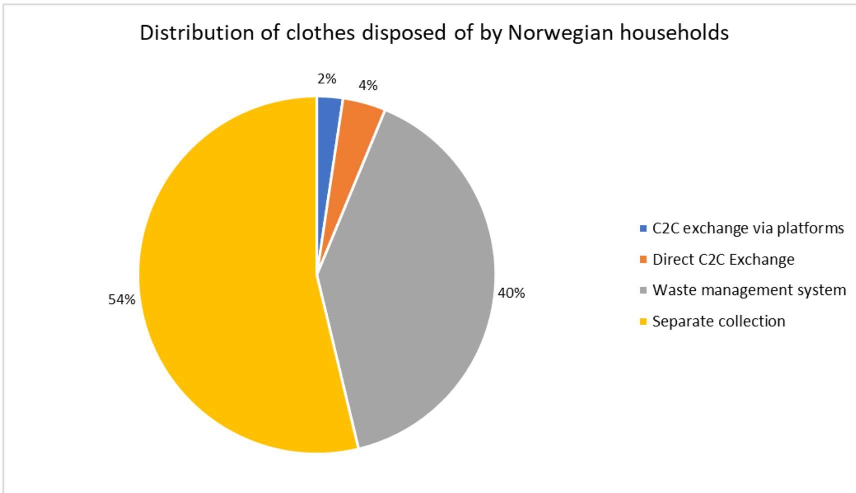
Figure 12 also allows to conclude that even though there are articles considered in this study as not suitable for reuse, these are still found as part of the garments that are acquired used, although to a lesser extent (12% pieces based). A report from SIFO investigating the acquisition of garments, indicates that one of the reasons why people is less likely to use secondhand items, is because of hygiene, and that this is especially true for underwear (Laitala & Klepp, 2020). However, it is possible to identify at least 3 reasons why this category of garments could still be represented within the used garments acquired, despite of aspects such as hygiene:

- **Level of aggregation:** the category of garments not suitable for reuse considers different types of underwear but also nightwear (see Table 2). These articles are considered together because of how the CN classification codes are structured (European Commission, 2016). However results from the same report done by SIFO, indicates that articles such as nightwear were more commonly inherited than bought from secondhand (Laitala & Klepp, 2020). This is consistent with the results of the MFA, as it can be seen from Table 7 that these garments are most likely acquired through Direct C2C exchange, rather than purchased.
- **Garments are assumed as used:** in this study it was assumed that all garments acquired through secondhand stores and C2C exchange (direct and via platforms) were already used. However, it is also possible to find unused garments through these acquisition channels. These could happen either because of unsold garments that retailers donate to charity shops (Fretex Norge AS, 2018; Watson et al., 2020), or because of new garments that those who acquired them in first place decide to re-sell them still new, either because they change their mind or because they did not fit them properly. This is likely to happen with garments acquired in first place through e-commerce, where in some cases retailers give the option to return the items (PostNord, 2019), but this is not always the case.
- **Exceptions:** despite the fact that research demonstrates that there is less willingness to acquired certain type of garments once they have been used (Laitala & Klepp, 2020), there are always exceptions, and there is probably still a percentage of people willing to do it.

4.1.3 Disposal of clothes by Norwegian Households in 2018

According to Norwegians disposed of clothes through 4 different channels, the waste management system (considering garments disposed of through household residual waste and at recycling stations), separate collection, and those exchanged either via platforms or directly. The total amount of tonnes diposed of by Norwegian households is 62424 tonnes (the same as the amount consumed due to the mass balance assumption, previously discussed). Figure 13 shows how the clothes are distributed through these channels. Together, both forms of C2C exchange account for only 6% (weight based) of the garments, whereas separate collection accounts for more than half of the garments disposed of.

Figure 13 Distribution of clothes through different disposal channels (weight based).



When excluding the amount of garments disposed of through C2C exchange channels, this amount goes down to 58522 tonnes, which corresponds to 92.5% of the same flows found by Watson et al. (2020), which considers household textiles. As it can be seen, when comparing the results of the MFA with the results from Watson et al. (2020), the share of clothes is higher on the disposal flows than on the flows associated to consumption. One possible explanation for this is that household textiles are changed with less frequency and have longer lifespans, hence they are disposed of to a lesser extent than clothes. As stated by Nørup et al. (2019a), the fact that the lifespan of household textiles could be longer is influenced by the fact that their consumption is driven by function (need) rather than a change in fashion. In the case of clothes, several factors influenced their disposals, such as fashion trends and physical changes of the owner (causing clothes not to fit the owner anymore) (Nørup et al., 2019a). These factors also imply that household textiles are most likely discarded because they are worn out.

Considering that household textiles are mainly discarded when they are worn out, can partially explain why when looking only at the flow of garments going into the waste management system (F_{8-9}) the share of clothes estimated in this study, goes down to 80% of the flow estimated by Watson et al. (2020). However, it is also possible that the flow of garments going into the waste management system (F_{8-9}) estimated in this study is underestimated. The reason for this is that this flow was calculated through mass balance after estimating the flow of garments disposed of through separate collection (F_{8-10}), which resulted to be 105% of the amount estimated by Watson et al. (2020), which also considers textiles. If the amount going into separate collection estimated by Watson et al. (2020), is considered as an upper limit, it could be that the amount of clothes estimated in this study as going through separate collection is overestimated. This happened because of how the flow going into separate collection was estimated. To estimate this flow, it was assumed that 60% of the disposed garments were disposed of through C2C exchange and through separate collection, and that the remaining 40% was disposed of as waste, according to figures from Laitala et. al (2012), whereas in Watson et al. (2020), the distribution between separate collection and the waste management system is 50% each (excluding C2C exchange which was not considered by Watson et al. (2020)). However, the amounts estimated in this study are still in the same order of magnitude as the ones estimated by Watson et al. (2020), and it is reasonable to assume that most of the textiles found in separate collection are clothes (Fretex Norge AS, 2018).

Regarding the composition of the flows, as the system is assumed to be balance, the composition of what is being disposed of, at an aggregated level, is the same of what is being acquired. However, there could be differences between the alternative paths. The composition of flows F_{7-5} and F_{7-6}, which correspond to the disposal of garments through C2C exchange, was previously analyzed when discussing the composition of the consumption taking place through these channels. Figure 14 and Figure 15 present the composition of the garments in the Waste Management System and in Separate Collection. However, the estimates of the composition of these flows are highly uncertain. For instance, estimating the composition of what goes into separate collection is difficult, as almost 97% of is exported, usually as "original", which means it has not been sorted in detail, as this is done at sorting facilities abroad (Watson, Palm, et al., 2016). Nevertheless, from Figure 14 and Figure 15 it can be seen that the categories of trousers and ensembles, together with garments not suitable for reuse, dominate the composition of both flows.

Figure 14 Composition of garments in the Waste Management System at level 2, per type of garment

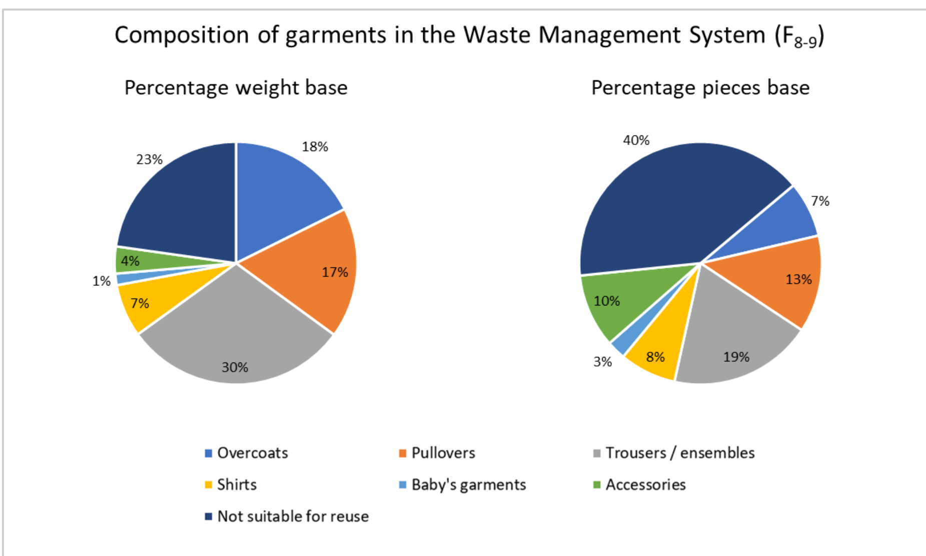
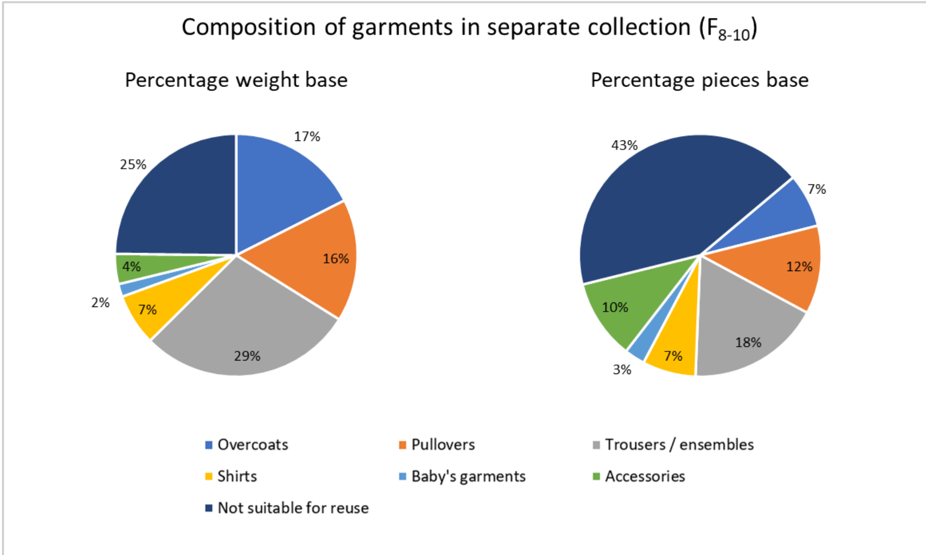
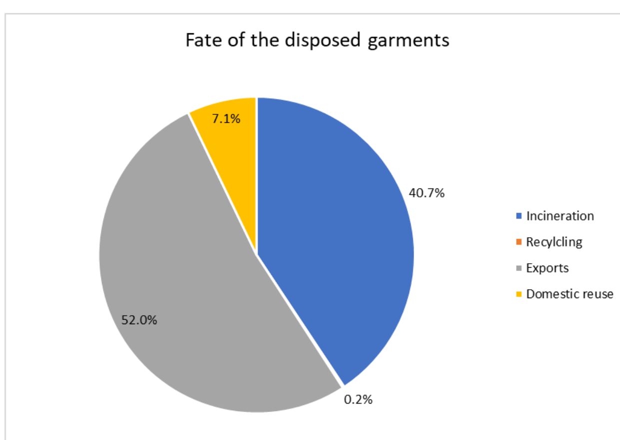


Figure 15 Composition of garments in Separate Collection at level 2, per type of garment



With respect to the final fate of the garments, Figure 16 presents the percentual distribution of the disposed garments, according to their final treatment. It can be seen that 52% of the garments are exported, followed by incineration (41%). Incinerating garments, is perceived as a loss (Ellen MacArthur Foundation, 2017), as the materials and labor embedded in the products is lost when they are incinerated. However, the distribution showed in this figure, together with the one presented in Figure 13 about the channels used by Norwegians to dispose their garments is expected to change in the following years as a result of the new regulations established by the EU, requiring separate collection of textiles by 2025 (European Parliament, Council of the European Union, 2018). This has already led to initiatives such as the project called "Tekstil 2025", carried out by Avfall Norge, which aims to increase the value obtained from discarded textiles (Måge, 2020).

Figure 16 Percentual distribution of the disposed garments, according to their final treatment (weight based).



From Figure 16 it can also be perceived that only 7.1% of the disposed garments are destined for domestic reuse, considering C2C exchange and secondhand stores. This means that for the year 2018, and from a national system perspective the Norwegian clothing system was approximately 93% linear. The analysis of the impacts of the exported garments is out of the scope of this study. However, despite concerns about the increasing amount of textiles that have been exported to developing countries, research has demonstrated that there are also environmental and social benefits derived from these exports (Watson, Nielsen, et al., 2016).

The results presented in this subsection could be used by manufacturers and retailers, when designing the garments, so that they can do it in a way that increases the suitability of the garment to be offered through a CBM.

4.2 Environmental impacts of the Norwegian Clothing System for the year 2018 (Baseline scenario)

This section presents the results of the LCA done to evaluate the baseline scenario. Results are presented and discussed first considering the magnitude of the overall environmental impacts and their implication. Followed by a discussion on the elements contributing the most to each environmental impact, and an analysis of the contribution of each of the business models.

The results for the environmental impacts investigated in this study and associated to the Norwegian households' clothing needs satisfied during the year 2018 are summarized in Table 8. According to the results from the MFA, the defined functional unit is 221107507 pieces of garment acquired in the year 2018, composed by a variety of garments, as presented in the MFA results (see Table 7)

Table 8 Environmental impacts of the Norwegian clothing system for the year 2018 (Baseline scenario)

Impact category	National level impact	Impact per capita
Climate Change	1.7 million t CO2 eq	317 kgCO_2 eq
Water Scarcity	2.9 billion m^3	550 m^3
Energy consumption	27861 million MJ	5261 MJ

The carbon footprint per capita derived from this study corresponds to approximately 3% of the carbon footprint associated to household consumption, according to results from Ivanova et al. (2016), where the latter was estimated in 10.3 tonnes of CO_2 eq per capita. This is also aligned with results from Ivanova et al. (2017), where it was concluded that for the EU, clothing contributed with 4% of household emissions. In addition, when analyzing the results from Ivanova et al. (2017) for other 18 countries, it can also be concluded that with the carbon footprint derived from this study, Norway would be part of the countries with the highest carbon footprint linked with clothes.

The results per capita presented in Table 8, can also be compared to the results per capita from Sweden, presented by Sandin et. al (2019), where climate change was estimated in 327 kg of CO_2 eq, water scarcity in 613 m^3 world equivalent, and the consumption of energy was estimated in 6000 MJ (Sandin et al., 2019). As it can be seen, the results for Norway are in the same order of magnitude. This was expected once it was found that the magnitude of the consumption through retailers was also similar (see section 4.1.2), together with the fact that the inventory used by Sandin et al. (2019), was one of the main sources of data used in this study.

Nevertheless, despite the differences in what this study and Sandin et al. (2019) considered to estimate their consumption, it is worth to notice that the overall consumption analyzed in this study (12 kg per capita) is higher than the overall consumption reported by Sandin et al. (2019) (10 kg per capita). And as it can be seen, from Table 8, still considering a higher consumption per capita in Norway, the environmental impacts per capita estimated in this study are slightly lower than the results for Sweden. These differences could be associated to uncertainties in the model, but also to some differences in the inventory used and methodological choices. For instance, the electricity mix of the processes taking place within Norway, was adjusted to represent the Norwegian electricity mix, instead of the Swedish one. According to data from Ecoinvent 3 database, used in this model, the Norwegian electricity mix has less environmental impact in the three categories under study.

Another difference between Sandin et al. (2019) and this study is how the distribution of garments to retailers was modelled. When modeling the distribution of garments in this study, only the ocean freight was considered, whereas terrestrial transport associated to the distribution of new garments was excluded, due to lack of data. This underestimates the results associated with the distribution of material. On the other hand, the study for Sweden considered terrestrial freight. However, Sandin et al. (2019) indicate that together distribution and retail, contribute to 3.1% of the climate change impact, 5% to the energy use and 0.3% to water scarcity. Among the elements considered for Sweden in distribution and retail are the ocean freight, the terrestrial freight, and the energy consumption for the facility management, all these aspects except for terrestrial freight, were considered in this study. Hence, if terrestrial freight dominates the contribution of distribution and retail, the figures from Sweden provide an idea of the underestimation of the impacts associated to it.

Furthermore, it is important to understand the elements contributing the most to each of the impact categories. This are presented as elements and not as processes, since some processes have elements in common (e.g. user's transport, and electricity for facility management). In addition, production and distribution, which are processes taking place outside Norway, were not shown in the MFA, but were considered for the LCA, as it is a cradle-to-grave study.

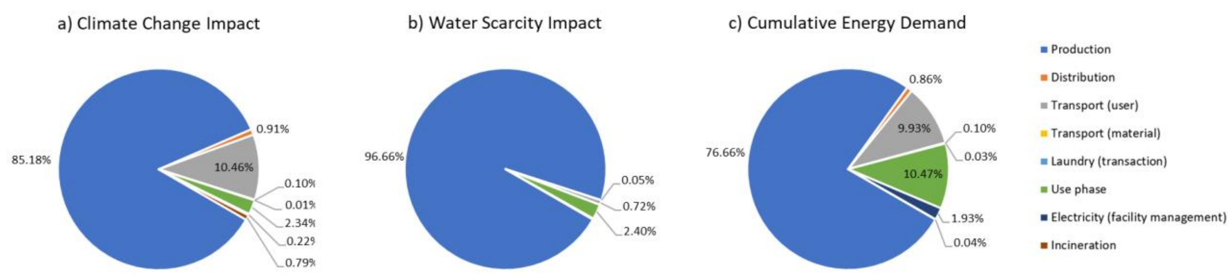
The percentual contribution of different elements in the system, for each of the environmental impacts analyzed is shown in Figure 17. The results indicate that the production of garments dominates all the environmental impacts in the system, accounting for more than 75% in each category. However, it is worth to notice, that the environmental impacts associated with the production of new garments could be overestimated. The reason for this is that approximately 1930 tonnes were estimated to be produced domestically, whereas for the LCA it was assumed that all the new garments from retailers and e-commerce were produced abroad. This assumption was done to simplify the system and due to lack of data about the Norwegian production of garments. However, due to the electricity mix used in Norway, based mainly on hydropower, it could be expected that domestic production has less environmental impact, than production abroad (mainly in developing countries). The importance and difference of embodied emissions in imports and in domestically produced products is also discussed by Ivanova et al. (2016), when analyzing the environmental impacts of household consumption. Their findings suggest that imports from developing countries are usually associated with a higher carbon footprint than products manufactured in developed countries (Ivanova et al., 2016).

The use phase, which considers laundry, drying, and ironing, outstands as the second element contributing the most in all the categories, except for climate change. With laundry contributing with more than half of the impact of the use phase in all the categories. This has to do with the fact that the frequency of drying and ironing is always assumed to be less than the frequency of washing. In addition, laundry also embeds the environmental impacts associated with the production of the detergent. Furthermore, the use phase is more relevant for the indicator of cumulative energy demand, than for climate change, due to the Norwegian electricity mix, which is mainly hydropower (Nordic Energy Research, 2018). This also explains why the contribution from facility management is almost 2% of the cumulative energy demand but is less than 1% in climate change, as facility management is associated to the energy required to operate the stores and the pre-sorting facility.

It is worth to notice that for the purpose of this study, it was assumed that Norwegians have a requirement of garments during the use phase, which is dependent on the type of garment, but not affected by the total number of garments they have of each type. This means that if they need to use a t-shirt 200 times in a year, these 200 uses will be distributed among the number of t-shirts the person has access to. Hence, the requirement of 200 uses is the parameter considered in this study, to model the use phase. This implies that if the person has 10 t-shirts, on average each t-shirt would be used 20 times, whereas if the person has 5 t-shirts, each one would be used approximately 40 times. By doing this it was also assumed that the frequency of use of the garments was independent of the business model used to acquired them. This was assumed to simplify the model, and due to the uncertainties linked to user behavior.

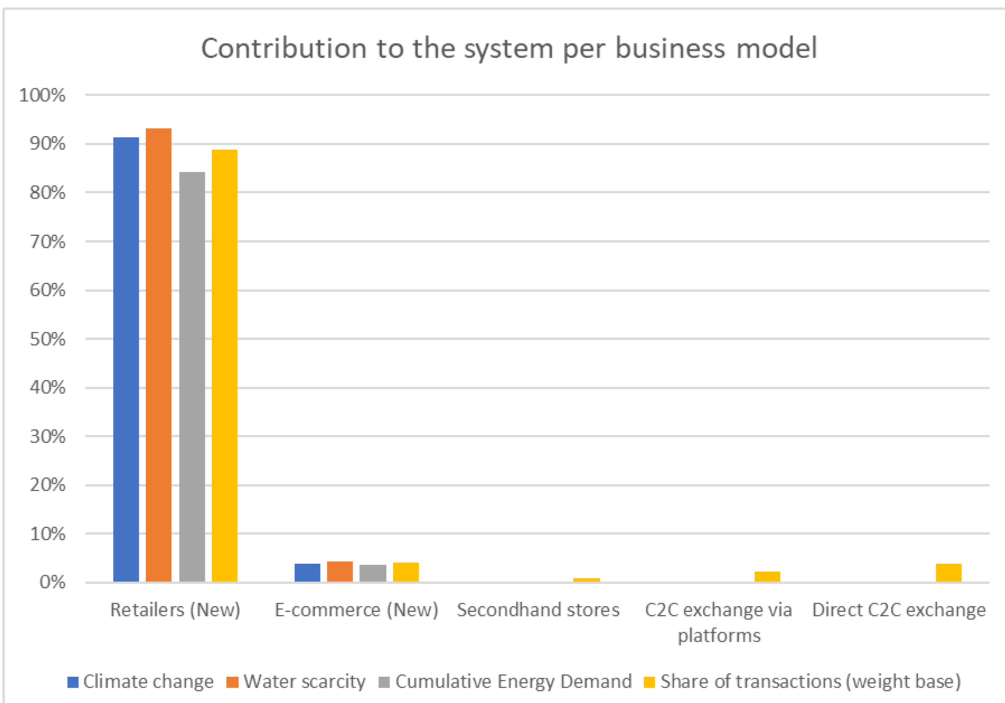
In the case of climate change the users’ transport is the second category contributing the most (10.46%). Users’ transport considers all the transports done by the user identified in the system, the ones associated to the acquisition of the garments (for all the business models), and the ones associated with the disposal (when delivering garments to separate collection). It is worth to notice, that the baseline scenario considered the distribution of mode of transport for the given distances, according to Norwegian’s behavior for the year 2018, which was mainly dominated by cars running on diesel and gasoline (Berge, 2019). However, this distribution has changed in the past years, due to the efforts done by Norway to electrify its transport system (Broom, 2020). Therefore, this 10% has probably already decreased. The environmental impacts of transport are further discussed in the scenario analysis.

Figure 17 Percentual contribution of each element on the system to each impact category



Moreover, it is important to understand the contribution that each of the business models analyzed in this study has on the overall impacts of the system, and how does this contribution relate to the share each business model has on the market. Therefore, Figure 18 shows the percentual contribution of each of the business models to each impact category, together with their share on the market (weight based). Note that the share on the market for each business model in terms of pieces is approximately the same as in terms of weight, with differences between of less than 2% (see Table 7).

Figure 18 Percentual contribution of each business model to the environmental impacts and the share of transactions



According to the results presented in Figure 18, the contribution of retailers of new garments, to the environmental impacts of climate change and water scarcity is higher than their share on the market. This is because the environmental impacts of this business model are mainly driven by the production of new garments, which is also the element contributing the most to the overall environmental impact of the system, specially for water scarcity (see Figure 17).

However, for cumulative energy demand, the contribution of the retailers is less than its share on the market. This despite the fact that production is also the element driving the impact of retailers of new garments. However, for cumulative energy demand, the overall contribution of production is less than 80%, as the contribution of other phases such as the use phase increased.

From Figure 18,it can also be seen that E-commerce follows the same behavior as retailers. When modeling E-commerce, the round trip of the user picking up the garment at a delivery pick up point, was included. However, the delivery of the garment to the pick-up point, was not considered, due to lack of data. Nevertheless, the contribution of this transport of garments, is not expected to be significant for climate change in the following years, due to efforts done by the providers of delivery services to offer fossil-free shipping (Jørstad, 2020), and transport does not have a significant contribution to water scarcity.

As previously mentioned, when analyzing the elements contributing the most to each environmental impact, the use phase was modeled considering a fix requirement of uses per type of garment and considering that the frequency of use of the garments was independent of the business model used to acquired them. Hence, the environmental burden of the use phase was not allocated to any of the business models, and it is not represented in Figure 18. Nevertheless, Klepp et al. (2020), indicate that the number of garments a user has access to, can influence the frequency of use of a piece. Hence, the selection of business model could have an impact on the frequency of use of the garments, however, this was not considered in this study. Nevertheless, it was assumed that the business models offering used garments could led to at least 1 additional laundry, linked to the transaction. When looking at Figure 17 and Figure 18, it can be concluded that, considering the Norwegian electricity mix, the environmental burden associated to this additional laundry is not significant as for all the impacts it contributes with less than 0.1%.

More information on how each element contributes to the environmental impacts of each business model and other phases of the system can be found in Appendix G.

The results presented in this subsection could also be useful for manufacturers and retailers, who could use them to identify where are the main impacts when offering CBMs. This is key in to consider problem shifting, and to take the necessary measures to reduce the overall impact of the businesses.

4.3 Increasing the circularity of the Norwegian households' clothing system

In order to investigate how some interventions aiming to increase the circularity of the Norwegian households' clothing system, affect its environmental impacts, a scenario denominated Circular Business Model scenario was elaborated. This scenario assumed that the number of transactions that took place during the year 2018 remains constant, and it is just reallocated between business models. Hence, the total amount of garments going into the use phase also remains the same. How this assumption could affect the obtained results is discussed when analyzing the environmental impacts.

To create the scenario 2 main interventions were defined. The first one corresponds to the inclusion of rental business models in the system, based on the willingness to rent associated to different types of garments. In addition, the second intervention assumes an increase in domestic reuse through secondhand stores. This increase is based on the potential for reuse that exists in garments that are currently disposed of as waste. Both interventions sought to reduce the requirement of new garments acquired through retail. The decrease in demand of new garments would also decrease the environmental impacts associated to their production, which proved to be the largest contributor of all the environmental impacts in the system. How these interventions were done is explained in section 3.3.

Table 9 presents the results on how the transactions were reallocated between the business models. The percentages are presented in terms of transactions (pieces), the detailed reallocation in terms of weight and per type of garment can be found in Appendix F. Because of how the interventions were defined, these only affected the allocation of transactions between retail of new garments, rental, and secondhand stores. Hence, the results presented previously for the other business models are not affected.

Table 9 Results for the reallocation of transactions, the percentages are pieces based.

Factors	Baseline Scenario (BAU)	Circular Business Model Scenario (CBM)
% of transactions – Retail (new)	90.7%	**82.9%** (↘)[1]
% of transactions – Rental	0%	**7.1%** (↗)[2]
% of transactions – Secondhand stores	0.7%	**1.3%** (↗)[2]
% of transactions – E-commerce (new)	4.1%	4.1%[3]
% of transactions – C2C exchange via platforms	1.6%	1.6%[3]
% of transactions – Direct C2C exchange	2.9%	2.9%[3]

Notes:

1. (↘) The % of transactions assumed in the CBM scenarios , represents a decreased on the percentage of transactions taking place through the specific acquisition channel in the year 2018.
2. (↗) The % of transactions assumed in the CBM scenarios, represents an increase from the percentage of transactions taking place through the specific acquisition channel in the year 2018.
3. In the CBM scenario there was no change in the percentage of transactions taking place through E-commerce, C2C Exchange via platforms, and Direct C2C Exchange.

The figures presented in Table 9 indicate that the cumulative impact the interventions had on the system, resulted in approximately 83% of the transactions taking place through retail of new garments, which implies a decrease of 8.6%, compared to the baseline scenario. The percentage of the transactions that were reallocated from retail (new) to rental, correspond to 7.1%. This figure is based on the assumptions done to translate the identified willingness to rent in terms of transactions taking place through this business model, as it was explained in section 3.3. Therefore, this figure is very uncertain. However, the way it was estimated allowed to consider for differences in the willingness to rent among different types of garments. For instance, overcoats, baby's garments and accessories were the categories associated to highest willingness to rent, whereas the category of garments not suitable for reuse was not included in the rental business model, due to the low willingness to rent associated to these garments.

In the case of secondhand stores, the increase in garments sent to separate collection resulted only in 1.3% of the transactions taking place through secondhand stores. Even if this is an increase of approximately 100% compared to the baseline scenario, it is still quite low. For instance, despite the reallocation, Direct C2C exchange still has a higher share of the transactions in the system.

The reason for the low increase perceived in secondhand stores is that this scenario only considers an increment on separate collection but does not modify how garments in separate collection are distributed among the alternative treatments (domestic reuse, incineration, recycling, and exports. And according to previous results, exports accounts for approximately 97% of what goes into separate collection. This is better exemplified in Table 10, which shows the results for the BAU-scenario (baseline), and the CBM scenario, for indicators that allow a better understanding of the flow of materials within the system, as it is explained below.

Table 10 Results of the indicators used to analyze the impact of the scenario across the flows.

Indicator	BAU-Scenario	CBM-Scenario	Percentual change
Collection rate	60.0%	84.3%	40.5%
Reuse rate after losses (excluding exports)	7.1%	8.2%	15.4%
Return rate	7.2%	7.6%	5.2%
Percentage of garments acquired new (weight based)	92.8%	83.6%	-9.9%
New garments to be produced (tonnes)	57925.7639	52763.64254	-8.9%

The collection rate presented in Table 10, calculated based on weight, considers all the garments that are disposed of through a path different than the waste management system. This means that it includes the amount of garments disposed of not only through separate collection but also through Direct C2C exchange, and C2C exchange via platforms. The results indicate that in the BAU scenario this indicator was estimated in 60%, whereas in the CBM scenario there was an increase of 40.5%, resulting in a collection rate of 84.3%. This increase took place as a result of the intervention, which diminish the amount of clothes suitable for reuse sent into the waste management system.

However, as previously mentioned, this increase of 40% in the collection rate, did not result in a similar increase of garments in secondhand stores. This can be seen with the indicators of reuse rate after losses and return rate, where the first one analyses the outputs from household consumption, and the second one analyses the inputs. The indicator of reuse rate after losses corresponds to the fraction that garments reused domestically (disposed of within Norway), represent from the total amount that is being disposed of. This indicator also considers both channels of C2C exchange. The indicator of return rate corresponds to the fraction that used garments represent of the total amount of garments acquired. If the loops in the system were closed these two indicators would be the same.

As these indicators are focus on the reuse that takes place in Norway, they exclude exports from the amount considered as reused, hence, this ended up been considered as losses. By doing this the circularity of Norway as a country is being analyzed, as the fate of the exported garments was not investigated in this study. However, this approach underestimates the reuse rate after losses, which goes only from 7.1% in the baseline to 8.2% in the CBM scenario, for an increase of 15.4%. According to Watson et al. (2016), 71% of the textiles exported from Nordic countries are destined for reuse. If this 71% is considered, the reuse rate after losses of the baseline would be of 44% and for the CBM scenario would increase to 61% (an increment of 40%). Accounting for the reuse of exports would also increase the difference between the reuse rate after losses and the return rate.

The results for the reuse rate after losses and the return rate showed in Table 10, are very close to each other. The small difference is because, even when excluding exports, the loop is not closed, as there are 46 tonnes of used garments that were imported to Norway in 2018, and that were assumed to be acquired by Norwegian households.

In addition to these indicators Table 10, also shows how the percentage of garments acquired new was reduced in approximately 10%, however, the decrease in required amount of garments to be produced is 1% less. The reason why the decrease in the demand of new garments to be produced is less than the percentage of garments acquired new, is because of how the rental model was set up. In this scenario it was assumed that the rental business model offers garments that were initially new, assuming that it reflects a shift on the current business model of some retailers. However, this figure is also associated to a lot of uncertainties, as it depends on aspects such as the quality of the garments to be rented. The quality will impact on how many users can make use of the garment before it is worn out. In the CBM scenario it was assumed that each garment was rented for 1 person each month, this means 12 different users in a year. Besides the quality of the garment itself, how frequently each user wears the garment during the period of rental would also have an impact on it service lifetime. In addition, the production of a stock in rental was also considered, which was assumed to be 20% of the garments needed to satisfy the rentals. The impacts of wear and tear in rental were considered assuming that 15% of the garments needed to satisfy the rentals were disposed of by the end of the year, however, these garments are not reflected in the production requirements for the year 2018, as they will impact the production of the year after, when they need to be replaced.

The effects that the intervention had on the flows is also reflected on the environmental impacts. Table 11 shows how the environmental impacts at national scale were impacted by the modifications done in the scenario. The highest reduction achieve is for climate change with a decrease of 9% compared to the baseline. Whereas the achieved reduction for water scarcity and energy consumption is 7%.

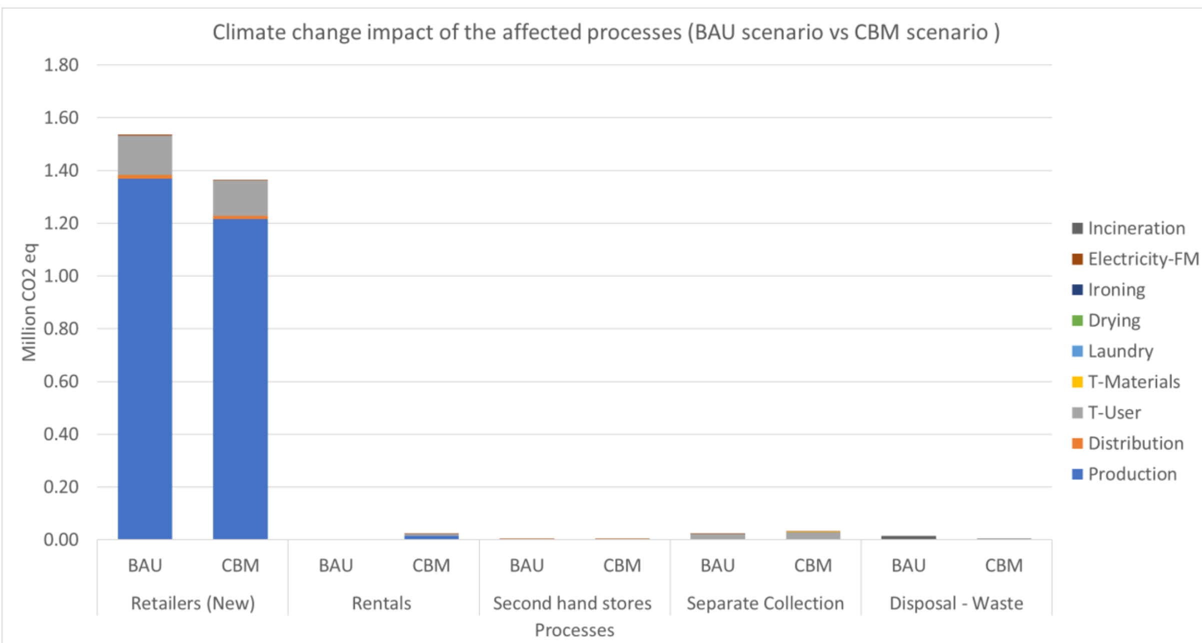
Table 11 Effect of the interventions on the environmental impacts

Impact category	BAU	CBM	Change
Climate Change (million t $CO_{2\ eq}$)	1.7	1.5	-9%
Water Scarcity (billion m^3)	2.9	2.7	-7%
Energy consumption (million MJ)	27861.8	25813.9	-7%

This reduction of less than 10% in all the categories is associated to the fact that the demand of production of new garments only decreased on approximately 9%, as shown in Table 10. And from the evaluation of the environmental impacts of the baseline it is known that production drives all the environmental impacts under study. Water scarcity and energy consumption present a slightly lower decrease, due to the increase in laundry associated to the increase of transactions from secondhand and rental. This as 1 extra laundry cycle was assumed to be linked with transactions from secondhand and 2 extra laundry cycles were assumed to be linked with transactions from rental. However, the impacts associated to the energy consumed during laundry, impact to a less extent the category of climate change, because of the Norwegian electricity mix.

Figure 19 presents a comparison of the climate change impact of the processes that were affected by the modifications done in the scenario. The figure also shows the contribution of each of the elements associated to these processes. It is clear that with the small reduction achieved in the share of retailers of new garments, this business model still dominates the impacts of the system. Results for water scarcity and cumulative energy demand present the same behavior and can be found in Appendix H.

Figure 19 Comparison of the climate change impact of the processes affected by the interventions done in the CBM scenario.



From Figure 19 it is possible to see an increase in the impact associated to separate collection, which represents a trade-off with the reduction of the impact associated to the disposal of garments as waste. This occurs because of how the garments were deviated from waste into separate collection as previously explained.

Nevertheless, the decrease of all the categories, presented in Table 11, and that is observed for retailers in Figure 19 is likely to be overestimated. This due to the assumption of 100% replacement rate, which implies that a transaction satisfied through rental or secondhand replaces on a 1:1 ratio a transaction taking place through retail of new garments. However, this replacement rate is likely to be lower (Fisher et al., 2011), implying that the acquisition of new garments from retailers would not decrease at the same rate as the increase in the alternative business models. Based on results form a survey about clothing acquisition behavior in Norway, considering new and used garments, Laitala & Klepp (2020) indicated that there is no clarity on the connection that exists between buying used and buying less new, however, they pointed out their results suggested that purchases of used clothing does not necessarily would reduce the purchase of new clothes. For instance, they concluded that the region of Oslo stood out as the region where there was more consumption of both, new and used garments (Laitala & Klepp, 2020). These aspects could considerably reduce the environmental benefits obtained through the CBM scenario. In addition, there is also a risk of rebound effect in other sectors. Bjelle et al. (2018), indicated that heir results suggest that household actions such as disposing less and reusing more, or a reduction in clothing purchases, could lead to rebound effects of up to 500% (Bjelle et al., 2018).

Despite the potential risk of a rebound effect, it is still important to understand how each business model contributes to each of the environmental impacts compared to their share of transactions in the system. This analysis was already done for all the business models, except for rental, during the evaluation of the impacts of the baseline scenario (see Figure 18). Hence, Table 12 presents and overview of the percentual contribution of rental to each of the environmental impacts and its market share (given as percentage of transactions, weight based).

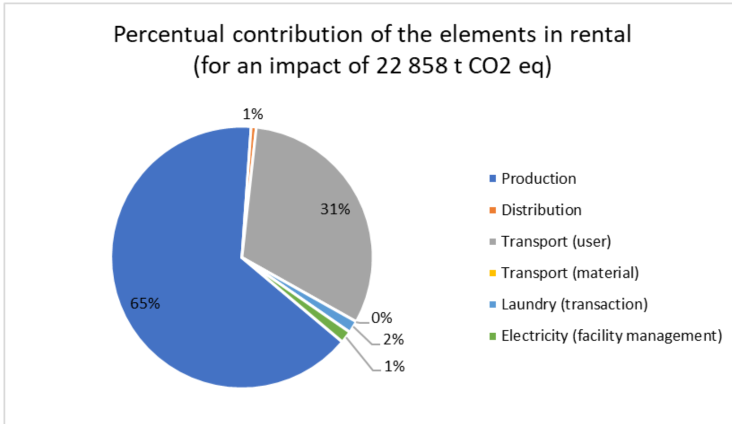
Table 12 Percentual contribution of rental to each environmental impact and its market penetration

Percentage of transactions (weight based)	Climate Change	Water Scarcity	Cumulative Energy Demand
8.8%	1.5%	0.9%	1.6%

As it can be seen from Table 12, despite having almost 9% of the market (weight base), its contribution to the environmental impacts is between 1% and 2%. However, as previously mentioned, the contribution of this business model to the environmental impacts is associated to the parameter of number of users per garment, which was an assumption done in this study. This parameter is of key relevance, and it is directly associated with the amount of production required for this business model, as it determines the number of garments required to satisfy the number of transactions. Garments of poor quality, which are worn out quickly, could worsen the environmental impact of the business model (Zamani et al., 2017).

Moreover, due to the concerns about problem shifting, linked to rental and the increase in transport (Zamani et al., 2017), it was decided to analyze the elements within rental that contribute the most to climate change. This is shown in Figure 20, where it is possible to see that transport accounts for 31% of the impact on climate change associated to rental, whereas for the transactions taking place through retail of new garments transport only represents 10% of the climate change impact. This result indicates that the transport of the user has a significant contribution to the environmental impact of the business. This decreases the potential of the business model, to reduce the environmental impacts when increasing even more its market penetration. The configuration of the rental business model in the CBM scenario that derived in this impact, considers 2 roundtrips to the delivery pick-up point (online store), each round trip of 3.7 km. The distribution of mode of transport was defined according to (Berge, 2019), for the given distance. This led to a distribution of 40% people walking, 54% taking the car (gasoline and petrol), and 6% taking the bus.

Figure 20 Percentual contribution of the elements in rental, considering a total contribution to climate change impact of 22 858 t CO_{2eq}.



In order to investigate how other configuration of the rental business model could affect its impact it was decided to analyze 2 additional configurations. The first configuration (configuration A) assumes that the store is located at the city center (offline store), as it is the case for retailers of new garments, and secondhand stores. Hence, the distance and mode of transports assumed for configuration A is the same as for these business models. The second configuration (configuration B) assumes that the store is online (as in the CBM scenario), but that the mode of transport is more efficient. The distances, mode of transport and environmental impact of both configurations, and its comparison to the one defined for the CBM scenario is presented in Table 13:

Table 13 Results for the sensitivity analysis on mode of transport for rental

	Configuration	t CO_2 eq (contribution at national level)	Percentual change compared to CBM scenario
Configuration A	-Set up: Offline -Distance (roundtrip): 11.1 km -Mode of transport: 13% walk 72% car 15% bus	45264	98%
CBM scenario - configuration	-Set up: Online -Distance (roundtrip): 3.7 km -Mode of transport: 40% walk 54% car 6% bus	22858.3	-
Configuration B	-Set up: Online -Distance (roundtrip): 3.7 km -Mode of transport: 40% walk 30% bus 30% electric car	19811	-13%

According to the results presented in Table 13, longer distances and a distribution among mode of transports, dominated by transport based on fossil fuels, could almost double the environmental impact associated to rental. Considering the same distance as in the baseline, but an improvement on the efficiency of the selection of mode of transport could still decrease the climate change impact of the rental business model in 13%. Hence, if the rental business model is expected to have a greater participation in the market, care must be taken to ensure logistics that reduce its environmental impacts. However, as previously mention the trends on the transport sector are on this direction (Broom, 2020).

The results of the scenario analysis corroborate that the environmental benefits that can be obtained through the implementation of CBMs is very limited. This indicates that the development of policies should strive for a higher market penetration rate, and for a reduction on the risk of the rebound effect. For instance, policy instruments such as taxes applied to the acquisition of new garments could discourage the acquisition of new garments, this could not only increase the transactions taking place through alternative business models but could also increase the true value of the replacement rate close to 1.

Furthermore, when considering the results presented for the baseline scenario and for the CBM scenario, it can be seen that they provide relevant insights for Norway's transition towards a more circular economy. As the results obtained are representative of Norway at a national level, they could be used by policy makers, who could identify the policies required for the transformation of the sector.

This research could also be used to educate consumers and create awareness of the environmental impacts associated with their apparel needs, and how these may be affected depending on the business model they choose to acquire their garments. Lastly, as this is a first attempt to elaborate an assessment of the environmental impacts associated to the needs of clothing in Norwegian households at a national level, this study could also serve as a base for further researchers aiming to analyze how different factors impact the obtained results.

5. Conclusion and recommendations

This research investigated the magnitude and composition of the flows within the Norwegian households' clothing system for the year 2018, together with its environmental impacts. This was done making use of Material Flow Analysis and Life Cycle Assessment, considering a cradle-to-grave perspective. Results from the MFA indicate that for the year 2018, approximately 58 000 tonnes of clothes were added to the Norwegian households' clothing system. However, when looking at the total acquisition of garments, it was possible to identify that approximately 7% of the garments acquired corresponded to garments being recirculated within Norway. When including these garments, the total household acquisition is estimated in 62 400 tonnes of clothes (approximately 221 million of transactions). Due to the mass balance assumption, the same number of garments was assumed to be disposed of by households during the same year. Further research should be carried out to have a better understanding of the outflows, and how these influence that stock of clothes in the Norwegian households.

In terms of the composition of the flows, garments classified as not suitable for reuse have one of the biggest shares on the acquisition of new garments, and on the disposal through the waste management system and separate collection, this despite the light weight of these category. This high representation in the system, together with their limitations for reuse, makes them a great target for strategies aiming to increase their lifespan, so that their flow can be slowed down. The flows associated to used garments are mainly composed by the category of trousers and ensembles, and the category of pullovers, both in terms of weight and pieces. These findings corroborate the different potential that garments have for implementing CBMs. However, results regarding the composition of the flows are more uncertain than the results at an aggregated level, as more assumptions were needed to estimate them. In addition to this, some categories of garments were not represented among the used data, hence, these categories could also be underestimated. It is recommended to investigate more the composition of these flows, to reduce the uncertainties on the system, and when doing this, an analysis based on types of fibre should also be consider, as this was out of the scope of this study.

The estimated consumption, and disposal of garments for the year 2018 together with the use phase resulted on a climate change impact of 1.7 million t CO_2 eq, which on a per capita basis (317 kg CO_2) corresponds to approximately 3% of the carbon footprint associated to the Norwegian household consumption. In addition, the system has an impact on water scarcity of 2.9 billion m^3 (550 m^3 per capita), and an energy consumption of 27 861 million MJ (5261 MJ per capita). Throughout the impact categories, the production of new garments stood out as the phase with the greatest contribution, representing in all the cases more the 76%. With respect to the use phase, this represents 2% of the impact on water scarcity, and 10% of the cumulative energy demand, however, due to the use of Norwegian electricity mix, its contribution to climate change impact is only of 2.3%. This means that if other electricity mix is used, more attention should be given to the use phase. Another element of concern was the contribution of the users' transport, which was estimated to be 10% of the climate change impact. Nevertheless, this share has probably already decreased due to the increasing use of electric vehicles, whereas for the year 2018, the Norwegian transport system was still dominated mainly by fossil fuels.

A plausible scenario was elaborated to evaluate how an increase in transactions taking place through rental and through secondhand stores could affect the system under study. Taking advantage of the potential for reuse that exist on garments that are being disposed of as waste, and deviating this into separate collection, the collection rate could increase from 60% to 84.3%. However, the indicator of reuse rate after losses, only increase from 7.1% to 8.1%, this is explained as approximately 97% of the collected garments are exported. Moreover, the interventions reduced the flow of new garments been sold through retailers in approximately 10%, which implied a decrease in the production of new garments of 9%. These modifications on the flows, resulted on a decrease of the environmental impacts that is between 7% and 9% for all of them.

The scenario also corroborated the risk of problem shifting between transport and production when introducing rentals. For the transactions that were reallocated to rental, transport represents approximately 31% of their contribution to climate change, whereas for the transactions taking place through retail of new garments transport only accounts for approximately 10%. A sensitivity analysis evaluating alternative modes of transports and distances was done, to investigate how this could be affected. Assuming longer distances and higher number of trips by car, the climate change impact of the rental can increase in 98%, whereas assuming more sustainable modes of transport but the same distance could lead to a reduction of 13%. This demonstrates the importance of ensuring a system structure that could foster this CBMs in an effective manner. If this type of CBMs is going to be scale up to a greater extent, an effective transport system needs to be in place.

However, these environmental benefits are subject to the extent up to which these CBMs can replace the transactions taking place through retail of new garments. For this study, a 100% replacement rate was assumed, which is likely to be less. This, together with the potential risk of a rebound effect in other areas, would result in less environmental benefits derive from the interventions.

Moreover, it is recommended to analyze more how the quality of the garments to be rented and the number of users could affect the environmental impacts on the system. Garments should be designed in such a way that their suitability for this business models is enhanced, so that as many users as possible can make use of the garments and thus further reduce the production of new garments, this implies designing for longevity.

The results of the scenario highlight the importance of the policies that have been developed recently. It demonstrates that interventions based on current trends and potentials are not enough to achieve greater reductions on the environmental impacts. More efforts should be done in order to have a significant environmental impact on the Norwegian clothing system, striving for a higher penetration rate of CBMs on the market and reducing the probability of a rebound effects (within and outside the clothing system). For instance, policy instruments such as taxes on new garments, could diminish the possibility of a rebound effect.

The comprehensive approach of this study allows for a better understanding of the complexity of the Norwegian households' clothing system. By knowing the composition of the flows in terms of types of garments, these results could serve as a base to further explore how the Norwegian households' needs of apparel could be satisfied in a more sustainable way, considering not only their acquisition, but also their use and disposal. This in addition to providing a baseline for the reduction of the environmental impacts.

The analysis elaborated in this study contributes to the identification of key factors, that should be considered when re-thinking the Norwegian households' clothing system for its transition towards a more circular economy.

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7. Appendixes

Appendix A. Material Flow Analysis of the Norwegian Clothing System carried out by Mora Sojo (2020).

Appendix B. Weight of the garments under study

Appendix C. Inventory data

Appendix D. Modelling the production phase and the use phase

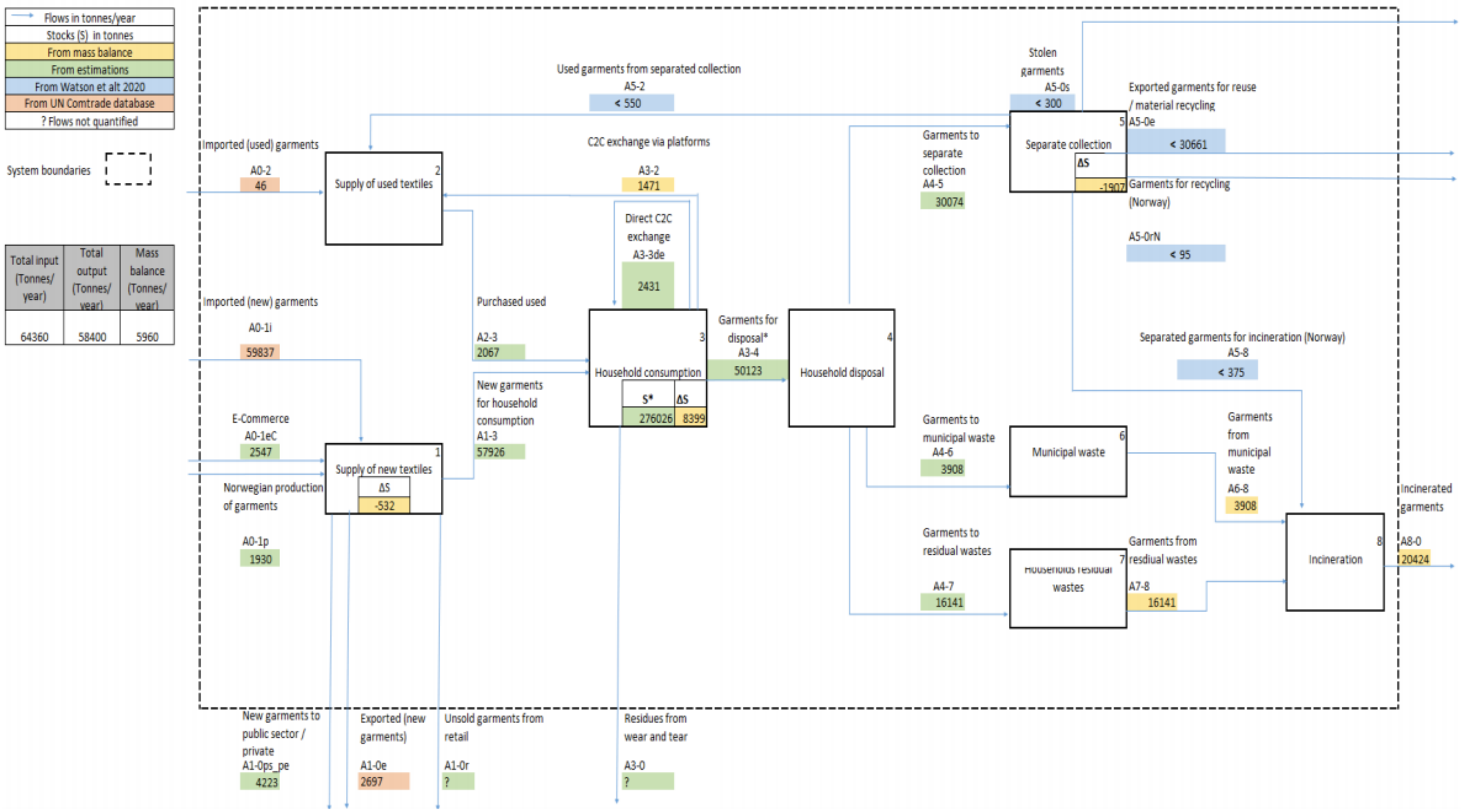
Appendix E. Modelling the scenario

Appendix F. MFA per type of garment of the Norwegian households' clothing system for the year 2018 (BAU-Baseline scenario)

Appendix G. Environmental impacts of the baseline scenario

Appendix H. Effects on the flows due to the interventions done in the CBM scenario, per type of garment.

Appendix A. Material Flow Analysis of the Norwegian Clothing System carried out by Mora Sojo (2020)



*Note: For the quantities indicated with * more than one approach to calculate them was presented in the methodology. There are differences in the results depending on the approach, this system shows the figures according to the following approaches:

S (Household consumption stock) = quantified using the fixed lifetime approach based on clothing category.

A3-4 Garments for disposal together = quantified using the approach 1-fraction of textiles

Flows analyzed in Mora Sojo (2020)				Treatment given in the present study	Equivalent flow in this study
Variable	Name of the flow	Main sources of data[1]	Level of detail[3]		
A0-2	Imported (used) garments	UN Comtrade database (United Nations, 2020)	1	Assumed to be the same at level 1. Level 2 was estimated assuming that the share that A0-2 represented of A2-3, was representative of the distribution at garment level. Since the composition of A0-2 was known, this factor was applied to all garment categories without distinction.	F_{0-4}
A0-1i	Imported (new) garments	UN Comtrade database (United Nations, 2020)	1 and 2	Mora Sojo (2020) used this flow to estimate A1-3 New garments of household consumption, the latter is the one considered in this study.	Included in F_{0-2}
A0-1p	Norwegian production of garments	Estimated: Considering the share that domestic production represents from the total supply of textiles (Watson et al., 2020), and the share that clothing represents of the total supply (based on data from Denmark presented in Watson et al. (2018))	1 and 2	Mora Sojo (2020) used this flow to estimate A1-3 New garments of household consumption, the latter is the one considered in this study.	Included in F_{0-2}
A0-1eC	E-Commerce	Estimated: Watson et al (2020), estimated this flow assuming that e-commerce included the same type of products as retail in Norway, and indicated that 77% of textiles in retail were clothes. The share of 77% was applied to estimate the amount that clothing represents from e-commerce. And level 2 was estimated assuming the same composition as in retail.	1 and 2	It was assumed that all the garments entering Norway through e-commerce were destined for household consumption. Aggregated to match the categories of garments defined in this study. No further modifications.	F_{3-7}

Flows analyzed in Mora Sojo (2020)				Treatment given in the present study	Equivalent flow in this study
Variable	Name of the flow	Main sources of data[1]	Level of detail[3]		
A1-0ps_pe	New garments to public sector / private enterprises	Estimated: The total supply (TS) was calculated as TS = Imports + e-commerce + domestic production - exports. The distribution of TS between sectors, per garment category was assumed to be the same as for Denmark (Watson et al., 2018)	1 and 2	Not related to household consumption - Excluded.	N/A
A1-0e	Exported (new garments)	UN Comtrade database (United Nations, 2020)	1 and 2	Not related to household consumption - Excluded.	N/A
A1-0r	Unsold garments from retail	Excluded due to lack of data	None	Excluded due to lack of data.	N/A
A2-3	Purchased used	Estimated: based on the shares per acquisition channel and types of categories identified in Laitala & Klepp (2020) and considering that A1-3. Their results considered purchased used (A2-3), purchased new (A1-3), and inheritance (approximated as A3-3de).	1 and 2	Segregated into flows $F_{0\text{-}4}$, $F_{5\text{-}7}$ and $F_{10\text{-}4}$.	$F_{0\text{-}4} + F_{5\text{-}7} + F_{10\text{-}4}$
A1-3	New garments for household consumption	Estimated: The total supply (TS) was calculated as TS = Imports + e-commerce + domestic production - exports. The distribution of TS between sectors, per garment category was assumed to be the same as for Denmark (Watson et al., 2018)	1 and 2	Segregated into flows $F_{0\text{-}2}$ and $F_{0\text{-}3}$.	$F_{0\text{-}2} + F_{0\text{-}3}$

Flows analyzed in Mora Sojo (2020)				Treatment given in the present study	Equivalent flow in this study
Variable	Name of the flow	Main sources of data[1]	Level of detail[3]		
A3-4	Garments for disposal	Estimated: 2 approaches were assumed: -1. Clothing outflow as a fraction of textiles outflow: based on figures from Watson et al (2020) and adjusted with data from Laitala et al. (2012). -2. Fixed lifetime: using estimated lifetimes. per type of garment, from Laitala et al. (2017) and data of imports from UN Comtrade database (United Nations, 2020), adjusted to account only for household consumption.	1 and 2	Recalculated through mass balance[4], at level 1 and level 2 assuming that $\Delta S = 0$.	$F_{7\text{-}8}$
A5-2	Used garments from separated collection	Watson et al. (2020)[2]	1	Assumed to be the same at level 1. Level 2 was estimated assuming that the share that A5-2 represented of A2-3, was representative of the distribution at garment level. Since the composition of A0-2 was known, this factor was applied to all garment categories without distinction.	$F_{10\text{-}4}$
A4-5	Garments to separate collection	Estimated: allocation factors estimated based on data from Watson et al. (2020) and Laitala et al. (2012), were applied to flow A3-4 in order to segregate it.	1	Modified[4] at level 1. Laitala et al. (2012), indicates that 60% of what is disposed of is destined for C2C exchange via platforms, C2C exchange directly and Separate collection. Knowing the total amount disposed of and the amount of C2C exchange, the amount and composition of what goes into SC is estimated.	$F_{8\text{-}10}$
A4-6	Garments to municipal waste	Estimated: allocation factors estimated based on data from Watson et al. (2020) and Laitala et al. (2012), were applied to flow A3-4 in order to segregate it.	1	Modified[4] at level 1. Aggregating A4-6 with A4-7 and knowing the amount and composition of what is disposed of by households, and what goes into separate collection, it was possible to recalculate the flow through mass balance approach.	Included in $F_{8\text{-}9}$

Flows analyzed in Mora Sojo (2020)				Treatment given in the present study	Equivalent flow in this study
Variable	Name of the flow	Main sources of data[1]	Level of detail[3]		
A4-7	Garments to residual wastes	Estimated: allocation factors estimated based on data from Watson et al. (2020) and Laitala et al. (2012), were applied to flow A3-4 in order to segregate it.	1	Modified[4] at level 1. Aggregating A4-6 with A4-7 and knowing the amount and composition of what is disposed of by households, and what goes into separate collection, it was possible to recalculate the flow through mass balance approach.	Included in $F_{8\text{-}9}$
A3-0	Residues from wear and tear	Excluded due to lack of data	None	Excluded due to lack of data.	N/A
A5-0s	Stolen garments from container	Watson et al. (2020)[2]	1	Excluded due to high uncertainty.	N/A
A5-0e	Exported garments for reuse / material recycling	Watson et al. (2020)[2]	1	Assuming that 97% of what goes into separate collection is exported (Fretex Norge AS, 2018). This factor is applied at level 1 and 2 without distinction between garments.	$F_{10\text{-}0}$
A5-0rN	Garments for recycling (Norway)	Watson et al. (2020)[2]	1	According to figures from Watson et al. (2020), from what is left in separate collection, after separating garments for domestic reuse and for exports, 20% goes into recycling. This factor is applied at level 1 and 2 without distinction between garments.	$F_{10\text{-}12}$
A5-8	Separated garments for incineration (Norway)	Watson et al. (2020)[2]	1	According to figures from Watson et al. (2020), from what is left in separate collection, after separating garments for domestic reuse and for exports, 80% is incinerated. This factor is applied at level 1 and 2 without distinction between garments.	$F_{10\text{-}11}$

Flows analyzed in Mora Sojo (2020)				Treatment given in the present study	Equivalent flow in this study
Variable	Name of the flow	Main sources of data[1]	Level of detail[3]		
A6-8	Garments from municipal waste	Mass balance	1	Aggregated with A7-8, to be able to estimate the flow at level 2, through mass balance assumption.	Included in $F_{9\text{-}11}$
A7-8	Garments from residual wastes	Mass balance	1	Aggregated with A6-8, to be able to estimate the flow at level 2, through mass balance assumption.	Included in $F_{9\text{-}11}$
A3-2	C2C exchange via platforms	Mass balance	1	Assumed to be the same at level 1. Level 2 was estimated assuming that the share that A3-3de represented of A2-3, was representative of the distribution at garment level. Since the composition of A0-2 was known, this factor was applied to all garment categories without distinction.	$F_{5\text{-}7}$
A3-3de	Direct C2C exchange	Estimated: based on the shares per acquisition channel and types of categories identified in Laitala & Klepp (2020) and considering that A1-3. Their results considered purchased used (A2-3), purchased new (A1-3), and inheritance (approximated as A3-3de).	1 and 2	Aggregated to match the categories of garments defined in this study. No further modifications.	$F_{6\text{-}7}$
A8-0	Incinerated garments	Mass balance	1	Mass balance at level 1 and level 2.	$F_{11\text{-}0}$

Notes:
1. The legend of colors represents how the flows were estimated: UN Comtrade Database, Watson et al. (2020), estimations, and mass balance.
2. Values taken directly from Watson et al. (2020) were considered as upper limits, since they also include household textiles.
3. Mora Sojo (2020) estimated the magnitude of the flows at the aggregated level 1 (tonnes of clothes/year) for 92% of the flows she investigated. However, it was only possible to estimate the composition of the flows per type of garment (level 2), for 38% of the flows.
4. Assuming that the system has an ΔS = 0, impacts the magnitude of the flows that are after the use phase, and that were calculated by Mora Sojo (2020).

Appendix B. Weight of the garments under study

The following table presents the weight defined for the garments under study. This was used to approximate some of the flows for the MFA, and to determine the number of transactions in the system.

G1	Name (G)1	Weight per piece (g)
1	Overcoats	669
2	Pullovers	379
3	Trousers / ensembles	442
4	Shirts	265
5	Baby's garments	171
6	Accessories	103
7	Not suitable for reuse (socks, underwear, nightwear, others)	159

Appendix C. Inventory data

The input data to model the system and its environmental impacts in SimaPro is presented in the following tables. P0a. Production was not model in SimaPro, hence the data used to model this process is not presented here, see Appendix D for more information on how the production phase was modeled. In addition, notice that P8. Household Disposal is a process created for the purpose of MFA, but it does not have any environmental impact directly associated with it, as the environmental impacts associated with the disposal of garments are generated by processes 5,6,9 and 10. Moreover, due to lack of data, all the garments going into recycling, were assumed to be incinerated, hence there is no inventory data for P12. Recycling.

<table>
<tr><th colspan="5">General description: P0b Distribution</th></tr>
<tr><td colspan="5">Transport of garments from the manufacturing country to the Norwegian Market, from Shangai to Oslo by sea freight.
Excludes: distribution inland from the port to the store.</td></tr>
<tr><td>Output</td><td>1</td><td>kg</td><td colspan="2">garments to be acquired</td></tr>
<tr><td colspan="5">Inputs</td></tr>
<tr><td rowspan="3">T_{IM}</td><td colspan="4">Transport import, from manufacturing country to Norway</td></tr>
<tr><td>Distance</td><td>23415</td><td>km</td><td>Assuming that a shipment from Shangai will arrive to the port of Oslo (Shipa, 2021).
Distance based on Ports.com (2021)</td></tr>
<tr><td>Type of vehicle</td><td colspan="2">Transport, freight, sea, transoceanic ship {GLO}| market for | Cut-off, S</td><td>Assumed as in Sandin et al (2019).</td></tr>
<tr><td colspan="5">Notes:
1. https://www.shipafreight.com/tradelane/china-to-norway/
2. http://ports.com/sea-route/port-of-oslo,norway/port-of-shanghai,china/#/?a=4595&b=2761&c=Port%20of%20Shanghai,%20China&d=Port%20of%20Oslo,%20Norway</td></tr>
</table>

General description: P1 Rental

Provides access to rented garments. Considers the activities of picking up the rented garment and delivering it back to the rental business. Wether the picking up and delivery takes place at the store in the city centre or at the delivery pick up point, depends on how the business is set up (offline or online business). For the CBM scenario an online business is assumed.

This process also takes into account the electricity required for the facility management, the same amount of electricity is assumed regardeless of the setting. In addition, it is assumed that the garment undergoes two washing cycles linked to the transaction itself. One laundry cycles is assumed to take place when it is rented and before using it and another laundry cycle is assumed to take place before returning it.

Output	**1**		**kg**	**garments rented**
		Inputs		
NG	New garment to be acquired	-	kg	See equation for flow F_{0-1} in section 3. Methodology
WG	Washed garment	2	kg	Assuming 2 laundry cycles per transaction. See P7.1 Residential Laundry
E_s	Electricity for stores			
	Electricity, low voltage {NO}| market for | Cut-off, S	1.94	kWh	Data from HM cited in Sandin et al (2019). Adjusted to represent Norwegian electricity market.
T-User	Transport user	-	-	Depends on how the business is set up (see general description of P1. Rental, and PT.Transport

General description: P2. Retail new

Process of selling new garments through an offline business model. Considers the activity of picking up the new garment from the store located at the city center (round-trip), and the electricity required for the facility management.

Output	**1**		**kg**	**new garments sold**
		Inputs		
NG	New garment to be acquired	1	kg	Selling 1 garment implies 1 garment that needs to be distributed to the store. From P0b. Distribution process
E_s	Electricity for stores			
	Electricity, low voltage {NO}| market for | Cut-off, S	1.94	kWh	Data from HM cited in Sandin et al (2019). Adjusted to represent Norwegian electricity market.
T-User	Transport user	-	-	PT.Transport- Transport to city center (assuming distribution of mode of transport - 2018)

General description: P3. E-commerce (new)				
Process of selling new garments through an online business model. Considers the activity of picking up the new garment at the delivery pick-up point (round-trip), and the electricity required for the facility management.				
Output	**1**	**kg**	**new garments sold through e-commerce**	
Inputs				
E_s	Electricity for stores			
	Electricity, low voltage {NO}| market for | Cut-off, S	1.94	kWh	Due to the lack of data, regarding the requirement of electricity for an e-commerce, it is assumed that it consumes the same as offline stores. Hence, the data use corresponds to data from HM cited in Sandin et al (2019). Adjusted to represent Norwegian electricity market.
T-User	Transport user	-	-	See PT.Transport- Transport to delivery pick-up point (assuming distribution of mode of transport - 2018)

General description: P4. Retail second hand				
Selling secondhand garments, through an offline business model, and where garments come from what is destined for domestic reuse from the process of separate collection. This process includes the transport from the facilities of separate collection to the second hand store, as well as the round-trip done by the customer to buy the used garment. It also considers the electricity for the facility management of the store. In addition, it is assumed that the garment undergoes 1 washing cycle linked to the transaction itself.				
Output	**1**	**kg**	**used garment**	
Inputs				
UG	Used garment from pre-sorting	1	kg	From P10. Separate collection
E_s	Electricity for stores			
	Electricity, low voltage {NO}| market for | Cut-off, S	1.94	kWh	Data from HM cited in Sandin et al (2019). Adjusted to represent Norwegian electricity market.
WG	Washed garment	1	kg	Assuming one laundry cycle associated to the transaction. From residential laundry. See P7.1 Residential Laundry
T_{SH}	Transport from pre-sorting to secondhand stores.			
	Distance	150	kgkm	According to Schmidt et al (2016), who also indicates that a variation form 10-150 km is possible.
	Type of vehicle	Transport, freight, lorry 7.5-16 metric ton, euro6 {RER}| market for transport, freight, lorry 7.5-16 metric ton, EURO6 | Cut-off, S		Schmidt et al (2016) indicates that the vehicle size used for distribution is 15 tonne or 7.5 tonne (gross weight), and that the weight of collected textiles is 2 tonnes on average. Hence, their transport is modelled using data for 12-14 tonne truck with 10 ton capacity and utilisation rate of 0.2.
T-User	Transport user	-	-	PT.Transport- Transport to city center (assuming distribution of mode of transport - 2018)

General description: P5. C2C exchange via platforms				
Process of selling garments through platforms, assumed to be online platforms. Includes the transport of the user to the delivery pick-up point, and 1 laundry cycle associated to the transaction, when the garment is acquired.				
Output	**1**	**kg**	**Used garment exchanged via platforms**	
Inputs				
WG	Washed garment	1	kg	Assuming one laundry cycle associated to the transaction. From residential laundry. See P7.1 Residential Laundry
T-User	Transport user	-	-	See PT.Transport- Transport to delivery pick-up point (assuming distribution of mode of transport - 2018)

General description: P6. Direct C2C exchange				
Process of acquiring garments through direct C2C exchange, usually without money in exchange (e.g. inheritance). It is assumed that the exchange happens when people meet for other reasons considered to be more important (e.g. family meeting), hence, there is no impact from transport allocated to the transaction. Includes 1 laundry cycle linked to the transaction.				
Output	**1**	**kg**	**used garment exchanged directly**	
Inputs				
WG	Washed garment	1	kg	Assuming one laundry cycle associated to the transaction. From residential laundry. See P7.1 Residential Laundry

General description: P7. Use phase				
Corresponds to the process where the garments are already at Norwegian Households, and users have them available to wear them. The use of the garments is associated with other sub-processes which are presented here and correspond to: Laundry, Use of Detergent (for laundry), Drying and Ironing.				
Output	**1**		**kg**	**garments from use phase**
Inputs				
WG	Washed garment	15.62	kg	From P7.1 Residential Laundry. Each kg of garment that is available for use during the use phase is worn a certain number of times, and it has a frequency of laundry related to the number of wears before washing it. This number of wears and frequency of laundry resulted in 15.62kg of washed garment / kg available (for more details on how this figure was obtained see section 3. Methodology).
DG	Dryed garment	4.99	kg	From P7.2 Residential Drying. Each kg of garment that is available for use during the use phase has a frequency of drying according to the frequency of laundry.This frequency of drying resulted in 4.99kg of dryed garment / kg available (for more details on how this figure was obtained see section 3. Methodology).
	Electricity for ironing			
E_I	Electricity, low voltage {NO}| market for | Cut-off, S	1.092	kWh	From Sandin et al. (2019) we know that 0.027kWh/min are required for the ironing sub-process. Each kg of garment that is available for use during the use phase has a frequency of ironing according to the frequency of laundry.This frequency of iroining resulted in a demand of 1.092 kWh/ kg available (for more details on how this figure was obtained see section 3. Methodology).

<table>
<tr><th colspan="5">General description: P7.1 Residential laundry</th></tr>
<tr><th colspan="2">Output</th><th>1</th><th>kg</th><th>Washed garment</th></tr>
<tr><td>Water to treatement</td><td>Wastewater, average {Europe without Switzerland}| market for wastewater, average | Cut-off, S</td><td>0.0052</td><td>m^3</td><td>According to Sandin et al. (2019) Table B-54, where 5.2kg are indicated. Associated to 1L of water lost during the laundry process.</td></tr>
<tr><th colspan="5">Inputs</th></tr>
<tr><td>Tap Water</td><td>Tap water {RER}| market group for | Cut-off, S</td><td>6.2</td><td>kg</td><td>According to Sandin et al. (2019) Table B-54.</td></tr>
<tr><td>LD</td><td>Liquid detergent</td><td>0.0158</td><td>kg</td><td>Amount according to Sandin et al. (2019) Table B-54. See P7.3 Liquid detergent.</td></tr>
<tr><td rowspan="2">E_W</td><td colspan="4">Electricity for washing</td></tr>
<tr><td>Electricity, low voltage {NO}| market for | Cut-off, S</td><td>0.225</td><td>kWh</td><td>0.225 are required to wash 1 kg at 40°C. According to Sandin et al. (2019) Table B-54. Adjusted to represent NO electricity mix.</td></tr>
</table>

<table>
<tr><th colspan="5">General description: P7.2 Residential drying</th></tr>
<tr><th colspan="2">Output</th><th>1</th><th>kg</th><th>Dryed garment</th></tr>
<tr><th colspan="5">Inputs</th></tr>
<tr><td rowspan="2">E_W</td><td colspan="4">Electricity for washing</td></tr>
<tr><td>Electricity, low voltage {NO}| market for | Cut-off, S</td><td>0.67</td><td>kWh</td><td>Amount according to Sandin et al. (2019) Table B-55. Adjusted to represent NO electricity mix.</td></tr>
</table>

<table>
<tr><th colspan="5">General description: P7.3 Liquid detergent</th></tr>
<tr><th colspan="2">Output</th><th>1</th><th>kg</th><th>Liquid detergent (density 0.95kg/l)</th></tr>
<tr><th colspan="5">Inputs</th></tr>
<tr><td rowspan="2">E_{LD}</td><td colspan="4">Electricity for liquid detergent</td></tr>
<tr><td>Electricity, medium voltage {RER}| market group for | Cut-off, S</td><td>0.25</td><td>kWh</td><td rowspan="14">According to Sandin et al. (2019) Table B-58.</td></tr>
<tr><td>Alkyl sulphate</td><td>Alkyl sulphate (C12-14) {GLO}| market for alkyl sulphate (C12-14) | Cut-off, S</td><td>0.1038</td><td>kg</td></tr>
<tr><td>Citric acid</td><td>Citric acid {RER}| production | Cut-off, S</td><td>0.0228</td><td>kg</td></tr>
<tr><td>Enzymes</td><td>Enzymes {RER}| enzymes production | Cut-off, S</td><td>0.0058</td><td>kg</td></tr>
<tr><td>Glycerine</td><td>Glycerine {RER}| market for glycerine | Cut-off, S</td><td>0.0285</td><td>kg</td></tr>
<tr><td>Non-ionic surfactant</td><td>Non-ionic surfactant {GLO}| market for non-ionic surfactant | Cut-off, S</td><td>0.0591</td><td>kg</td></tr>
<tr><td>Soap</td><td>Soap {RER}| production | Cut-off, S</td><td>0.0241</td><td>kg</td></tr>
<tr><td>Sodium hydroxide</td><td>Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, S</td><td>0.0231</td><td>kg</td></tr>
<tr><td>Water</td><td>Water, deionised, from tap water, at user {Europe without Switzerland}| market for water, deionised, from tap water, at user | Cut-off, S</td><td>0.7022</td><td>kg</td></tr>
<tr><td>HDPE bottle</td><td>Polyethylene, high density, granulate {GLO}| market for | Cut-off, S</td><td>0.0466</td><td>kg</td></tr>
<tr><td>Polyethylene</td><td>Polyethylene, linear low density, granulate {GLO}| market for | Cut-off, S</td><td>0.0466</td><td>kg</td></tr>
<tr><td>PP cork</td><td>Polypropylene, granulate {GLO}| market for | Cut-off, S</td><td>0.0101</td><td>kg</td></tr>
<tr><td>Label</td><td>Printed paper {GLO}| market for | Cut-off, S</td><td>0.00126</td><td>kg</td></tr>
</table>

General description: P9. Waste Management				
Corresponds to the process where the garments that are considered as waste are colleted and further carried to the incineration plant.				
Output	**1**	**kg**	**garment collected and transported to the incineration plant**	
Inputs				
T_{U-MSW}	Transport for Municipal waste collection			
	Distance	14	kgkm	14 km distance based on Lausselet et al., 2016. And the distances defined for the base scenario, their data correspond to average data based from operators.
	Type of vehicle	Municipal waste collection service by 21 metric ton lorry {GLO}| market for | Cut-off, S		
$T_{MSW-Incineration}$	Transport to incineration plant			
	Distance	50	kgkm	50 km distance based on Lausselet et al., 2016. And the distances defined for the base scenario, their data correspond to average data based from operators.
	Type of vehicle	Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | Cut-off, S		

<table>
<tr><th colspan="5">General description: p10. Separate collection</th></tr>
<tr><td colspan="5">Charity organizations usually collect textiles through containers located next to supermarkets or in municipal car parks (Schmidt, 2016). The collected textiles are then transported to pre-sorting facilities, where it is decided wheter these are exported, recycled, incinerated or reused in the domestic market. This process considers the transport of the user disposing the garment at the container, the transport of the material from the container to the presorting facility and the electricity required for the management of the pre-sorting facility.</td></tr>
<tr><td>Output</td><td colspan="2">1</td><td>kg</td><td>pre-sorted garments</td></tr>
<tr><td colspan="5">Inputs</td></tr>
<tr><td>T-User</td><td>Transport user</td><td>-</td><td>-</td><td>See PT.Transport- Transport to delivery pick-up point (assuming distribution of mode of transport - 2018)</td></tr>
<tr><td rowspan="3">T_{PS}</td><td colspan="4">Transport to pre-sorting facility</td></tr>
<tr><td>Distance</td><td>150</td><td>kgkm</td><td>According to Schmidt et al (2016), where it is indicated that a variation from 10 to 150 km is possible, hence they assumed a distance of 150km.</td></tr>
<tr><td>Type of vehicle</td><td colspan="2">Transport, freight, lorry 7.5-16 metric ton, euro6 {RER}| market for transport, freight, lorry 7.5-16 metric ton, EURO6 | Cut-off, S</td><td>Schmidt et al (2016) indicates that, according to direct communication with Fretex, the vehicle size used for collection is 15 tonne or 7.5 tonne gross weight, hence they modelled this using data for a 12-14 tonne truck with 10-ton capacity.</td></tr>
<tr><td rowspan="2">E_{PS}</td><td colspan="3">Pre-sorting Energy consumption</td><td></td></tr>
<tr><td>Electricity, low voltage {NO}| market for | Cut-off, S</td><td>0.25</td><td>MJ</td><td>Schmidt et al (2016) indicates that, according to direct communication with Fretex, energy consumption is approximately 70 kWh electricity per tonne of clothes sorted, which is equal to 0.25 MJ/kg. These figures exclude electricicty consumption in a second sorting facility (Schmidt, 2016). Electricity mix selected for Norway.</td></tr>
</table>

General description: P11. Incineration (NO)				
Waste treatment given to the garments. Where they are incinerated together with other fractions of waste. Considers the incineration process. Transports are included in P9. Waste Management.				
Output	**1**		**kg**	**Incinerated garments**
Inputs				
Incineration	Municipal solid waste {NO}| treatment of, incineration | Cut-off, S	1	kg	

Appendix D. Modelling the production and use phase

The production phase is modelled considering the results presented in the Swedish study called "Environmental assessment of Swedish Clothing consumption- six garments, sustainable futures" (Sandin et al., 2019). However, to use their results it was necessary to adjust the data as it is presented in this section.

Each of the 7 garment categories defined in the present study are associated with 1 or more CN codes, as shown in the following table. For each CN code, the Sandin et al. (2019) also assigned a representative garment, for which they model the whole life cycle. Their allocation between CN codes and representative garments can also be found in the following table.

Allocation between garment categories and representative garments

G[1]	Name (G)[1]	Knitted or crocheted			Not Knitted or crocheted		
		Codes[2]		Representative garment[4] (RG)	Codes[2]		Representative garment[4] (RG)
		M or B[3]	W or G[3]		M or B[3]	W or G[3]	
1	**Overcoats**	6101	6102	Dress	6201	6202	Jacket
		6112	6112	T-shirt	6211	6211	Jacket
		6113	6113	Jacket	6210	6210	Jacket
2	**Pullovers**	6110	6110	Dress			
3	**Trousers / ensembles**	6103	6104	Jeans	6203	6204	6203 Jeans 6204 Jacket
4	**Shirts**	6105	6106	6105 T-shirt 6106 Dress	6205	6206	Uniform
5	**Baby's garments**	6111	6111	T-shirt	6209	6209	Jeans
6	**Accessories**	6116	6116	Socks	6216	6216	Socks
		6117	6117	Socks	6214, 6217	6214, 6217	6214- Dress 6217 Jacket
					6215		Jacket
7	**Not suitable for reuse (socks, underwear, nightwear, others)**	6107,6109	6108,6109	T-shirt	6207	6208	Uniform
		6114	6114	Socks			
		6115	6115	Socks			
			6212	Jacket		6212	Jacket
					6213	6213	Dress

Notes:
1. Classification defined for the purpose of this study
2. Codes that appear under both, Women and Men classification, or under both Knitted or not Knitted classification, is either because the code does not make distinction of these classifications or because the distinction between classification takes place at 6-digit level of the CN classification, and not at 4-digit level.
3. M or B: Men's or boys', W or G: Women's or girls'
4. Representative garment according to (Sandin et al., 2019).

The classification proposed by the Sandin et al (2019), considers whether the garment is knitted or woven, the fibre type, and similarity in terms of use pattern and the function of the garment. At the same time, with the proxies they defined, they took into account different production technologies.

Therefore, it is decided to use the representative garments proposed in the Sanding et al (2019). to quantify the environmental impacts associated with the production phase of the garments produced to satisfy Norwegian's demand for the year 2018. This, as it is assumed that the providers of clothes for Sweden are similar as the providers for Norway, hence, their production phase could be assumed to be the same.

Based on this assumption, the production process of each of the Swedish representative garments is considered as a representative production process (RPP). Each of these RPP, consists of certain production steps, depending on aspects such as the textile fibres to be processed, and the desire outcome, as it is shown in the following tables. The processes are described according to the information presented in Sandin et al. (2019).

Characteristics of the representative production processes, data from Sandin et al. (2019)

Characteristics of the processes	Representative production processes					
	RP1	RP2	RP3	RP4	RP5	RP6
Mass (g)	110	477	478	444	43	340
Textile composition	100% Cotton	98% cotton 2% elastane	100% polyester	43.6% polyamide 36.6% polyester 18.8% cotton/ elastane mix	72% viscose 27% polyamide 1% elastane	50% cotton 50%polyester
Other materials included	-	3% zipper, buttons, leather laber	-	13% zippers, buttons	-	1% buttons
Packaging weight (g)	9	33	33	31	3.4	0.22
Total weight processed (g)	119	510	511	475	46.4	340.22
Total weight processed (tonnes)	0.000119	0.00051	0.000511	0.000475	0.0000464	0.00034022

Note: information for each process according to Sandin et al. (2019), where RP1= producion process of a t-shirt, RP2= producion process of a jeans, RP3= producion process of a dress, RP4=producion process of a jacket, RP5=producion process of a socks, RP6=producion process of a hospital uniform.

Description of the representative production processes, information from Sandin et al. (2019).

Representative production process	Description of the production process	Fabric details
RP1	Cotton fibre production, yarn production (e.g. spinning), fabric production (e.g. knitting), wet treatment, confectioning (e.g. cutting, seweing), packaging.	110 g white cotton tricot, single jersey, 169 dtex
RP2	Elastane fibre production, cotton fibre production, yarn production (e.g. spinning), wet treatment, fabric production (e.g. weaving), other material production, confectioning (e.g. cutting, sewing), packaging.	Weave consisting of: 299 g blue cotton warp, 578 dtex 144 g white cotton (93%)/ elastane (7%) weft, 470 dtex
RP3	Polyester fibre production, yarn production (e.g. spinning), fabric production (e.g. knitting, weaving), wet treatment, confectioning (e.g. printing, cutting, sewing), packaging.	241 g printed black & white polyester weave, cover part, 119/114 dtex (warp/weft), 231 g black polyester tricot, under part, 114 dtex
RP4	Cotton fibre production, elastane fibre production, polyamide fibre production, polyester fibre production, yarn production (e.g. spinning), fabric production (e.g. knitting, weaving), wet treatment, fabric production (non-woven), confectioning (e.g. cutting, seweing), packaging.	57 g black and 110 g olive-green polyamide weave, cover part, 200/90 dtex (warp/weft), 59 g orange polyester weave, lining, 70 dtex, 85 g polyester nonwoven, padding (dtex not measured), 72 g black and olive-green cotton (90%)/ elastane (10%) tricot, gussets, 300 dtex (estimate)
RP5	Elastane fibre production, polyamide fibre production, viscose fibre production, yarn production (e.g. spinning), wet treatment, fully - fashioned knitting, packaging.	43 g black viscose (72%)/polyamide (27%)/ elastane (1%) tricot, 300 dtex (estimate)
RP6	Cotton fibre production, polyester fibre production, yarn production (e.g. spinning), fabric production (weaving), wet treatment, confectioning (e.g. cutting, sewing), packaging.	340 g blue cotton (50%)/ polyester (50%) weave, 200 dtex (estimate)

Note: information for each process according to Sandin et al. (2019), where RP1= producion process of a t-shirt, RP2= producion process of a jeans, RP3= producion process of a dress, RP4=producion process of a jacket, RP5=producion process of a socks, RP6=producion process of a hospital uniform.

Considering the defined RPPs, the steps that were followed to quantify the environmental impacts of the production phase are described below.

- **Step 1. Retrieve import's data:** The import data for the year 2018, were retrieved from the UN Cometrade database (United Nations, 2020), using the CN classification codes.
- **Step 2. Allocating imports to the garment categories:** knowing the CN codes that composed each of the 7 garment categories, it was possible to allocate the data from imports to each garment category.
- **Step 3. Matching up representative production processes:** To make use of the RPPs, a match is made between the garment categories defined in this study and the RPP defined from the Swedish study, using as a base the CN codes. From a practical point of view, this means that each of the layers of the 7 categories of garments defined in this study are composed by garments that underwent different production processes. Knowing how each G category is composed in terms of CN codes, it was possible to calculate the percentages of each G category that were produced following each of the representative production processes. The percentages were calculated based on weight as it is shown in the table below. It is worth notice that even if these percentages represent the composition of the flow at imports level, the percentages are assumed as constants across all the flows of the system.

- **Step 4. Converting impacts:** the Swedish study calculated the impacts per type of representative garment (e.g., impact per t-shirt). Hence, the impacts of the production phase in the Swedish study were calculated per one piece of garment produced. However, there is a difference between the weights assumed for a piece of RG (from the SS), and the weights assumed for the garment categories used in this study. Therefore, it was decided to take the total weight of each RG and convert the environmental impacts from the production phase, from impact/piece to impact/tonne processed. This means that if a dress considering all its components weights 511g, the environmental impacts from the production phase provided in the Swedish report are divided by 0.000511 tonnes, to get the environmental impact per tonne processed through that specific RPP. This, as we are interested in the production process associated with the dress, rather than in the dress itself. The exact results of the environmental impacts per type of garment, from the Swedish report were obtained through S. Roos (personal communication, March 17, 2021).

- **Step 5. Quantification of production impacts:** once the impacts of the production processes, were converted in terms of impacts/tonnes processed, these impacts were multiplied by the tonnes required to satisfy the Norwegian consumption of new garments. This allows us to calculate the environmental impacts associated with the production.

Percentage of each garment category associated to each RPP, weight base.

Garment Category		Representative Garment						Total
G	Name	RPP1	RPP2	RPP3	RPP4	RPP5	RPP6	
1	Overcoats	3%	0%	8%	89%	0%	0%	100%
2	Pullovers	0%	0%	100%	0%	0%	0%	100%
3	Trousers / ensembles	0%	62%	0%	38%	0%	0%	100%
4	Shirts	14%	0%	12%	0%	0%	74%	100%
5	Baby's garments	83%	17%	0%	0%	0%	0%	100%
6	Accessories	0%	0%	16%	7%	77%	0%	100%
7	Not suitable for reuse (socks, underwear, nightwear, others)	62%	0%	0%	4%	31%	2%	100%

Note:
1. Percentages presented according to imports, based on CN classification and the representative garment according to (Sandin et al., 2019).

The following table presents the data used to model the use phase.

Factors [1]	G1	G2	G3	G4	G5	G6	G7		
	Overcoats	**Pullovers**	**Trousers / ensembles**	**Shirts**	**Baby's garments**	**Accessories**	**Not suitable for reuse**		
Weight per garment (kg)	0.669186545	0.378756622	0.44175371	0.264510092	0.170663272	0.103298934	0.158705457		
Total # of wears in a year/person	325	325	200	200	2555	487.5	1095		
# of wears before washing	100	5.7	10	2	1	100	1.5		
# Washing cycles in a year for 1 garment	3.25	57.01754386	20	100	2555	4.875	730		
Ratio of drying and washing	0.21	0.19	0.29	0.34	0.34	0.58	0.34		
#of drying cycles in a year for 1 garment	0.6825	10.83333333	5.8	34	868.7	2.8275	248.2		
Ratio of washing and ironing	0.05	0.18	0.15	0.15	0.15	0.01	0.15		
# of ironing cycles in a year for 1 garment	0.1625	10.26315789	3	15	383.25	0.04875	109.5		
Minutes ironing/ cycle	4	6	6	3	3	1	3		
PERSON									
kg washed per person in a year	2.17485627	21.59577228	8.83507421	26.45100915	436.0446591	0.503582302	115.8549835		
kg dryed per person in a year	0.456719817	4.103196734	2.562171521	8.993343112	148.2551841	0.292077735	39.39069439		
Minutes ironing per person in a year	0.65	61.57894737	18	45	1149.75	0.04875	328.5		
NORWAY								**Total (kg)**	**kg processed/ kg output**
kg washed in a year Norway	11131142.75	110529430.1	45218837.49	135379042.2	77404031.62	2577387.097	592957970.4	975197841.6	15.62216201
kg dryed in a year Norway	2337539.977	21000591.72	13113462.87	46028874.35	26317370.75	1494884.516	201605709.9	311898434.1	4.99645063
Minutes ironing in a year Norway [2]	3326768.25	315167518.4	92125890	230314725	204096721.5	249507.6188	1681297493	2526578623	40.47447493
Total output from use phase for the year 2018	**62424000**	**kg**							

Notes:

1. Data for the frequency of use, the number of wears before wahsing, the ratio of drying and washing, the ratio of iroining, and the minutes per ironing cycle were retrieved from Sandin et al. (2019), and allocated to the garment categories of this study base on the function of the garments. However, this was not the case for Baby's garments, for this categories the assumptions were done in this study.

2. The total minues of iroining is multiply by 0.027 kWh/ min (Sandin et al., 2019), to obtained the total demand of kWh, giving as a result 1.093 kWh.

Appendix E. Elaborating the scenario

Data used to estimate the potential for rental (Mukendi & Henninger, 2020).

Category	Willingness to rent
Underwear	0
Smart casual	5
Outerwear	7
Outerwear	7
Occasionwear	8
Accessories	6
Everydaywear	4
Activewear	2
Workwear	4
Jeans	4
Vintage	8
Designer	6
Peers	5
Swimwear	0

Reduction in retail of new garments based on the willingness to rent

G	Garment Category	Norwegian requirement for 2018 (pieces)	Retailers (New)		
			BAU	% Δfrom BAU	CBM
1	Overcoats	**16456921**	88%	-20%	68%
2	Pullovers	**28670386**	85%	-10%	75%
3	Trousers / ensembles	**42386400**	86%	-10%	76%
4	Shirts	**16675013**	87%	-10%	77%
5	Baby's garments	**5586736**	96%	-20%	76%
6	Accessories	**21757679**	96%	-20%	76%
7	Not suitable for reuse (socks, underwear, nightwear, others)	**89574372**	94%	0%	94%
Norwegian household's apparel needs for the year 2018 (met by acquisition)		**221107507**			

Data from Nørup et al. (2019) used to estimate the potential for reuse.

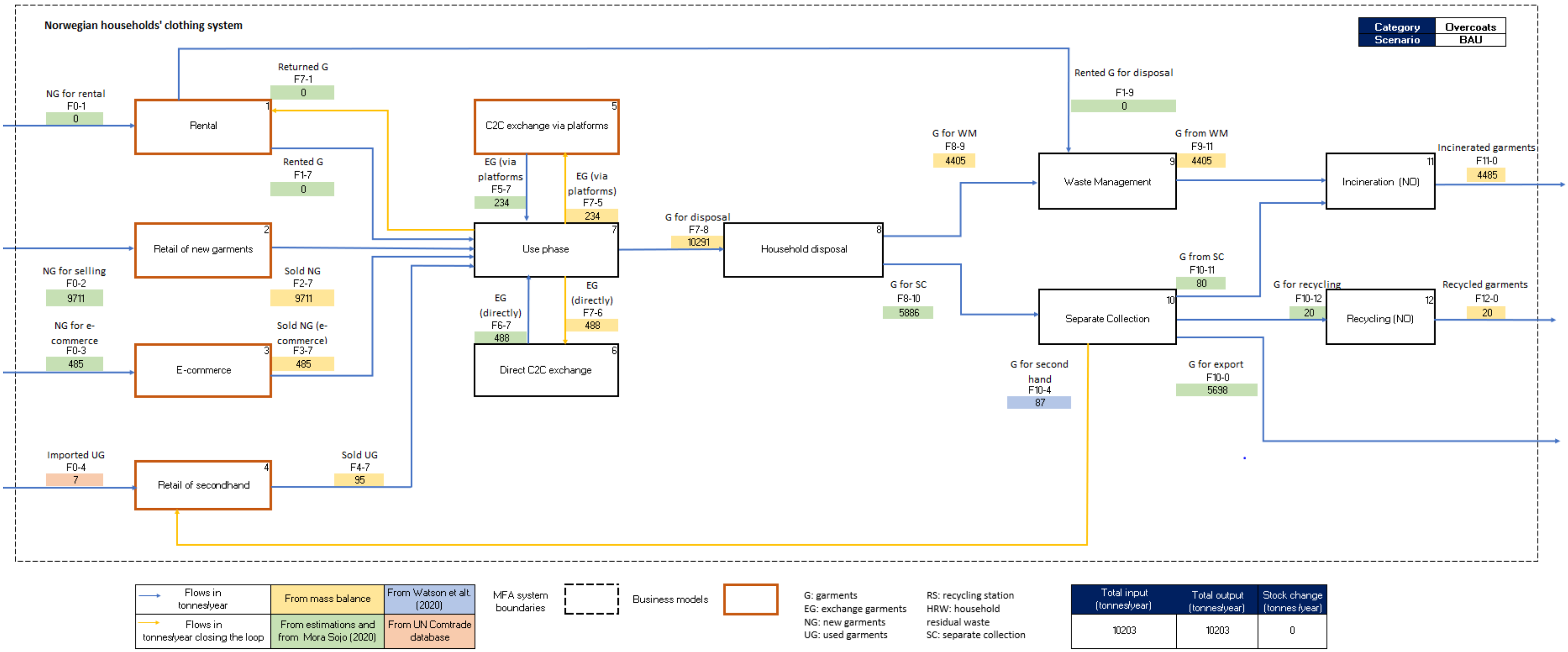
G	Garment type[1]	CN codes[2]	Products[3]	In residual waste (kg)				In small combustion (kg)			
				Reusable	Reusable A	**Total before re**	**Total after redirec**	Reusable[6]	Reusable /	**Total befo**	**Total after redirecting**
1	Overcoats	6101,6102,6201,6202	Overcoats, anoraks, wind jackets (60% of winter clothing)[4]	0.42	0.348923077	**0.42**	**0.071076923**	6.84	5.960571	**10.32**	**4.359428571**
		6211	Aprons	0.1	0.083076923	**0.1**	**0.016923077**	2.1	1.83	**2.7**	**0.87**
		6112,6211	Swimwear	0.2	0.166153846	**0.2**	**0.033846154**	9.1	7.93	**9.5**	**1.57**
2	Pullovers	6110	Jerseys and pullovers (40% of winter clothing)[4]	0.28	0.232615385	**0.28**	**0.047384615**	4.56	3.973714	**6.88**	**2.906285714**
3	Trousers / ensembles	6103,6104,6203,6204	Trousers	40.1	33.31384615	**46.1**	**12.78615385**	121.1	105.53	**159.6**	**54.07**
		6103,6104,6203,6204	Shorts	4.3	3.572307692	**4.6**	**1.027692308**	8	6.971429	**11.5**	**4.528571429**
		6103,6104,6203,6204	Dresses	2.7	2.243076923	**2.9**	**0.656923077**	14.3	12.46143	**17.1**	**4.638571429**
		6103,6104,6203,6204	Skirts	0.5	0.415384615	**0.6**	**0.184615385**	6.6	5.751429	**8.7**	**2.948571429**
		6103,6104,6203,6204	Jackets	13.1	10.88307692	**15.7**	**4.816923077**	63.7	55.51	**84.6**	**29.09**
		6103,6104,6203,6204	Work wear	10.1	8.390769231	**14.5**	**6.109230769**	32.3	28.14714	**56.4**	**28.25285714**
4	Shirts	6105, 6106,6205,6206	Tops	5.3	4.403076923	**5.7**	**1.296923077**	11.6	10.10857	**13.5**	**3.391428571**
		6105, 6106,6205,6206	Blouses	25.7	21.35076923	**28.3**	**6.949230769**	118.7	103.4386	**159**	**55.56142857**
		6105, 6106,6205,6206	Shirts	6.3	5.233846154	**6.8**	**1.566153846**	27.7	24.13857	**36.6**	**12.46142857**
5	Baby's garments	6111,6209	Infants clothes (including socks & gloves)	3.6	2.990769231	**3.72**	**0.729230769**	2.7	2.352857	**3.9**	**1.547142857**
6	Accessories	6116,6216	Gloves	3.3	2.741538462	**7.3**	**4.558461538**	10.8	9.411429	**19.4**	**9.988571429**
		6117,6214,6217,6215	Scarfs & ties	2.1	1.744615385	**2.5**	**0.755384615**	11	9.585714	**11.5**	**1.914285714**
		6117, 6217	Parts of clothing[5]	0	0	**0.1**	**0.1**	0	0	**1.9**	**1.9**
7	Not suitable for reuse (socks, underwear, nightwear, others)	6107,6108, 6109,6207,6208	T-shirts	26.3	21.84923077	**29.2**	**7.350769231**	60.7	52.89571	**90.1**	**37.20428571**
		6107,6108, 6109,6207,6208	Vests	0.6	0.498461538	**0.6**	**0.101538462**	22.3	19.43286	**22.5**	**3.067142857**
		.07,6108, 6109,6207,6208,62:	Underwear	21.3	17.69538462	**30.8**	**13.10461538**	16.7	14.55286	**25**	**10.44714286**
		6107,6108, 6109,6207,6208	Nightwear	3.6	2.990769231	**4.2**	**1.209230769**	6.7	5.838571	**7.6**	**1.761428571**
		6107,6108, 6109,6207,6208	Bathrobes	1.2	0.996923077	**1.2**	**0.203076923**	4.6	4.008571	**7.1**	**3.091428571**
		6115	Socks	0.6	0.498461538	**41.7**	**41.20153846**	4.5	3.921429	**35**	**31.07857143**
		6213	Handkerchiefs	0.1	0.083076923	**0.14**	**0.056923077**	0.9	0.784286	**1.2**	**0.415714286**
		6114	Costumes	0.6	0.498461538	**0.6**	**0.101538462**	3.8	3.311429	**5.4**	**2.088571429**
		Total (kg)		172.4	143.2246154	**248.26**	**105.0353846**	571.3	497.8471	**807**	**309.1528571**

Notes:

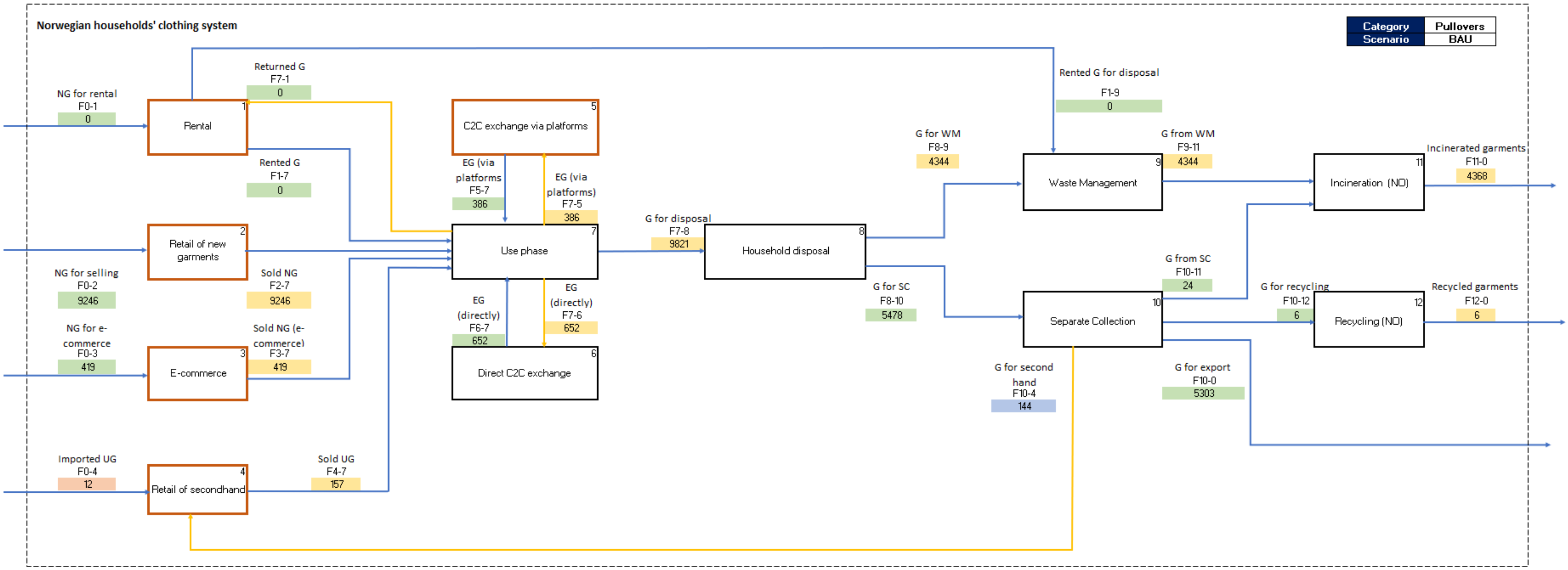
1. Category of garments defined in this study
2. Allocation of CN codes done in this study considering and based on the understanding of the heading provi ded in (Nørup, et al., 2019), as this was not done explicitly in (Nørup, et al., 2019).
3. Category of products defined in (Nørup, et al., 2019). The category of Pieces of clothing defined as "things that are clearly clothing but cut into pieces" (Nørup, et al., 2018), are not considered in this study, as it is assumed that the flows are composed of entire pieces of clothes.
4. Not Nørup, et al. (2019), nor Nørup, et al. (2018) defines explicitly what the category of winter clothing contains, hence, it is assumed that contains articles such as overcoats, anoraks, wind jackets, ski suits, jerseys and pullovers. However, for the purpose of this study, this items are considered under 2 different categories. Therefore, in order to adjust the data to the categories of garments used in this study, it is decided to split the amount of clothes under winter clothing in these two categories: 1. overcoats, and 2. Pullovers. Since the data is weight-based, the first categoy is assumed to represent 40% of the winter clothing, category (as it considers heavier items), whereas the second one is assumed to represent 60%. This factors were defined considering the weight distribution of a boundle consisting of 1 item of each category. Overcoats weight: 0.67 kg, Pullovers weight: 0.38kg
5. Parts of clothing: "items belonging to one of the other garments but where the rest of the garment is not there, such as a removable hood for a jacket or a belt for a robe" (Nørup, et al., 2018).
6. Data as presented in (Nørup, et al., 2019).
7. The fractions of reusable, recyclable and waste were added up to verify if the figures corresponded to the total presented in (Nørup, et al., 2019), however, as some differences were found, it was decided to calculate and adjusted total, corresponding to the addition of the 3 fractions. The adjusted figures are the ones used to estimate the percentages shown in the table.

Appendix F. MFA per type of garment of the Norwegian households' clothing system for the year 2018 (BAU-Baseline scenario)

G1. Overcoats



G2. Pullovers



Flows in tonnes/year	From mass balance	From Watson et alt. (2020)
Flows in tonnes/year closing the loop	From estimations and from Mora Sojo (2020)	From UN Comtrade database

MFA system boundaries

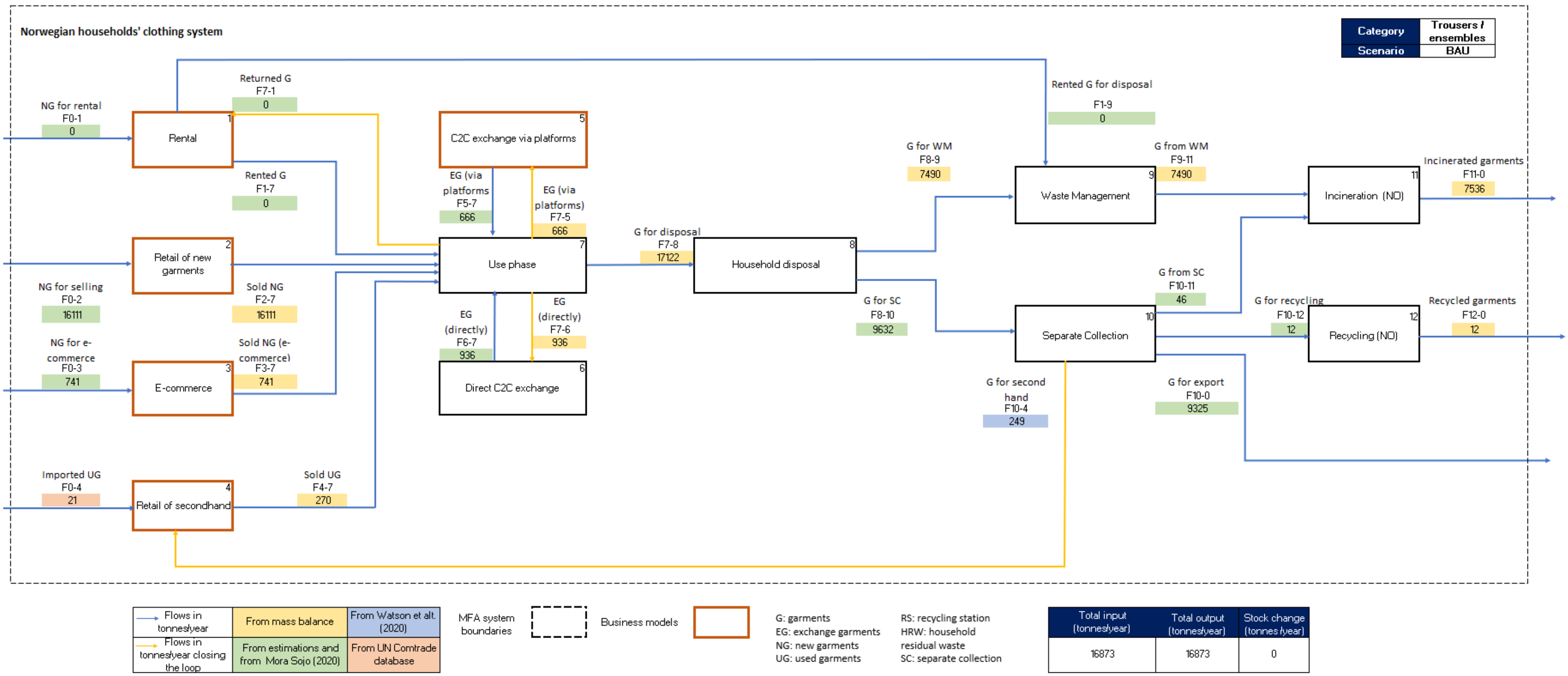
Business models

G: garments
EG: exchange garments
NG: new garments
UG: used garments

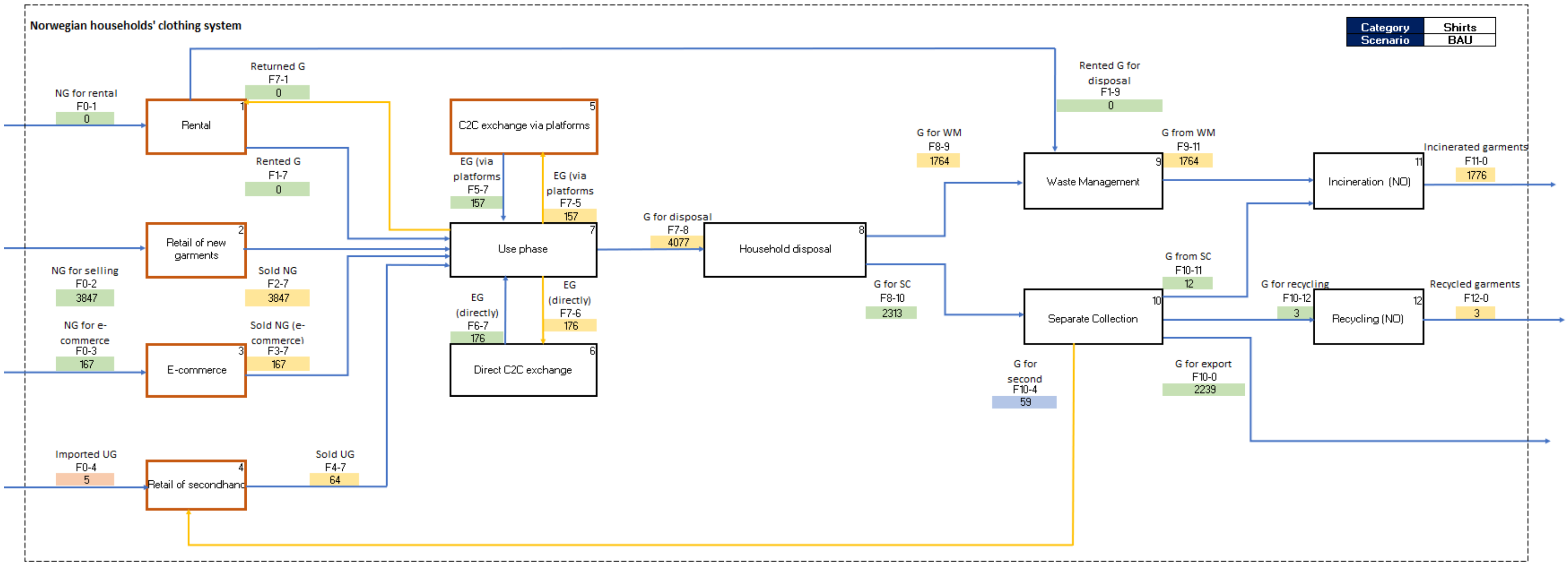
RS: recycling station
HRW: household residual waste
SC: separate collection

Total input (tonnes/year)	Total output (tonnes/year)	Stock change (tonnes /year)
9677	9677	0

G3. Trousers / Ensembles



G4. T-Shirts



Flows in tonnes/year	From mass balance	From Watson et alt. (2020)
Flows in tonnes/year closing the loop	From estimations and from Mora Sojo (2020)	From UN Comtrade database

MFA system boundaries

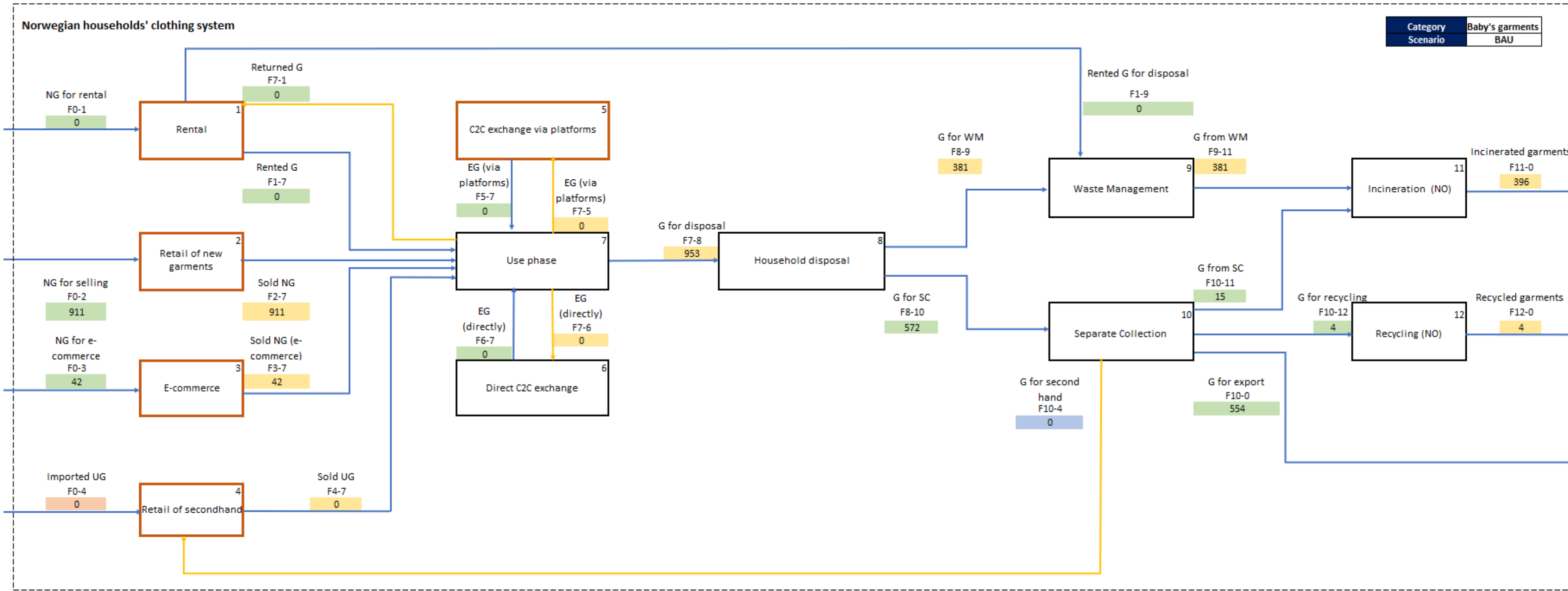
Business models

G: garments
EG: exchange garments
NG: new garments
UG: used garments

RS: recycling station
HRW: household residual waste
SC: separate collection

Total input (tonnes/year)	Total output (tonnes/year)	Stock change (tonnes /year)
4019	4019	0

G5. Baby's garments



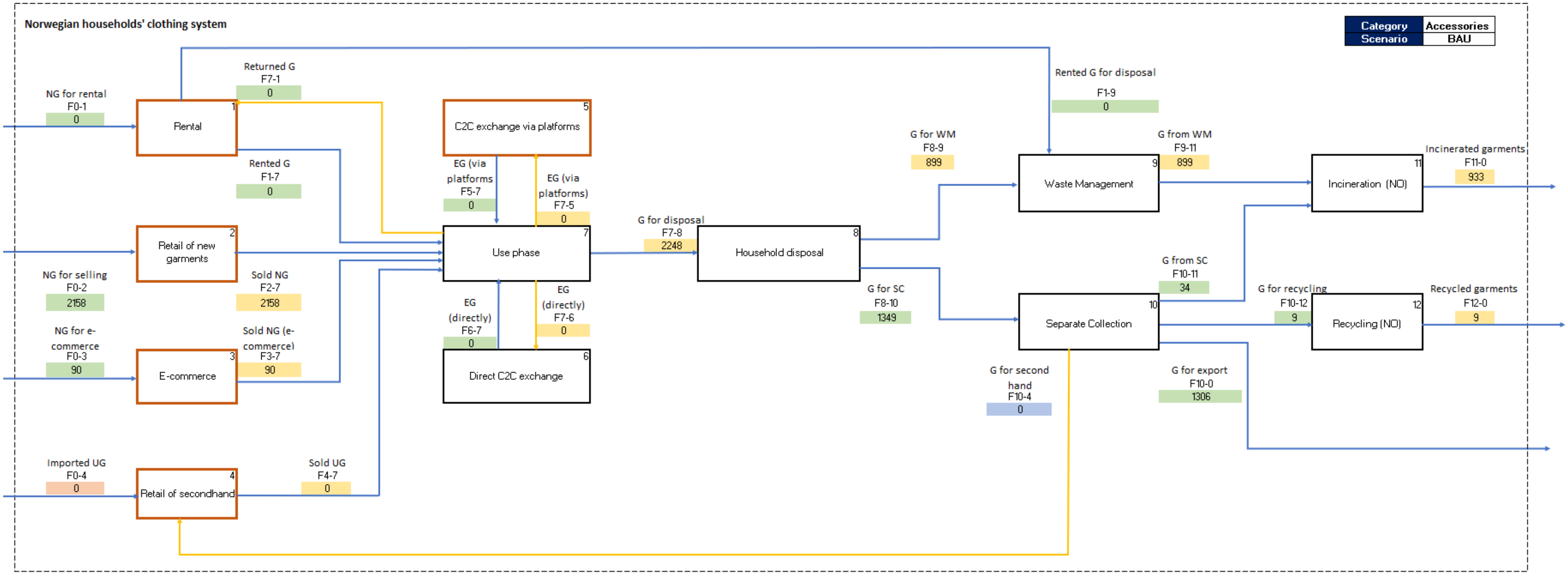
Flows in tonnes/year	From mass balance	From Watson et alt. (2020)	MFA system boundaries	Business models
Flows in tonnes/year closing the loop	From estimations and from Mora Sojo (2020)	From UN Comtrade database		

G: garments
EG: exchange garments
NG: new garments
UG: used garments

RS: recycling station
HRW: household residual waste
SC: separate collection

Total input (tonnes/year)	Total output (tonnes/year)	Stock change (tonnes /year)
953	953	0

G6. Accessories



Flows in tonnes/year	From mass balance	From Watson et alt. (2020)
Flows in tonnes/year closing the loop	From estimations and from Mora Sojo (2020)	From UN Comtrade database

MFA system boundaries

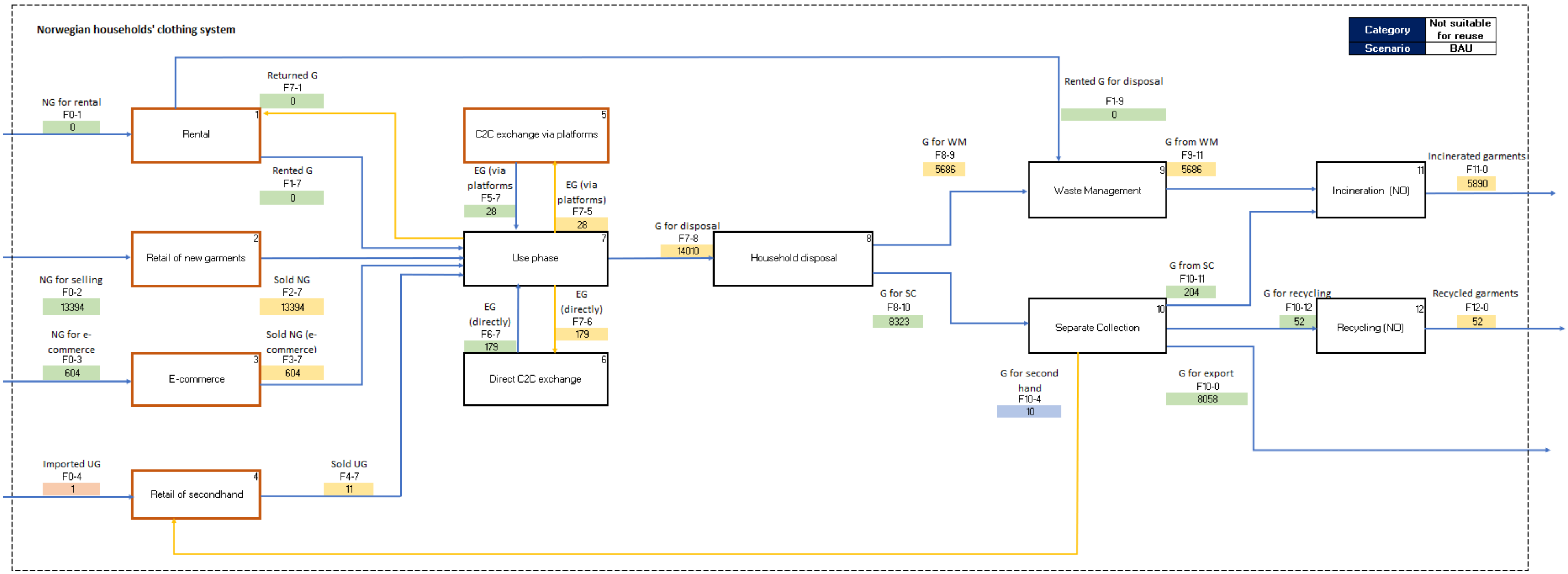
Business models

G: garments
EG: exchange garments
NG: new garments
UG: used garments

RS: recycling station
HRW: household residual waste
SC: separate collection

Total input (tonnes/year)	Total output (tonnes/year)	Stock change (tonnes /year)
2248	2248	0

G7. Not suitable for reuse



Flows in tonnes/year	From mass balance	From Watson et alt. (2020)
Flows in tonnes/year closing the loop	From estimations and from Mora Sojo (2020)	From UN Comtrade database

MFA system boundaries

Business models

G: garments
EG: exchange garments
NG: new garments
UG: used garments

RS: recycling station
HRW: household residual waste
SC: separate collection

Total input (tonnes/year)	Total output (tonnes/year)	Stock change (tonnes /year)
13999	13999	0

Appendix G. Environmental impacts of the baseline scenario

The following graphs present the environmental impact for all the phases of the processes, and the contribution of each element.

Climate change impact

Climate Change Impact - Baseline Scenario-Norwegian clothing system 2018

	Retailers (New)	E-commerce (New)	Rentals	Second hand stores	C2C exhange via platforms	Direct C2C exchange	Use Phase	Separate Collection	Disposal - Waste
Sum of Incineration	0	0	0	0	0	0	0	0	13243
Sum of Electricity-FM	3421	157	0	37	0	0	0	74	0
Sum of Ironing	0	0	0	0	0	0	2171	0	0
Sum of Drying	0	0	0	0	0	0	6646	0	0
Sum of Laundry	0	0	0	19	46	76	30451	0	0
Sum of T-Material	0.00000	0.00000	0.00000	18.92287	0.00000	0.00000	0.00000	1065.25178	650.55314
Sum of T-User	149554	1668	0	1610	963	0	0	21963	0
Sum of Distribution	14632	673	0	0	0	0	0	0	0
Sum of Production	1368510	63292	0						

Water scarcity impact

Water Scarcity impact Baseline Scenario - Norwegian Clothing System 2018

	Retailers (New)	E-commerce (New)	Rentals	Second hand stores	C2C exhange via platforms	Direct C2C exchange	Use Phase	Separate Collection	Disposal - Waste
Sum of Incineration	0	0	0	0	0	0	0	0	1671590
Sum of Electricity-FM	2833618	130329	0	30497	0	0	0	61455	0
Sum of Ironing	0	0	0	0	0	0	1797918	0	0
Sum of Drying	0	0	0	0	0	0	5504561	0	0
Sum of Laundry	0	0	0	38330	94602	156340	62706064	0	0
Sum of T-Material	0	0	0	1492	0	0	0	84004	41589
Sum of T-User	17785520	200063	0	191417	115544	0	0	2634111	0
Sum of Distribution	1319768	60701	0	0	0	0	0	0	0
Sum of Production	2693076063	123290781	0						

Cumulative Energy Demand

	Retailers (New)	E-commerce (New)	Rentals	Second hand stores	C2C exhange via platforms	Direct C2C exchange	Use Phase	Separate Collection	Disposal - Waste
Sum of Incineration	0	0	0	0	0	0	0	0	9858473
Sum of Electricity-FM	498189280	22913574	0	5361766	0	0	0	10804607	0
Sum of Ironing	0	0	0	0	0	0	316098987	0	0
Sum of Drying	0	0	0	0	0	0	967778152	0	0
Sum of Laundry	0	0	0	997722	2462498	4069530	1632243009	0	0
Sum of T-Material	0	0	0	307654	0	0	0	17319203	10234068
Sum of T-User	2353410792	26232995	0	25328604	15150583	0	0	345395710	0
Sum of Distribution	228684629	10518055	0	0	0	0	0	0	0
Sum of Production	20415582766	942827525	0						

Appendix H. Effects on the flows due to the interventions done in the CBM scenario, per type of garment.

Magnitude of the flows in terms of tonnes and pieces, for each type of garment and per business model

G	Garment Category	Circular Business Model Scenario												Total tonnes acquired	Total transactions	Percentage	Total/ person[4]
		1BM		2BM		3BM[1]		4BM[2]		5BM[2]		6M					
		Retailers (New)		Rentals		E-commerce (New)		Second hand stores		C2C exhange via platforms		Direct C2C exchange					
		F_{1-7} (Tonnes)	Pieces[3]	F_{2-7} (Tonnes)	Pieces[3]	F_{3-7} (Tonnes)	Pieces[3]	F_{4-7} (Tonnes)	Pieces[3]	F_{5-7} (Tonnes)	Pieces[3]	F_{6-7} (Tonnes)	Pieces[3]				
1	Overcoats	7727	11546658	1942	2902233	485	725208	136	203860	234	349447	488	729514	**11013**	**16456921**	**7%**	3.1
2	Pullovers	8337	22010741	925	2441074	419	1105899	141	372270	386	1020177	652	1720223	**10859**	**28670386**	**13%**	5.4
3	Trousers / ensembles	14517	32861330	1611	3647104	741	1676724	253	573688	666	1508234	936	2119320	**18724**	**42386400**	**19%**	8.0
4	Shirts	3465	13099145	385	1454459	167	629675	61	231388	157	593347	176	667001	**4411**	**16675013**	**8%**	3.1
5	Baby's garments	717	4201883	182	1068140	42	246038	12	70676	0	0	0	0	**953**	**5586736**	**3%**	1.1
6	Accessories	1700	16456109	432	4178043	90	867462	26	256065	0	0	0	0	**2248**	**21757679**	**10%**	4.1
7	Not suitable for reuse (socks, underwear, nightwear, others)	13207	83216228	0	0	604	3806130	199	1252526	28	173752	179	1125736	**14216**	**89574372**	**41%**	16.9
Total number acquired		**49669**	**183392095**	**5476**	**15691053**	**2547**	**9057136**	**829**	**2960473**	**1471**	**3644957**	**2431**	**6361794**	62424	221107507	100%	42
% of pieces acquired through		**79.6%**	**82.9%**	**8.8%**	**7.1%**	**4.1%**	**4.1%**	**1.3%**	**1.3%**	**2.4%**	**1.6%**	**3.9%**	**2.9%**				

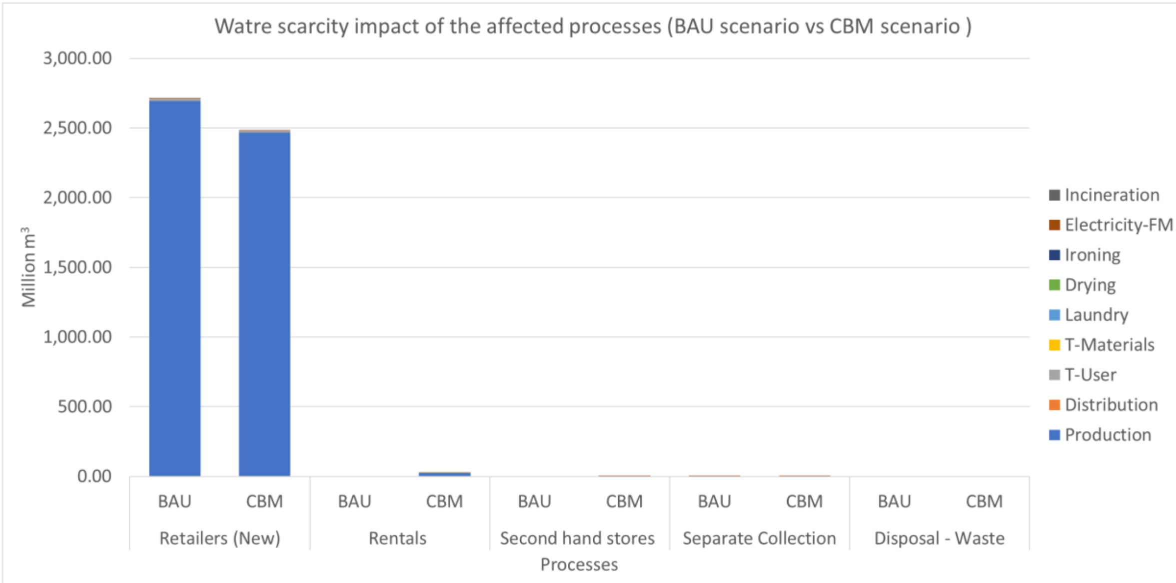
Notes:
1. It was assumed that all the transactions that took place through e-commerce in 2018, were for household consumption.
2. The magnitude of the flows from Secondhand stores, and C2C exchange via platforms, were calculate at an aggregated level (level 1: tonnes of clothes/ year) by Mora Sojo (2020), but not their composition in terms of garment category. However, Mora Sojo (2020) estimated the composition per type of garment of all the purchases of used garments together (without making distinction of the acquisition channel, secondhand stores or exchange via platforms). According to her results C2C exchange via platforms represent 71% (weight-base) of the purchases and the remaining 29% corresponds to used garments that were imported and obtained from separate collection and assumed to be sold through secondhand stores. These shares were applied at a garment category level to distribute the garments across the different acquisition channels.

Percentual change of the transactions per type of garment and business model

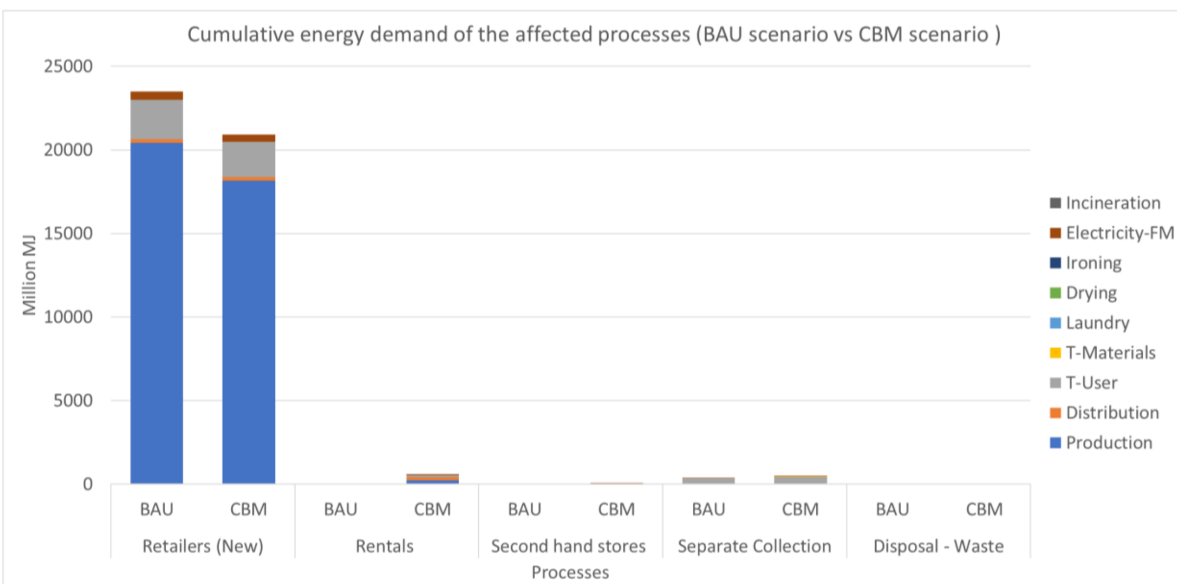
G	Garment Category	Norwegian requirement for 2018 (pieces)	Retailers (New)			Rentals[1]		Second hand stores			E-commerce (New)[2]	C2C exhange via platforms[2]	Direct C2C exchange[2]
			BAU	% Δfrom BAU	CBM	BAU	CBM	BAU	% Δfrom BAU	CBM	BAU	BAU	BAU
1	Overcoats	**16456921**	88.2%	-20.4%	70.2%	0.0%	17.6%	0.9%	44.0%	1.2%	4.4%	2.1%	4.4%
2	Pullovers	**28670386**	85.1%	-9.8%	76.8%	0.0%	8.5%	1.4%	-9.9%	1.3%	3.9%	3.6%	6.0%
3	Trousers / ensembles	**42386400**	86.0%	-9.9%	77.5%	0.0%	8.6%	1.4%	-6.1%	1.4%	4.0%	3.6%	5.0%
4	Shirts	**16675013**	87.2%	-9.9%	78.6%	0.0%	8.7%	1.4%	-3.8%	1.4%	3.8%	3.6%	4.0%
5	Baby's garments	**5586736**	95.6%	-21.3%	75.2%	0.0%	19.1%	0.0%	-	1.3%	4.4%	0.0%	0.0%
6	Accessories	**21757679**	96.0%	-21.2%	75.6%	0.0%	19.2%	0.0%	-	1.2%	4.0%	0.0%	0.0%
7	Not suitable for reuse (socks, underwear, nightwear, others)	**89574372**	94.2%	-1.4%	92.9%	0.0%	0.0%	0.1%	1679.2%	1.4%	4.2%	0.2%	1.3%
Norwegian household's apparel needs for the year 2018 (met by acquisition)		**221107507**	90.7%	-8.6%	82.9%	0%	7.1%	0.7%	100.5%	1.3%	4.1%	1.6%	2.9%

Notes:
1. It was assumed that there were not rental in the year 2018.
2. The interventions done in the CBM scenario do not impact the transactions allocated to E-commerce, C2C exchange via platforms, and Direct C2C exchange.

Effects of the intervention on the environmental impact of water scarcity impact, for the phases that were affected



Effects of the intervention on the cumulative energy demand, for the phases that w



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